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Neighborhood built environments and cognition in later life

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ABSTRACT

Objectives: Maintaining good cognition is crucial in later life. However, most existing research has focused on individual factors impacting cognition, and few studies have investigated the association between neighborhood built environment and older adults' cognition. This study examined the association between neighborhood built environment and cognition among community-dwelling older adults and identified variations in this association between different age groups in the older population.

Methods: Data were derived from a cross-sectional survey of 1873 people aged 65 years and above in Hong Kong. We merged individual data from the survey with neighborhood built environment data based on community auditing and geographical information system. After controlling for individual covariates, we used multivariable linear regression to examine the association between neighborhood built environment and cognition.

Results: Residents aged 80 and younger in neighborhoods with a higher land-use mix and more public transport terminals exhibited better cognition. Only the number of community centers in a neighborhood was positively associated with cognition for people older than 80.

Conclusion: The built environment creates diverse impacts on different age groups among older adults. Our findings provide useful information for urban planners and policymakers for planning community facilities and built environments that consider the needs of different age groups within the older population.

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Introduction

With increasing life expectancy globally, staying 'healthy' during the extra years of life becomes important (Beard et al., 2016). The World Health Organization proposed a new framework of healthy aging in 2015 to optimize older adults' functional ability to be and do what they value in their lives (World Health Organization, 2015, 2017). Functional ability is the combination of the individual's intrinsic capacity, their living environment and the interactions between them (World Health Organization, 2015, 2020). Cognition, as an ingredient of intrinsic capacity in the healthy aging framework, is crucial in later life because of its association with autonomy, well-being and quality of life (Fiocco & Yaffe, 2010; Zuidema et al., 2007) and is also recognized as a global public health priority (World Health Organization, 2012). Although the healthy aging framework indicates the importance of the physical and social environment on intrinsic capacity (Beard et al., 2016), existing literature on older adults' cognition has mainly focused on the association between cognition with individual factors such as socioeconomic status, medical conditions and lifestyle (Kujawski et al., 2018; Zaninotto et al., 2018), as well as social environmental factors such as neighborhood socioeconomic status and psychosocial disorder (Besser et al., 2017). While the association was found between socioeconomic status and physical living environment condition (Evans & Kantrowitz, 2002), the neighborhood with higher socioeconomic status does not equal to better physical environment for cognition (Taylor et al., 2012). Therefore, more attention is needed to understanding the association between neighborhood built environment and cognition (Wu, Prina, & Brayne, 2015).

Neighborhood built environments are broadly defined as man-made buildings and spaces for day-to-day living, recreation and working (Roof & Oleru, 2008). In previous studies, neighborhood built environments are assessed in four different dimensions, including density (e.g. population density), diversity (e.g. land-use mix), design (e.g. greenery) and destination (e.g. availability of facilities) (Ewing & Cervero, 2010; Zhang, Ye, et al., 2019). They are particularly important for older adults' health and cognition compared to other age groups because older adults tend to spend more time in their immediate neighborhoods than younger people (Besser et al., 2017). According to the environmental-press competence model, the increasing environmental press may result in a higher potential for negative adaptive outcomes for people with lower competencies (Lawton, 1982). This is the result of age-related mobility decline and lifestyle changes (Yen et al., 2009). Growing evidence suggests that older adults living in a well-designed environment, which facilitate social interaction, social engagement, exercise and cognitive stimulation, are associated with better cognition (Besser et al., 2017; Wu, Prina, Jones, et al., 2015). In contrast, older adults living in an

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impoverished environment offering few opportunities for physical and social activity have poorer cognitive function and faster cognitive decline (Volkers & Scherder, 2011).

The mechanisms of the impact of neighborhood built environment on cognition are complex and multifaceted (Besser et al., 2018) and can be classified into direct and indirect forms. The built environment can enhance cognition directly in two ways, where an enriched environment may facilitate cognitive stimulation and a natural environment may enhance attentional performance and memory (both being important elements of cognition) (Cassarino & Setti, 2015). People exposed to an enriched environment (i.e. an environment with an increased level of novelty and complexity) may build cognitive and brain reserve through cognitive stimulation from the environment (Tucker & Stern, 2014), prevent brain degeneration (Hannan, 2014) and perform better in cognitive tasks (Berardi et al., 2007). For example, greater street connectivity in a neighborhood that requires more cognitive complexity to navigate among streets and the route to the destination are associated with better cognitive function among older adults because this process enables them to practice and strengthen their cognitive abilities (Watts et al., 2015). Conversely, the availability of natural or green space may reduce perceptual load and improve attentional performance and memory (Cassarino & Setti, 2015). For example, a longitudinal study on greenness surrounding a neighborhood found that higher levels of neighborhood greenery were associated with slower cognitive decline (de Keijzer et al., 2018). Another study also found greater neighborhood greenery was associated with a lower prevalence of Alzheimer's disease (Brown et al., 2018).

