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Association between the perceived built environment and health behaviors in older adults: a cross-sectional study from Beijing, China

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Abstract

Background Under the background of the increasing trend of population aging, the health and quality of life of older adults have become the focus of social concern. As an important part of older adults' daily life, the design and configuration of the built environment may positively or negatively affect older adults' health behaviors. Therefore, this study aims to explore the relationship between older adults' perceived built environments and health behaviors, which is the association between perceived built environments and older adults' physical activity (PA) and social interactions. This is important for optimizing the community built environment and improving the quality of life of older adults.

Methods In this study, a questionnaire was surveyed on 916 Chinese older adults aged 60 and above. The questionnaire was used to collect demographic information and social interaction from the participants, and the Physical Activity Neighborhood Environment Scale (PANES) and the Physical Activity Scale for the Elderly (PASE) were used to assess older adults' subjective perceptions of the built environment in their neighborhoods and their levels of PA, respectively. In data analysis, ANOVA and chi-square tests were used to compare the significance of differences between groups, and multiple linear regression model were used to estimate the association between older adults' perceived characteristics of the built environment and their PA and social interaction.

Results After controlling for confounders such as gender, age, BMI, and education level, the multiple linear regression model showed that perceived destination accessibility, neighborhood infrastructure, aesthetic qualities, and neighborhood environment indices were significantly correlated with PA ($\beta = 0.083 \sim 0.095$, $P < 0.05$) and social interaction ($\beta = 0.087 \sim 0.144$, $P < 0.05$) among older adults. In addition, neighborhood safety ($\beta = -0.084$, $P < 0.05$), social environment ($\beta = 0.091$, $P < 0.01$), and street connectivity ($\beta = 0.112$, $P < 0.001$) were also strongly associated with older adults' social interaction.

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Conclusions Different perceived built environment attributes are correlated with the health behaviors of Chinese older adults to different degrees. This finding helps to guide community planning and construction, provides an empirical basis for improving health behaviors of older adults, and provides an important reference for building healthy communities for older adults and realizing comprehensive healthy development of older adults.

Trial registration There was no trial registration for this study, but the study was approved by the Institutional Review Board of Tsinghua University (No. THU0120230196).

Keywords Built environment, Health behavior, Physical activity, Social interaction, Older adults

Introduction

Health behaviors refer to the actions or habits taken by individuals in their daily lives that are beneficial to their physical and mental health, including physical activity(PA), social interaction, dietary habits, and so on [1]. Good health behaviors help to prevent diseases, promote health, and improve the quality of life. However, physical inactivity is becoming an increasingly prominent public health problem globally. Lack of PA is statistically one of the major risk factors for global mortality and a major contributor to the increase in overweight and obesity in adults [2]. These trends are reflected in multiple age groups, including older adults.

Physical inactivity is associated with the incidence of cardiovascular and cerebrovascular disease, as well as an increased risk of chronic disease and premature death [3]. This was particularly highlighted during the coronavirus disease 2019 (COVID-19) pandemic and the dramatic reduction in PA due to social isolation is of particular concern among older adults, who are typically less active and more susceptible to chronic diseases than younger age groups [4]. Besides PA, social interaction is an important part of healthy behavior. Social interaction is also a fundamental part of society and is essential for shaping relationships and understanding social identities [5]. The importance of social interaction is multifaceted. For example, social interaction is also an integral part of urban planning as it shapes interpersonal exchanges and relationships in the interstitial spaces of urban areas and has a significant impact on the social fabric of communities [6]. Social interaction among older adults is critical to their health and well-being. By interacting with others, older adults can build and maintain relationships, gain emotional and social support, and reduce feelings of loneliness and depression [7]. Social interaction also promotes cognitive function and mental health, enhances quality of life, and slows the progression of cognitive decline and dementia in older adults [8].

An individual's health behavior is influenced by a variety of factors. The social-ecological model suggests that an individual's health behaviors are influenced by the environment surrounding the individual, including the residential, work, and natural environments [9, 10]. The built environment plays a crucial role in shaping the physical environment in which we live. This involves not only the design of cities and buildings but also how land is used, the planning of transportation systems, and the development of related infrastructure [11]. These environmental factors can be either favorable conditions that promote healthy behavior or barriers that hinder it. For example, one study showed that adults were less likely to be obese when living in communities with high density homes, close to train stations and well-served by transit. This means that people living in well-designed transit-oriented communities are more inclined to use active transportation modes, which leads to opportunities for moderate PA and promotes health behaviors [12].

