

BMJ Open Cross-sectional associations of objectively assessed neighbourhood attributes with depressive symptoms in older adults of an ultra-dense urban environment: the Hong Kong ALECS study

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ABSTRACT

Objectives This study aimed to examine the associations between objectively assessed neighbourhood environmental attributes and depressive symptoms in Hong Kong Chinese older adults and the moderating effects of neighbourhood environmental attributes on the associations between living arrangements and depressive symptoms.

Design Cross-sectional observational study.

Setting Hong Kong.

Participants 909 Hong Kong Chinese community dwellers aged 65+ years residing in preselected areas stratified by walkability and socioeconomic status.

Exposure and outcome measures Attributes of participants' neighbourhood environment were objectively assessed using geographic information systems and environmental audits. Depressive symptoms were measured using the Geriatric Depression Scale.

Results Overall, pedestrian infrastructure (OR=1.025; P=0.008), connectivity (OR=1.039; P=0.002) and prevalence of public transport stops (OR=1.056; P=0.012) were positively associated with the odds of reporting depressive symptoms. Older adults living alone were at higher risk of reporting any depressive symptoms than those living with others (OR=1.497; P=0.039).

This association was moderated by neighbourhood crowdedness, perceptible pollution, access to destinations and presence of people. Residing in neighbourhoods with lower levels of these attributes was associated with increased deleterious effects of living alone. Living in neighbourhoods with lower public transport density also increased the deleterious effects of living alone on the number of depressive symptoms. Those living alone and residing in neighbourhoods with higher levels of connectivity tended to report more depressive symptoms than their counterparts.

Conclusions The level of access to destinations and social networks across Hong Kong may be sufficiently high to reduce the risk of depressive symptoms in older adults. Yet, exposure to extreme levels of public transport density and associated traffic volumes may increase the risk of

Strengths and limitations of this study

- A large range of neighbourhood environmental attributes were examined in relation to depressive symptoms.
- The use of geographic information systems and environmental audits to quantify neighbourhood environmental attributes allowed to partially control for potential reverse causality due to depressed mood affecting individuals' perceptions of environmental exposures.
- A novel aspect of this study is the examination of the moderating effects of objectively assessed neighbourhood attributes on the associations between living arrangements and depressive symptoms.
- This is a cross-sectional observational study and, hence, causal relations cannot be inferred.

depressive symptoms. The provision of good access to a variety of destinations, public transport and public open spaces for socialising in the neighbourhood may help reduce the risk of depressive symptoms in older adults who live alone.

INTRODUCTION

Depression is a growing public health concern. According to the WHO, it is the leading cause of ill health and disability worldwide.¹ More than 300 million people are estimated to be suffering from depression, corresponding to 4.4% of the global population.¹ Depression is more common among older adults, with a prevalence of 7% and believed to be underestimated.² As the world population ages, there will be a corresponding increase in the number of older adults with depressive symptoms and associated global health burden.³

Social-ecological models emphasise the importance of multilevel environmental factors for the health of entire populations.^{4–7} Older adults are more susceptible to the influence of their local environment and adverse neighbourhood conditions due to ageing-related decreases in physical function and mobility.⁸ The neighbourhood environment is deemed to impact on older adults' health outcomes (eg, depressive mood) by interacting with their diminished physical functioning (eg, impaired mobility) and related maladaptive responses (eg, social isolation).⁹ For example, specific neighbourhood characteristics, such as access to age-friendly recreational facilities, may facilitate older adults' engagement in physical and social activities which, in turn, may help develop adaptive responses (eg, resilience to negative affectivity) to declining physical capacity.

There is some evidence that neighbourhood social environmental attributes may influence depressive symptoms in older adults. Perceived neighbourhood disorder was found to be predictive of late-age depression,¹⁰ and higher social cohesion^{11–13} and neighbourhood-level socioeconomic status (SES)^{14–16} were associated with fewer depressive symptoms. Also, several studies have found associations between physical aspects of the neighbourhood environment and depression. For instance, availability of retail destinations was positively related to depression in older Australian men,¹⁷ whereas higher levels of perceived traffic safety in the neighbourhood were associated with fewer depressive symptoms in a sample of US older adults.¹⁸ More consistent associations have been found between social than physical aspects of the neighbourhood environment and depressive symptoms.¹⁹ These differences in patterns of associations may be due to the fact that physical aspects of the neighbourhood environment have been less frequently examined than their social counterparts using diverse measures.^{19,20}

It is noteworthy that many studies that examined neighbourhood environmental correlates of depressive symptoms in older adults used self-report measures of neighbourhood attributes. In such case, there is a high risk of reverse causality whereby participants' depressive mood may affect their perceptions of the environmental exposures of interest (eg, neighbourhood safety from crime).²¹ Environmental data collected using more objective measures of the neighbourhood environment, including geographic information systems (GIS)²² and environmental audits conducted by independent auditors,²³ are likely to provide more robust estimates of the potential causal effects of neighbourhood environmental attributes on residents' depressive symptoms.