A well-designed built environment also indirectly benefits older adults' cognition through enhancing their opportunity for physical activities, cognitive-enhancing lifestyles and social interactions (Cassarino & Setti, 2015; Van Cauwenberg et al., 2011). These activities have been proven empirically to enhance older adults' cognition and reduce the odds of cognitive impairment and dementia (Etnier et al., 2019; Lee & Yeung, 2019; Valenzuela & Sachdev, 2006). For example, a neighborhood with a higher land use mix was associated with reduced odds of dementia because of the better access to local services and opportunity for social interactions and cognitive stimulation (Wu, Prina, Jones, et al., 2015). In addition, a cohort study found that a higher number of public parks in the neighborhood from early to mid-life was associated with slower cognitive decline in later life (Cherrie et al., 2018). Another cohort study found that the availability of community centers and public transit stops in the neighborhood was associated with a slower rate of cognitive decline (Clarke et al., 2015). This is possibly the result of increased opportunities for social and physical activities occurring in the parks and the community centers and improvement in accessibility to facilitate those activities by public transit stops.

Despite the growing attention paid to the association between the built environment and older adults' cognition, existing empirical evidence is insufficient (Wu, Prina, & Brayne, 2015) and research findings to date remain inconclusive (Besser et al., 2017; Wu et al., 2017). Such inconsistencies are the possible result of different studies adopting different measurements of cognition and the environment with the diverse definition of neighborhoods (Besser et al., 2018). For example, studies on greenery and cognitive impairment by Brown et al. (2018) found that more neighborhood greenery was associated with a lower prevalence of Alzheimer's disease. However, Wu, Prina, Jones, et al. (2015) found the opposite correlation between cognitive impairment and dementia. Watts et al. (2015) study on the association between neighborhood street connectivity and cognitive performance found contradictory results by using different measurements of street connectivity. They found faster cognitive decline was associated with greater street connectivity using one measure (the number of turns needed to reach the destination in the network) but slower decline using a different measure (the number of paths, streets or nodes connected to respondents' road network) (Watts et al., 2015). More importantly, some studies may only measure a single attribute of an environmental factor but overlook other important attributes that are highly influential to the same factor. For example, studies on public open space (POS; including parks) only measure its area but ignore its accessibility, which is an important element in park planning and usage (Guo et al., 2019). This may account for discrepancies between the study conducted by Cherrie et al. (2018), who found more public park areas were associated with slower cognitive decline, and that of Clarke et al. (2012) who found no association. Given the limited research on the built environment and cognition among older adults and the inadequate measurement of environmental factors, additional work is needed to provide more empirical evidence on the association along with a comprehensive measurement on some of the environmental factors, such as measuring POS from both of its area and accessibility.

In terms of methodology, some existing studies are methodologically limited in two significant ways. First, most studies aggregate individual characteristics as the environmental attribute (Wu, Prina, & Brayne, 2015). These aggregating data are endogenous to the individual-level factor and lead to difficulties in identifying the independent effect of the environment (Roux, 2004). Second, most studies use participants' perceptions of neighborhood features (e.g. satisfaction with the living environment and satisfaction with services and facilities) rather than using objective measures. Overreliance on perceptions may lead to 'same-source bias' especially when studying mental health outcomes (Wu, Prina, & Brayne, 2015). There is a strong correlation between individual health status and their perception, meaning that healthier individuals are more likely to report positive outcomes regarding their environment than less-healthy individuals (Roux, 2007). Therefore, the use of objectively measured built environment indicators in this study, residential surrounding greenness, land-use mix, the total number of facilities and area of POS that earlier research has identified as having significant associations with the health of older adults (Kerr et al., 2012; Yen et al., 2009), would overcome these challenges.