Research on the relationship between neighborhood built environments and health behaviors has generally shown that different characteristics of the built environment have different effects on individual health behaviors. Smith et al. conducted a systematic review of the relationship between objectively measured characteristics of the built environment and the PA of children or adults, and found that suitable walking environments, the availability of parks and playgrounds, and the installation of or improvements to active transportation infrastructure had a positive impact on residents' PA levels had a positive impact [13]. A study of older adults in Japan used a Geographic Information System (GIS) to objectively measure built environment characteristics such as population density, street connectivity, and recreational space, and showed that population density and the presence of parks or green spaces were positively correlated with the frequency of PA among older adults [14]. Walking is the most common type of PA among older adults. A study in Taiyuan, China, showed that the objective built environment had a significant effect on the walking activity of older adults [15].

According to the Theory of Planned Behavior, an individual's behavior is primarily influenced by his or her intentions, which are determined by attitudes, subjective norms, and perceived behavioral control [16, 17]. Thus, residents' perceptions of the neighborhood built environment may influence their behavior more directly than the objective built environment and have a more significant impact on their health behaviors in daily life. Therefore, understanding the relationship between older

adults' perceived built environments and their health behaviors is of great practical importance for promoting older adults' health. For example, in terms of perceived community built environment, a study of older adults in Ningbo, China, found that older adults' walking activity was significantly associated with their scores of perceived access to services, walking/biking facilities, aesthetic quality and land use mix diversity [18].

In studies exploring the association between neighborhood built environment and social interaction, research from five cities in the United Kingdom has shown that residents living in moderately dense areas have higher levels of frequency of interaction with their neighbors and participation in community group activities [19]. Research by Norwegian scholars showed that easier access to destinations around the community helped adults expand their social networks and increase the frequency of social interactions [20]. In addition, a study of Chinese adults showed that residents' positive perceptions of their neighborhood's built environment promoted PA and reduced sedentary behaviors, and that health behaviors moderated the effects of perceived built environment on health outcomes and life satisfaction [21].

According to the 2020 China survey, older adults aged 60 and above accounted for 18.7% of the total population, indicating that China has entered an aging society [22]. Among the many cities in China, Beijing is one of the first to enter an aging society and one of the most densely populated cities. As of 2020, the older adult population in Beijing has reached 4.299 million, and by 2035 it is expected to approach 7 million. The city is facing a serious aging problem, which puts tremendous pressure on social and economic development. Therefore, the health of older adults in Beijing requires urgent attention. However, research on the relationship between neighborhood built environment and health behaviors of older adults is relatively scarce for older adults in Beijing, especially in high-density residential environments, and further exploration is urgently needed. In addition, the results of previous studies have been mixed, and the effect of perceived built environment on older adults' health behaviors is still controversial compared to the objective built environment. In addition, existing studies have mainly focused on a single dimension of health behaviors, and few studies have comprehensively explored the effects of different dimensions of the perceived built environment on older adults' PA and social interactions.

Therefore, this study aims to explore the relationship between perceived characteristics of the built environment and health behaviors (including PA and social interactions) among older adults in Beijing, complementing empirical research on this relationship in high-density urban environments. At the same time, this study also aims to provide a theoretical basis for environmental-based interventions to promote older adult health behaviors.

Methods

Participants

The data for our study came from the Tsinghua University Retiree Health Survey, which was collected in October 2023 survey data. Participants who took part in the survey were asked to complete a paper questionnaire after signing an informed consent form. The questionnaire collected information on the retirees' gender, age, height, weight, education level, smoking and drinking status, PA level, social interactions, and perceived built environment. In the paper questionnaire, PA level, social interactions, and perceived built environment were assessed using standardized scales in addition to basic information about the retiree. All participants were presented with a $1 gift after completing and submitting the questionnaire. Based on the purpose of this study and to ensure the accuracy and reliability of the data, strict exclusion criteria were set during the processing and analysis of the questionnaires. The specific exclusion criteria were as follows: (1) age less than 60 years old, (2) participants who failed to provide a complete questionnaire, (3) participants with physical or cognitive impairments that prevented them from engaging in physical activity independently, and (4) participants who did not live in their residence for more than one year; any participant meeting one of these criteria needed to be excluded, and ultimately a total of 916 retired older adult's data were included in this study. The study was approved by the Tsinghua University Institutional Review Board (No. THU01-20230196).