Finally, available literature on environment and cognition often examines older adults as a homogenous group that overlooks the dynamic relationship between individuals and their living environment from the life course perspective. Considering the changing dependence on neighborhood environment resulting from changing functional performance and cognitive function in advanced age (Daly et al., 2013; Tucker-Drob, 2019) and the different prevalence rates of dementia (Cenko et al., 2021), there is a need to study older adults by separating them into different meaningful age groups instead of regarding them as a homogenous group.

To address the above research gaps, the objectives of this study, therefore, were to examine: (1) the association between objectively measured built environment indicators and cognition among community-dwelling older adults and (2) whether such associations vary among different groups of older adults.

Methods

Study design and participants

We conducted a cross-sectional study with 1873 older adults aged 65 years and above residing in twelve public rental housing estates in Hong Kong. The residents or these twelve estates have an average of 27.7% older adults (people aged 65 or above) and one third of the residents (33.4%) have primary education or below. The average median household income of these estates was HK$17203.1 (*SD* =$2763.5) per month (Census and Statistics Department, 2016). Probability proportional to size (PPS) sampling was used where participants were randomly sampled in three age strata (65–74 years, 75–84 years, 85 years and older) with target sample sizes of 50, 60 and 70 for each group, respectively, to generate a sample of 180 per estate. All assessments were conducted by trained researchers during a home visit in 2014. The study method has been published previously (Liu et al., 2018). Neighborhood built environment was assessed within the 200-m slope-adjusted network buffer area of a participant's home using ArcGIS 10.5. Data on land-use mix and facilities were extracted from The Hong Kong Government Lands Department (https://www.landsd.gov.hk). The 200-m buffer area was selected since it captures the neighborhood built environment within a 5-min walk of older adults' homes (Gehl, 2010). Many existing studies on older adults and their living environment uses a 200-m buffer to capture the immediate neighborhood context (e.g. Lu et al., 2021; Strath et al., 2012). This small buffer area can reveal the high-density nature of the built neighborhood environments in Hong Kong (Liu et al., 2021), and such proximal land uses may be more relevant to older adults with the assumption that the older adults have a slower walking speed than the younger age group (Rodríguez et al., 2009; Van Cauwenberg et al., 2011). In 2019 four trained researchers undertook community auditing to gather information regarding the accessibility of POS in 200-m buffer areas in each estate. The study was approved by the Human Research Ethics Committee of The University of Hong Kong [Reference Number: EA050814].

Dependent variable

Cognition was measured by the validated Cantonese Chinese Montreal Cognitive Assessment (CC-MoCA) (Chu et al., 2015). Scores for the CC-MoCA range from 0 to 30, a higher score indicating better cognition. As recommended, the scores were adjusted by adding two points for participants who reported having received no education and one point for those who had completed one to six years of formal education only (Chu et al., 2015). The Cronbach's alpha for CC-MoCA in this sample was 0.79.

Independent variables – neighborhood built environments

*Residential surrounding greenne*ss was measured by the Mean Normalized Difference Vegetation Index (NDVI) (Crippen, 1990). This represents the quality and intensity of greenery by measuring the difference between absorbance and reflectance of wavelengths by chlorophyll in the leaf cells of plants. The NDVI score ranges from −1 to 1. Positive scores indicate the coverage of green vegetation, and a higher positive score represents denser coverage. NDVI greenness was derived from a series of 6-m resolution images collected by Satellite Pour l'Observation de la Terre (SPOT) (De Bie et al., 2011).

Land-use mix captures the diversity of five land-use types: residential, commercial/industrial, institutional, open space and others (Frank et al., 2006). The score range is between 0 and 1. The minimum score (0) indicates homogenous land-use and the maximum reveals highly-mixed land use with equal contributions from the five land-use categories.

The total number of each type of facility within the 200-m buffer area of participants' homes was computed to reveal its availability. Commercial facilities refer to convenience stores, supermarkets, bazaars and malls. Community centers comprise community centers, family service centers and welfare centers. Cultural facilities are libraries, civic centers and town halls. Active leisure facilities include indoor sports venues, sports grounds, football fields and swimming pools. Public transport terminals include bus terminals and metro stations.

POS within the 200-m buffer area of participants' building address or estate were measured by their area and accessibility. Participants' POS area was calculated by the sum of all POSs' area within the buffer. POS accessibility was evaluated through community audit by four trained researchers in two groups who visited each POS during the day-time. They independently rated the accessibility to the POS from the centroid point of the sampled neighborhood to the entrance of the POS. Inter-rater reliability between the two researchers in each group reached 80%. The ratings were based on the following criteria: (1) distance from the center point of the housing estate assigned to the POS; (2) presence and features of stairs; (3) presence and features of slopes; (4) presence and effectiveness of barrier-free facilities, including but not limited to handlebars and ramps. POS accessibility was rated on a three-point scale: '1' for difficult; '2' for moderate; or '3' for easy. Participants' POS accessibility was calculated by the sum of all POS accessibility scores within the buffer and normalized.

Covariates

Control variables included age, gender, marital status (married vs. others), chronic disease, physical function and participation in activities. Chronic disease was assessed by the total number of chronic diseases reported by participants from a list of the 30 most common chronic diseases affecting older adults. The result was further grouped into '0' for no chronic disease, '1' for one type of chronic disease or '2' for two or more types of chronic disease. Physical function was assessed by activity of daily living (ADL) and visual, hearing and walking ability. ADL was measured by the Barthel Index (Collin et al., 1988), ranging from 0 to 20, a higher score indicating more independence. Visual, hearing and walking ability were self-reported with two possible answers: '0' for no difficulty or '1' for having difficulty. Participation in activities measured the frequency of participation in three types of activity (i.e. mind stimulation, physical and social activities) during the past week. The responses were: '0' for 0–2 days per week, '1' for 3–4 days per week or '2' for 5 days or more per week.

Statistical analysis

The Covariate-dependent missingness (CDM) assumption test indicated the missing data pattern of CC-MoCA, mind-stimulation activity, physical activity and social activity were missing at random (χ 2 distance = 108.71, df = 153, p = .997) (Li, 2013). We excluded 73 (3.9%) participants from the analysis because of missing data, giving a final sample of 1800. As the prevalence rate of dementia is 2% to 6% among people aged over 65, but 11% to 29% among those aged over 80 (Wu et al., 2018), we regrouped the three age groups to two meaningful groups (i.e. people aged 65–80 and people older than 80) for further analysis. We first reported sample characteristics and then examined the differences between the two groups using chi-square and *t*-test. The intra-class correlation coefficient (ICC) for multilevel models was 0.013, indicating no evidence of clustering effects in the data (Holodinsky et al., 2020). Therefore, we used a multivariable linear regression model to examine the association between built environment and cognition after controlling for individual covariates for the first research objective. Quadratic terms were added to the model to examine curvilinear relationships between built environmental attributes and cognition. The variance inflation factor (VIF) ranged from 1.03 to 9.06 and all of them were lower than 10, indicating that multicollinearity was not a concern (Hair et al., 1995). Finally, we repeated the same regression model for the two age groups to answer the second research objective. We performed a sensitivity analysis to examine the effects of 500-m built environment variables on model outcomes. The statistical analysis was done by SPSS 26.

Results

Table 1 shows the characteristic of the sample. Participants ranged from 65 to 98 years of age (Mean = 79.4, *SD* = 8.0 years). The majority (53.5%) were women, married (60.2%), and had two or more chronic diseases (64.1%). The mean CC-MoCA score was 19.6 (*SD* = 5.8), with a mean ADL of 19.2 (*SD* = 1.8). Nearly one-third reported visual impairment (30.8%), hearing impairment (24.1%) and difficulty in walking (27.3%). Approximately half reported participating in physical activities (46.6%) five days or more a week, but few reported participating in stimulating cognitive activities (21.6%) or social activities (14.4%) five days or more a week. Regarding the built environment attributes, the means for NDVI per IQR and land-use mix were 2.6 (*SD* = 0.7) and 0.7 (*SD* = 0.2), respectively. Commercial facilities in the community had the highest number (Mean = 1.7, *SD* = 1.5), followed by community centers (Mean = 0.5, *SD* = 0.6), public transport terminals (Mean = 0.4 *SD* = 0.7), active leisure facilities (Mean = 0.4 *SD* = 0.6) and cultural facilities (Mean = 0.1 *SD* = 0.3). The average total area of POS was 3.3 hectares (*SD* = 2.2) and the accessible POS score was 4.8 (*SD* = 2.8).