Measurement of built environment

The Physical Activity Neighborhood Environment Scale (PANES) was used to assess older adults' subjective perceptions of the built environment. The PANES consists of 17 items, and the reliability and validity of the Chinese version of the PANES have been validated, which is suitable for assessing the subjective perceptions of the built environment of the Chinese population [23].

All PANES items were derived from multiple prior perceived built environment assessment studies [24, 25], some adapted as appropriate. Neighborhood in the scale refers to the residential environment within a 10–15 min walk from home. Among the 17 items of the scale, 16 items were used to assess seven key attributes of the built environment including residential density, access to destinations (such as accessibility to shopping stores, markets, food courts, parks, and public transportation stops), community infrastructure (sidewalk infrastructure, bikeway infrastructure), aesthetic qualities, social

environment, street connectivity, and community safety (traffic safety, crime safety), and the other item was a survey on the ownership of motor vehicles by residents' households. Of these 17 entries, responses to the other 15 were assessed using a five-point Likert scale, except question 1 on the type of housing in the neighborhood and question 11 on the number of motor vehicles owned by the household. Options were included: strongly disagree, somewhat disagree, somewhat agree, strongly agree, don't know, or refused to answer. Each response option had a corresponding score: strongly disagree = 1, somewhat disagree = 2, somewhat agree = 3, and strongly agree = 4. The don't know or refused option was not included in the data analysis. For items 7–8 and 15–16, reverse scoring was used (strongly disagree = 4, some disagree = 3, some agree = 2, strongly agree = 1).

In addition, Sallis et al. constructed questions 1–6 in PANES as the Neighborhood Environment Index (NEI), which is an index that synthesizes perceived built environment attributes [26]. The higher the NEI score, the more beneficial the built environment is to physical activity or health.

Measurement of physical activity

The Physical Activity Scale for the Elderly (PASE) was used to assess PA. The PASE is an extensively validated self-administered assessment tool for measuring PA in Chinese older adults [27, 28]. PASE examined the levels of different types of PA among older adults, including transportation PA, leisure PA, and household PA.

The transportation PA includes walking and biking. Total hours of walking in the last week were constructed based on the answers to the two questions from the PASE assessment tool [29]—"How many of the past seven days have you walked outside for more than 10 minutes?", and "On average, how many hours per day did you spend walking?" Total hours of walking in the last week were calculated by multiplying the daily average number of hours spent walking by the corresponding number of days. Total hours of cycling in the last week were constructed based on the answers to the two questions adapted from the U.S. Centers for Disease Control and Prevention's Physical Activity Questionnaire [30]—"How many days over the past seven days did you bike for at least 10 minutes continuously to get to and from places?", and "On average, how many hours per day did you bike?" Total hours of cycling in the last week were calculated by multiplying the daily average number of hours spent biking by the corresponding number of days.

Leisure PA includes light physical activity (LPA), moderate physical activity (MPA), and vigorous physical activity (VPA) done during leisure time. The total number of hours of LPA in the past week is based on responses to two questions in the PASE assessment tool [29] —"How many days in the past seven days have you engaged in the following light physical activities? For example, yoga, watering flowers, hiking, etc.?" and "On average, how many hours per day do you spend engaged in LPA? Multiply the average number of hours of LPA per day by the corresponding number of days to calculate the total number of hours of LPA for the last week.

The total number of hours of MPA in the past week is based on responses to two questions in the PASE assessment tool [29] —"How many days in the past seven days have you engaged in the following moderate physical activities? For example, aerobics, Tai Chi, table tennis, etc.?" and "On average, how many hours per day do you spend engaged in MPA? Multiply the average number of hours of moderate physical activity per day by the corresponding number of days to calculate the total number of hours of MPA for the last week.

The total number of hours of VPA in the past week is based on responses to two questions in the PASE assessment tool [29] —"How many days in the past seven days have you engaged in the following vigorous physical activities? For example, tennis, soccer, rope skipping, etc.?" and "On average, how many hours per day do you spend engaged in VPA? Multiply the average number of hours of VPA per day by the corresponding number of days to calculate the total number of hours of VPA for the last week.