Table 1 also shows the difference between people aged 65–80 and people older than 80. Regarding cognitive function, people older than 80 had significant lower CC-MoCA scores (Mean = 17.0 *SD* = 5.6) than those aged 65–80 (Mean = 22.0 *SD* = 4.9). The over-80s also comprised fewer females (49.9%) and married (45.8%), a higher number of chronic diseases (67.5% with two or more types of chronic disease), poor ADL (Mean = 18.8 *SD* = 2.2) and a higher proportion of visual (35.5%), hearing (29.6%) and walking (39.1%) impairment than people aged 65–80. No significant difference was found between the

Table 1. Characteristics of participants.

	All (n = 1800)	Age 65–80 (n = 944)	Age > 80 (n = 856)	*p*-value
Cognitive function				
Cantonese Chinese Montreal Cognitive Assessment[a] (mean ± *SD*)	19.63 ± 5.79	22.00 ± 4.85	17.02 ± 5.62	<.001
Individual-level covariates				
Age (mean ± *SD*)	79.40 ± 8.03	72.86 ± 4.71	86.63 ± 3.44	<.001
Gender (female %)	53.5	56.8	49.9	.003
Marital status (Married %)	60.2	73.3	45.8	<.001
Number of chronic diseases (%)				.001
Two or more types of chronic disease	64.1	61.0	67.5	
One type of chronic disease	22.6	23.1	22.1	
No chronic disease	13.3	15.9	10.4	
Physical function				
Activity of daily living (mean ± *SD*)	19.20 ± 1.81	19.55 ± 1.27	18.82 ± 2.19	<.001
Visual (impairment %)	30.8	26.6	35.5	<.001
Hearing (impairment %)	24.1	19.2	29.6	<.001
Walking (impairment %)	27.3	16.5	39.1	<.001
Activities				
Mind stimulation activities (%)				.158
0–2 days a week	70.2	71.4	68.9	
3–4 days a week	8.2	8.7	7.6	
5 days or more a week	21.6	19.9	23.5	
Physical activities (%)				<.001
0–2 days a week	44.5	40.4	49.1	
3–4 days a week	8.9	11.3	6.2	
5 days or more a week	46.6	48.3	44.7	
Social activities (%)				.251
0–2 days a week	76.4	77.5	75.2	
3–4 days a week	9.1	9.3	8.9	
5 days or more a week	14.4	13.1	15.9	
Neighborhood built environments within 200-m buffer area of participants' home (mean ± SD)				
Normalized Difference Vegetation Index[b] (range = 1·59–4·12)	2.62 ± 0.68	2.62 ± 0.69	2.62 ± 0.67	.983
Land-use mix (range = 0·24–0·98)	0.72 ± 0.17	0.73 ± 0.17	0.71 ± 0.17	.062
Commercial facilities[c] (range = 0–6)	1.71 ± 1.51	1.76 ± 1.53	1.64 ± 1.49	.097
Community centers[c] (range = 0–3)	0.53 ± 0.64	0.51 ± 0.61	0.56 ± 0.68	.135
Cultural facilities[c] (range = 0–1)	0.10 ± 0.30	0.09 ± 0.29	0.11 ± 0.32	.161
Active leisure facilities[c] (range = 0–3)	0.35 ± 0.60	0.34 ± 0.57	0.37 ± 0.62	.404
Public transport terminals[c] (range = 0–4)	0.39 ± 0.67	0.40 ± 0.59	0.39 ± 0.75	.763
Area of public open space (range = 0.87–9.71)	3.25 ± 2.24	3.23 ± 2.22	3.27 ± 2.27	.736
Accessibility of public open space (range = 0–11)	4.82 ± 2.77	4.79 ± 2.83	4.84 ± 2.69	.715

[a] Cantonese Chinese Montreal Cognitive Assessment score adjusted by education.
[b] Normalized Difference Vegetation Index (mean NDVI per IQR).
[c] Neighborhood service facilities measured by the number of facilities.

two groups in terms of their neighborhood built environment (i.e. residential surrounding greenness, land-use mix, the total number of each type of facility and the area or accessibility of POS) within 200-m buffer area.

Table 2 shows the results of unstandardized regression. After controlling for the covariates, a curvilinear relationship was found between active leisure facilities and cognition (β = –2.15, p < .001 with squared term of active leisure facilities β = 0.59, p = .007), but no significant relationship was found between cognition and other environmental attributes. Individual factors including older age (β = –0.30, p < .001), being female (β = –1.93, p < .001), hearing impairment (β = –0.68, p = .012) and having walking difficulty (β = –1.33, p < .001) were negatively associated with cognition. However, being married (β = 0.74, p = .005), better ADL (β = 0.29, p < .001) or engaged in more cognitive stimulating activities (β = 0.52, p < .001) and physical activities (β = 0.30, p = .013) were associated with better cognition.

Table 2 also shows the results of subgroup analysis and, as expected, the two age groups differed significantly. For people aged 65–80, living in a neighborhood with higher land-use mix (β = 2.89, p = .015) and more public transport terminals (β = 0.96, p = .001) was associated with better cognition. A curvilinear relationship was found between active leisure facilities and cognition (β = –3.47, p < .001 with squared term of active leisure facilities β = 0.96, p = .001). Neighborhood environment had less impact on cognition for the over-80s. The only significantly positive association was found between cognition and the number of community centers (β = 0.71, p = .018).

In the sensitivity analysis, the two buffer area models (200-m and 500-m) had a comparable model fit index, measured by the adjusted R square. However, the VIF of active leisure facilities and its squared term in this 500-m buffer model are higher than 10, indicating multicollinearity concerns (Hair et al., 1995). Therefore, this study reports findings using the 200-m buffer area.

Discussion

To the best of our knowledge, this is the first study to combine survey, geographical information system (GIS) and community auditing data to investigate the association between neighborhood built environment and cognition in different older age groups. We found that more neighborhood built environment attributes were associated with cognition among people aged 65–80 than people older than 80. Three built environmental attributes – land-use mix, public transport terminals and active leisure facilities – were positively associated with cognition among people aged 65–80. Only the number of community centers was associated with better cognition among people over 80.

The study generated several additional insights. First, it revealed that various aspects of the built environment affect older adults differently, indicating the importance of examining older adults as a heterogeneous group, unlike most existing studies. Differences in findings among people aged 65–80 and people older than 80 may reflect the dynamic interplay between individual competencies and environment facilitators or stressors. For example, easy access to public transport terminals enables people aged 65–80 to travel to places other than their immediate neighborhood and engage in various pursuits, thus providing opportunities for participating in cognitively and socially stimulating activities. This finding is consistent with an earlier study that found a positive association between transportation use and cognition among older adults (Reinhard et al., 2019). However, such impact was insignificant for people over 80. Given their deteriorating physical abilities, it is probable that the over- 80s become depending on the number of available social activities in their immediate neighborhood and making less use of public transportation.

Moreover, our finding is consistent with existing literature that higher land-use mix is associated with better cognition among older adults (Ng et al., 2018; Wu et al., 2017). This result

Table 2. Unstandardized regression coefficients (β) and 95% confidence intervals (CI) for cognition in old age according to different older age groups and neighborhood environmental attributes.

	All			
	Unadjusted model		Adjusted model	
	β (95% CI)	p	β (95% CI)	p
Individual-level covariates				
Age			−0.30 (−0.33, −0.27)	<.001
Female			−1.93 (−2.42, −1.43)	<.001
Married			0.74 (0.22,1.27)	.005
Chronic diseases			0.29 (−0.03,0.60)	.072
Physical function				
Activity of daily living			0.29 (0.15,0.43)	<.001
Visual impairment			−0.31 (−0.81,0.19)	.227
Hearing impairment			−0.68 (−1.22, −0.15)	.012
Walking impairment			−1.33 (−1.91, −0.75)	<.001
Mind stimulating activities			0.52 (0.24,0.81)	<.001
Physical activities			0.30 (0.07,0.54)	.013
Social activities			−0.17 (−0.49,0.16)	.310
Neighborhood built environments within 200-m buffer area of participants' homes				
Normalized Difference Vegetation Index (per IQR)	0.73 (0.12,1.34)	.018	0.46 (−0.04,0.97)	.069
Land use mix	1.57 (−0.49,3.62)	.134	1.19 (−0.50,2.89)	.168
Commercial facilities[a]	0.19 (−0.09,0.46)	.181	0.07 (−0.16,0.30)	.545
Community centers[a]	0.04 (−0.43,0.51)	.867	0.08 (−0.31,0.47)	.678
Cultural facilities[a]	0.10 (−0.91,1.11)	.841	0.20 (−0.64,1.04)	.639
Active leisure facilities[a]	−2.15 (−3.46, −0.84)	.001	−2.15 (−3.23, −1.06)	<.001
Active leisure facilities[b]	0.41 (−0.11,0.93)	.126	0.59 (0.16,1.03)	.007
Public transport terminals[a]	0.15 (−0.39,0.69)	.586	0.34 (−0.11,0.78)	.136
POS (area)	−0.05 (−0.20,0.09)	.463	0.04 (−0.08,0.16)	.534
POS (accessibility)	0.00 (−0.11,0.12)	.936	−0.03 (−0.13,0.07)	.583