The total number of hours of household PA in the past week is based on responses to two questions in the PASE assessment tool [29] —"How many days in the past seven days have you engaged in the following household physical activities? For example, cooking, dishes, laundry, cleaning, etc.?" and "On average, how many hours per day do you spend engaged in household PA? Multiply the average number of hours of household PA per day by the corresponding number of days to calculate the total number of hours of household PA for the last week.

The PASE uses frequency, duration, and intensity level of activity over the last seven days to assign a score, ranging from 0 to 400, with higher scores indicating greater PA [29]. We calculated last week's transportation PA score, leisure PA score, household PA score, and total PASE score for each survey participant based on their answers to the assessment questions.

Measurement of social interactions

In order to assess participants' social interactions, we asked residents how often they had interacted with their neighbors in the past six months [31, 32]. The frequency scale ranged from 1 to 4, indicating "never", " rarely", "sometimes", and "often" respectively. The content of the interactions included four types of interactions of varying intensity: visiting each other's homes, having meals together, exercising together, and helping each other, and

the scores for the four types of interactions were summed to assess the overall closeness of the participants' interactions in the community.

Statistical analyses

This study provided descriptive statistics on participants' basic personal information, perceived built environment variables, PA, and social interactions. For quantitative variables, mean and standard deviation (SD) values were reported. For categorical variables, percentages were reported. ANOVA and Chi-square tests were performed to test whether the differences between variables are significant.

In order to study the relationship between older adults' perceptions of the built environment and health behaviors, we used multiple linear regression analysis to construct multiple linear regression models between the perceived built environment and PA, and the perceived built environment and social interactions, respectively. We conducted correlation analysis and variance inflation factor (VIF) calculation for all independent variables beforehand, and the results showed that the correlations between all independent variables were within the acceptable range, and the VIF values were all lower than 4, indicating that multicollinearity did not exist in our model. In addition, in the multiple linear regression model, we controlled for potential confounders (including age, gender, body mass index (BMI), education level, smoking and drinking status) and examined the relationship between each perceived built environment variable and PA and social interaction separately. All statistical procedures were performed in SPSS 27.0 and significance was set at $P<0.05$.

Results

Table 1 presents descriptive statistics of all participants, which mainly include demographic characteristics such as gender proportion, age, height, weight, education level and smoking and drinking status of all participants. A majority of the participants were composed by females (64.41%). The mean age of the sample was 73.52 ($SD=7.62$). The mean height and mean weight of all participants were 162.17 cm ($SD=7.35$) and 63.10 kg ($SD=10.00$), respectively. In addition, 7.9% of participants had an education level of junior high school and below, 26.0% had high school or junior college, and 49.8% and 6.8% had college and graduate degrees, respectively. A rather small proportion of these participants were current smokers (7.9%) and drinkers (8.4%).

Table 2 shows descriptive information on built environment and health behavior scores that reflect participants' mean scores on different built environment variables, PA, and social interactions and their gender differences. As shown in Table 2, among the different built environment variables, the mean scores for residential density for all participants were 1.44($SD=0.67$), access to destinations was 3.18($SD=0.67$), neighborhood infrastructure was 3.08(SD=0.74), and neighborhood safety were 2.41($SD=0.87$). The mean scores for subjective perception of social environment, aesthetic qualities, and street connectivity for all participants were 3.16($SD=0.94$), 3.03($SD=0.91$), and 2.74($SD=1.06$), respectively. Moreover, the Neighborhood environment index scored 2.90($SD=0.59$). There were significant differences between male and female participants in subjective perceptions of neighborhood safety ($P=0.014$) only.

In the PA scores, the mean scores for transportation PA, leisure PA, and household PA for all participants were 32.03 ($SD=30.53$), 49.46 ($SD=48.48$), and 41.98 ($SD=35.38$), respectively. In addition, the participants'

Table 1 Descriptive statistics of all participants

Characteristics	Total	Male	Female	*P*
N	916	326	590	
Age (yr), mean (SD)	73.52 (7.62)	76.43 (7.59)	71.92 (7.16)	< 0.001
Height (cm), mean (SD)	162.17 (7.35)	168.50 (5.97)	158.68 (5.48)	< 0.001
Weight (kg), mean (SD)	63.10 (10.00)	68.79 (9.73)	59.95 (8.68)	< 0.001
Education level, N (%)				< 0.001
Junior high school and below	160 (17.5)	54 (16.6)	106 (18.0)	
High school or junior college	238 (26.0)	52 (16.0)	186 (31.5)	
College	456 (49.8)	177 (54.3)	279 (47.3)	
Graduate	62 (6.8)	43 (13.2)	19 (3.2)	
Smoking, n (%)				< 0.001
Current smoker	72 (7.9)	61 (18.7)	11 (1.9)	
Current nonsmoker	844 (92.1)	265 (81.3)	579 (98.1)	
Drinking, n (%)				< 0.001
Current drinker	77 (8.4)	70 (21.5)	7 (1.2)	
Current nondrinker	839 (91.6)	256 (78.5)	583 (98.8)	