[a]Neighborhood service facilities measured by the number of facilities.
[b]Squared term of active leisure facilities.

Table 2. (continue). Unstandardized regression coefficients (β) and 95% confidence intervals (CI) for cognition in old age according to different older age groups and neighborhood environmental attributes.

	Age 65–80				Aged > 80			
	Unadjusted model		Adjusted model		Unadjusted model		Adjusted model	
	β (95% CI)	*p*	*β (95% CI)*	*p*	*β (95% CI)*	*p*	*β (95% CI)*	*p*
Individual-level covariates								
Age			−0.27 (−0.33, −0.20)	<.001			−0.30 (−0.40, −0.20)	<.001
Female			−1.17 (−1.79, −0.56)	<.001			−2.83 (−3.63, −2.04)	<.001
Married			0.53 (−0.16,1.21)	.132			0.65 (−0.15,1.46)	.113
Chronic diseases			0.00 (−0.40,0.39)	.993			0.53 (0.03,1.03)	.038
Physical function								
Activity of daily living			0.30 (0.04,0.56)	.022			0.28 (0.10,0.45)	.002
Visual impairment			0.07 (−0.62,0.76)	.838			−0.79 (−1.52, −0.07)	.033
Hearing impairment			−1.53 (−2.27, −0.78)	<.001			0.08 (−0.69,0.84)	.844
Walking impairment			−0.57 (−1.45,0.31)	.201			−1.76 (−2.54, −0.97)	<.001
Mind stimulating activities			0.45 (0.07,0.83)	.020			0.64 (0.22,1.06)	.003
Physical activities			0.32 (0.00,0.64)	.047			0.22 (−0.14,0.59)	.221
Social activities			−0.02 (−0.46,0.42)	.926			−0.19 (−0.67,0.29)	.433
Neighborhood built environments within 200-m buffer area of participants' homes								
Normalized Difference Vegetation Index (per IQR)	0.52 (−0.16,1.21)	.136	0.40 (−0.24,1.04)	.224	0.80 (−0.08,1.69)	.076	0.52 (−0.27,1.31)	.196
Land use mix	2.47 (−0.01,4.95)	.051	2.89 (0.57,5.20)	.015	−0.52 (−3.28,2.25)	.715	−0.15 (−2.61,2.31)	.904
Commercial facilities[a]	−0.07 (−0.39,0.25)	.656	−0.04 (−0.34,0.26)	.789	0.22 (−0.16,0.61)	.259	0.13 (−0.22,0.48)	.465
Community centers[a]	−0.36 (−0.92,0.20)	.208	−0.50 (−1.02,0.03)	.064	0.76 (0.09,1.42)	.026	0.71 (0.12,1.30)	.018
Cultural facilities[a]	0.52 (−0.67,1.71)	.390	0.49 (−0.63,1.60)	.390	0.15 (−1.25,1.54)	.836	0.11 (−1.13,1.35)	.861
Active leisure facilities[a]	−3.24 (−4.81, −1.68)	<.001	−3.47 (−4.93, −2.00)	<.001	−1.18 (−2.98,0.62)	.199	−1.02 (−2.62,0.58)	.212
Active leisure facilities[b]	0.81 (0.18,1.44)	.011	0.96 (0.37,1.55)	.001	0.25 (−0.46,0.96)	.489	0.27 (−0.36,0.90)	.409
Public transport terminals[a]	1.00 (0.31,1.69)	.004	1.12 (0.48,1.76)	.001	−0.61 (−1.32,0.10)	.094	−0.37 (−1.00,0.27)	.257
POS (area)	0.00 (−0.17,0.16)	.969	0.02 (−0.13,0.17)	.791	−0.07 (−0.27,0.13)	.475	0.05 (−0.13,0.23)	.586
POS (accessibility)	0.06 (−0.08,0.19)	.400	0.03 (−0.09,0.16)	.603	−0.05 (−0.22,0.12)	.579	−0.11 (−0.27,0.04)	.149