Table 2 Descriptive information for built environment and health behavior scores

Variables	Total	Male	Female	*P*
Built Environment Scores, mean (SD)				
Residential density	1.44 (0.67)	1.49 (0.72)	1.41 (0.64)	0.076
Access to destinations	3.18 (0.67)	3.22 (0.63)	3.16 (0.69)	0.191
Neighborhood infrastructure	3.08 (0.74)	3.12 (0.70)	3.05 (0.76)	0.161
Neighborhood safety	2.41 (0.87)	2.51 (0.87)	2.36 (0.87)	0.014
Social environment	3.16 (0.94)	3.17 (0.93)	3.16 (0.95)	0.930
Aesthetic qualities	3.03 (0.91)	3.01 (0.94)	3.04 (0.89)	0.632
Street connectivity	2.74 (1.06)	2.80 (1.03)	2.71 (1.07)	0.218
Neighborhood environmental index	2.90 (0.59)	2.93 (0.55)	2.87 (0.61)	0.162
Physical Activity Scores, mean (SD)				
Transportation physical activity	32.03 (30.53)	34.43 (32.99)	30.70 (29.03)	0.077
Leisure physical activity	49.46 (48.48)	46.00 (43.83)	51.37 (50.81)	0.108
Household physical activity	41.98 (35.38)	32.41 (31.11)	47.27 (36.49)	< 0.001
Total physical activity	123.47 (79.00)	112.84 (72.99)	129.35 (81.61)	0.002
Social Interaction Scores, mean (SD)				
Neighbors visit	2.28 (1.03)	2.15 (1.01)	2.35 (1.04)	0.005
Having meals with neighbors	1.98 (1.00)	1.89 (0.97)	2.03 (1.00)	0.046
Exercising with neighbors	2.56 (1.11)	2.30 (1.11)	2.70 (1.10)	< 0.001
Neighbors help	3.00 (0.87)	2.86 (0.85)	3.08 (0.87)	< 0.001
Total social interaction	9.81 (3.36)	9.20 (3.38)	10.15 (3.30)	< 0.001

Table 3 Association between the built environment and physical activity

	B (SE)	β	95% CI	R^2	Adjusted R^2
Residential density	2.692(3.910)	0.023	[-4.982,10.365]	0.058	0.051
Access to destinations	10.342(3.781)	0.088**	[2.922,17.762]	0.065	0.058
Neighborhood infrastructure	8.803(3.429)	0.083*	[2.073,15.532]	0.064	0.057
Neighborhood safety	0.230(2.995)	0.003	[-5.648,6.109]	0.057	0.050
Social environment	4.611(2.703)	0.055	[-0.694,9.915]	0.060	0.053
Aesthetic qualities	7.238(2.799)	0.083*	[1.745,12.732]	0.064	0.057
Street connectivity	2.439(2.444)	0.033	[-2.359,7.236]	0.058	0.051
Neighborhood environmental index	12.650(4.306)	0.095**	[4.200,21.100]	0.066	0.059

Notes: *All models were adjusted for age, gender, BMI, education level, smoking and drinking status*

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$

total PA scores were 123.47 (SD=79.00). There were significant differences between male and female participants in total PA scores(P=0.002) and household PA scores (P<0.001). In the social interaction scores, the total social interaction scores for all participants were 9.81(SD=3.36). Among them, the average score for neighbor visits was 2.28(SD=1.03), the average score for having meals with neighbors was 1.98(SD=1.00), the average scores for exercising with neighbors were 2.56(SD=1.11), and the average scores for neighbors help were 3.00(SD=0.87). There was a significant difference between male and female participants in the total social interaction score as well as in the social interaction scores for each dimension(P<0.05).

Table 3 shows the associations between the built environment and PA, where destination accessibility, neighborhood infrastructure, aesthetic qualities, and neighborhood environmental index of the built environment significantly influence older adults' PA levels. Multiple linear regression models (one for each built environment variable) were used to assess the relationship between perceived built environment variables and PA of older adults, controlling for potential confounders of age, gender, BMI, education level, smoking, and drinking status. In these models applied to the overall sample, there were significant associations between PA and access to destinations (β=0.088, P<0.01), neighborhood infrastructure (β=0.083, P<0.05), aesthetic qualities (β=0.083, P<0.05), and neighborhood environment index (β=0.095, P<0.01), respectively.

Table 4 shows the relationship between the built environment and social interaction. The results show that several aspects of the built environment can influence older adults' social interactions after controlling for potential confounders. There were significant associations between social interaction and access to destinations (β=0.105, P<0.01), neighborhood infrastructure (β=0.099, P<0.01), neighborhood safety (β = -0.084,

Table 4 Association between the built environment and social interaction

	B (SE)	β	95% CI	R^2	Adjusted R^2
Residential density	-0.090(0.167)	-0.018	[-0.418,0.237]	0.048	0.041
Access to destinations	0.524(0.161)	0.105**	[0.207,0.840]	0.059	0.052
Neighborhood infrastructure	0.446(0.146)	0.099**	[0.159,0.733]	0.058	0.050
Neighborhood safety	-0.326(0.127)	-0.084*	[-0.576,-0.075]	0.055	0.047
Social environment	0.325(0.115)	0.091**	[0.099,0.551]	0.056	0.049
Aesthetic qualities	0.533(0.119)	0.144***	[0.300,0.766]	0.069	0.061
Street connectivity	0.356(20.104)	0.112***	[0.153,0.560]	0.060	0.053
Neighborhood environmental index	0.492(0.184)	0.087**	[0.131,0.853]	0.055	0.048

Notes: *All models were adjusted for age, gender, BMI, education level, smoking and drinking status*

*$P<0.05$; **$P<0.01$; ***$P<0.001$

$P<0.05$), social environment (β=0.091, $P<0.01$), aesthetic qualities ($\beta=0.144$, $P<0.001$), street connectivity ($\beta=0.112$, $P<0.001$), and neighborhood environment index ($\beta=0.087$, $P<0.01$), respectively.

Discussion

The purpose of this study was to investigate the relationship between the perceived built environment and health behaviors of older adults in Beijing, China. The results of the study showed that the perceived built environment characteristics of older adults were correlated with their PA and social interactions to varying degrees. Among them, perceived destination accessibility, neighborhood infrastructure, aesthetic quality, and neighborhood environment index were significantly related to PA and social interaction of Chinese older adults. In addition, neighborhood safety, social environment, and street connectivity were also significantly related to the social interactions of older adults.

In an analysis of the relationship between older adults' PA and their perceived built environment, this study found that older adults' perceived destination accessibility, community infrastructure, and aesthetic quality were significantly associated with their PA. This finding underscores the potential role of older adults' perceived built environment characteristics in promoting their healthy lifestyles. Malambo et al. also showed that perceived characteristics of the built environment (such as proximity to stores, public transportation stops, transportation accessibility, availability of sidewalks and crosswalks, and natural landscaping) were associated with individuals achieving levels of PA of at least 150 min per week of moderate to vigorous intensity [33]. In addition, Yoo et al.'s analysis of qualitative research using a multi-method approach indicated that both perceived destinations and public transportation accessibility for older adults were related to their level of PA [34]. These findings support the Theory of Planned Behavior, which states that individuals' attitudes, subjective norms, and perceptions largely determine their behavior [16, 17].

In addition, the results of this study did not find significant correlations between residential density, neighborhood safety, social environment, and street connectivity with PA among older adults, which is different from the results of previous studies [35]. For example, a study in Singapore noted that older adults' subjective assessments of residential density and street connectivity were significantly associated with transportation-based PA [36]. There may be multiple reasons for the differences in the results of these studies. On the one hand, people from different cultural backgrounds perceive and utilize the built environment in different ways, which in turn affects their PA levels. On the other hand, differences in the economic levels of the study populations may also play a role. In regions with different levels of economic development, there may be significant differences in people's needs for the built environment. Therefore, future studies should adopt a more comprehensive and diversified approach, taking into account the effects of geographic, socio-cultural and economic factors. At the same time, it is recommended that detailed consideration be given to the characteristics of specific regions and that quantitative and qualitative analysis methods be combined in the research process in order to explore the relationship between the built environment and PA in greater depth.