[a]Neighborhood service facilities measured by the number of facilities.
[b]Squared term of active leisure facilities.

may support the assumption that neighborhoods providing better access to different services and a variety of resources to meet multiple needs (Wu, Prina, Jones, et al., 2015) could provide an interactive environment for social and cognitively stimulating activities among older adults, thus, resulting in better cognition (Clarke et al., 2012; Wu, Prina, & Brayne, 2015). However, our finding of the curvilinear relationship between active leisure facilities and cognition requires further investigation. Such a relationship could result from the different types of active facility or different levels of accessibility among the facilities that were not examined in this study.

Second, we found that the number of community centers was positively associated with cognition among people older than 80 only, possibly because declining mobility among the over 80s increases their dependence on neighborhood community centers for cognitively and socially stimulating activities. Conversely, more mobile and less geographically bounded younger older adults can participate in similar activities outside their immediate neighborhood. However, this postulation warrants further examination. Future studies may consider the heterogeneity of older adults that previous environmental gerontological studies have overlooked and how different types of activity may affect the cognition of older adults in different age groups.

Third, inconsistent with Clarke and colleagues' research that found POS may lead to slower cognitive decline among older adults (Clarke et al., 2015), our study found no association between POS (i.e. both area and accessibility) and cognition for either age group. Such inconsistencies may result from the different attributes we measured in a POS. We focused on the size and the ease of access of POS, while Clarke and colleagues focused on conditions inside the POS. These different results suggest that conditions inside the POS (i.e. the availability of simulation sources such as recreational facilities) might be more important for maintaining older adults' cognition than size itself or accessibility. The significant effect of active leisure facilities and insignificant effect of POS in our study echoed this hypothesis. Further research examining the effect of different POS features and their utilization on cognition will improve understanding of the underlying mechanism. Our findings nonetheless provide useful information for urban planners for designing functional POS that incorporate adequate active leisure facilities to encourage older adults' activity and improve their cognition.

This study has several limitations. First, all data were collected from public rental housing estates that could limit the generalizability of the findings to older adults living in private housing. However, about 55.9% of older adults in Hong Kong live in public rental housing estates (Census and Statistics Department, 2018), and our findings are relevant to them. Second, our environmental audit and associated GIS data are confined to a 200-m buffer. We are therefore unable to generalize our findings to larger buffer areas. Moreover, there was a five-year gap between survey data collection (in 2014) and environmental audit data collection (in 2019). However, since all these public housing estates were relatively old, built between 31 and 60 years ago, their environments have been very stable during the last decade. Finally, our model did not control personal socioeconomic status and past occupation, which are possible individual factors influencing cognition. Future research using a comparable time frame for both survey and environment data collection, including older adults with diverse socioeconomic characteristics and occupation, and with a larger buffer area could address these limitations.

To conclude, we combined objective measures of environment and survey data to understand the association between built environment and cognition. This helped overcome the 'same-source bias' challenging the results of many earlier studies. Moreover, we investigated both POS areas and accessibility together to provide a more comprehensive measurement than investigating POS area alone, as most previous studies have done. Finally, we also compared such associations between people aged 65–80 and people older than 80. This study generated certain new findings to the existing literature. First, we found that land-use mix, public transport terminals and active leisure facilities were associated with cognition for people aged 65–80 and community centers were associated with cognition for people older than 80. Second, POS accessibility and area might not be associated with older adults' cognition. Finally, we revealed the importance of active leisure facilities in maintaining the cognition of older adults. In a rapidly aging society, designing a built environment that enables older adults to engage in active aging activities, promote aging-in-place and that in turn maintains cognition is imperative. Our findings provide useful information for policymakers and urban planners in future city planning in Hong Kong and other urban cities.

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