In the analysis of perceived built environment and social interactions of older adults, this study found that most of the built environment attributes were significantly associated with social interaction activities of older adults, which is generally consistent with the results of previous studies [37, 38]. The characteristics of the built environment of a community affect the social interaction activities of older adults, probably because older adults' perceptions of the convenience, safety, and comfort of public spaces in the community affect their willingness to participate in community activities and interact with their neighbors. Features such as friendly street design, convenient neighborhood facilities, and a rich variety of public activity spaces can enhance older people's sense of belonging to the community and their sense of social support [39], thus promoting their more active participation

in social interaction activities and the establishment of a closer social network with their neighbors. Therefore, the characteristics of the built environment perceived by the elderly affect their social interaction behavior, showing a significant correlation.

This study did not find an association between residential density and social interactions of older adults. More notably, the results of this study showed a significant negative correlation between perceived neighborhood safety and social interaction among older adults. These findings may reflect the complexity and diversity of social interaction behaviors among older adults. First, residential density does not necessarily have a direct impact on older adults' social interactions, which are more influenced by factors such as individual preferences, community culture, and social support [40]. Second, there may be some discrepancies between the perceived neighborhood safety and the actual safety of older adults. Older adults may choose to reduce social interactions because of uncertainty about their surroundings, even if there is no apparent threat to neighborhood safety. Thus, these findings may reflect the complex cognitive and behavioral patterns of older adults' social interactions and their heightened sensitivity to environmental safety, rather than simply being directly influenced by residential density or neighborhood safety.

There are two main strengths of this study. First, as the global trend of population aging intensifies, this study examines the association between neighborhood built environments perceived by older adults and their health behaviors, using older adults aged 60 years and older in Beijing, China. This empirical study adds to the evidence on the relationship between neighborhood built environments and health behaviors of older adults in high-density residential cities in developing countries. This finding is critical for the development of targeted policies and interventions to promote healthy ageing. Second, this study focuses on older adults' subjective perceptions of the built environment, and explores the relationship between perceived built environment and older adults' PA and social interactions separately from multiple factors of the built environment, which provides richer findings and guidance for improving older adults' health.

The limitations of this study are the cross-sectional research design, which is based on one-time data collection, and the study is unable to observe individual changes and trends over time, thus it is not possible to determine the long-term effects of, or the causal relationship between, the perceived built environment and health behaviors of older adults. Secondly, participants may have inaccurate recall or be influenced by subjective factors when completing the questionnaire, thus affecting the reliability of the study results. Third, the participants in this study were retirees from Tsinghua University, which may be a limitation since the sample came from a single organization, and future studies could consider retirees from more organizations to improve representativeness. In addition, for the older adult population, marital status or living alone, self-rated health status, and chronic diseases may affect their PA and social interactions, and these variables should be considered as potential confounders. However, information on these variables was not addressed in the data collection process for this study. Therefore, these limitations need to be carefully considered when interpreting the results of the study and combined with other research designs to enhance the understanding of the relationship between the perceived built environment and the health behaviors of older adults.

Conclusion

This study reveals the association between the perceived built environment and health behaviors among Chinese older adults. It was found that perceived destination accessibility, neighborhood infrastructure, aesthetic quality, and neighborhood environment indices were positively associated with PA and social interactions of older adults. In addition, neighborhood safety, social environment, and street connectivity were also strongly associated with older adults' social interactions. These findings emphasize the important role of the built environment in promoting health behaviors among older adults and provide useful references for future community planning and health policies for older adults.

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Author contributions

Yiling Song: Conceptualization, Writing – original draft; Yangyang Wang: Writing –review & editing; Mingzhong Zhou: Formal analysis; Zhiyang Suo: Data curation; Xiaoxin Wang: Investigation; Chengwei Li: Methodology; Xiaolu Feng: Methodology; Jiali Cheng: Investigation; Hongjun Yu: Funding acquisition.

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Data availability

The data and materials in this manuscript are available upon request.

Declarations

Ethics approval and consent to participate

This study was approved by the Tsinghua University Institutional Review Board. All the participants gave written informed consent before completing the survey.

Consent for publication

Not applicable.

Competing interests
The authors declare no competing interests.

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