Apart from emphasising the importance of environmental factors for health outcomes, social-ecological models also posit that individual-level factors interact with environmental factors to yield specific health outcomes.^{6,9} An important individual-level factor that has been associated with a higher risk of depressive symptoms is living alone as opposed to living with family members or others.^{24,25} Older adults who live alone are likely to be

more socially isolated and, hence, at risk of depression. Living in a neighbourhood that facilitates engagement in various activities may reduce the risk of depressive symptoms especially in older adults who live alone. In fact, a recent study found that living alone was more highly associated with depression in mid-aged and older adults reporting low levels of perceived quality of social interactions with neighbours.²⁶ However, to our knowledge, no studies have examined the moderating effect of objectively assessed neighbourhood environment attributes on the associations between living arrangements (living alone vs living with others) and older adults' depressive symptoms. This is an important issue for Hong Kong as well as many other high-density urban areas experiencing rapid increases in number of older adults living alone.²⁷

The primary aim of this study was to examine associations of objectively assessed neighbourhood environmental attributes with depressive symptoms in Hong Kong Chinese older adults. The secondary aim was to estimate the moderating effects of neighbourhood environmental attributes on the associations between living arrangements (living alone vs living with others) and older adults' depressive symptoms. We hypothesised that (1) objective measures of availability/access to destinations, greenness and a pedestrian-friendly infrastructure would be negatively associated with depressive symptoms; (2) environmental stressors such as signs of crime/disorder, pollution, traffic-related variables and presence of stray dogs would be positively associated with depressive symptoms; (3) older adults living alone would report more depressive symptoms than their counterparts; (4) and the negative effects of living alone on depressive symptoms would be attenuated by better access/availability of destinations and lower levels of environmental stressors.

METHODS

We used data from the Active Lifestyle and the Environment in Chinese Seniors (ALECS) project,²⁸ an observational study of built and social neighbourhood environmental correlates of depressive symptoms and quality of life in Hong Kong Chinese community dwellers aged 65+ years.

Study design and neighbourhood selection

The ALECS project adopted a two-stage sampling method that involved the recruitment of participants living in selected areas (Tertiary Planning Units (TPUs)). TPUs, the smallest administrative area units in Hong Kong with census data, were stratified by SES (represented by TPU-level median household income) and walkability (a composite index of net residential density, intersection density and land use mix).^{29,30} TPUs with high and low levels of SES and walkability, classified into four types of neighbourhoods (ie, high SES/high walkable, high SES/low walkable, low SES/high walkable and low SES/low walkable), were preselected prior to participant recruitment to maximise the variability of environmental

attributes (eg, dwelling density, access to destinations and safety from crime) in the sample. A total of 124 out of 289 TPUs were included.³¹ Such a sampling strategy has been previously used in single-country²³ and multi-country³² studies that investigated associations of environmental attributes with behavioural outcomes (eg, physical activity) related to depression.^{33 34} Further details on the neighbourhood selection procedure are reported elsewhere.^{28 35}

Participants

As Hong Kong Personal Data (Privacy) Ordinance³⁶ restricts direct access to residential addresses and other contact details, participants were recruited in person from 11 Elderly Health Centres (EHCs) of the Department of Health, Hong Kong Special Administrative Region (HKSAR) and eight elderly community centres located in the preselected TPUs. The majority of participants (72%) were recruited through EHCs, which are distributed across all 18 Hong Kong districts. The EHCs were established in 1998 to provide comprehensive primary healthcare services, including health assessment, physical check-up and curative treatment, to persons aged 65 years or above. We used EHCs as recruitment sites because they provide health-related information that can be used for eligibility screening purposes, and their clients are usually willing to participate in health-related studies endorsed by the Department of Health, HKSAR.³⁷ Although EHCs' clients are representative of the general population of older adults in terms of age and SES,³⁷ they tend to be more health conscious.³⁸ To examine the potential bias (better mental health) associated with recruiting participants from the EHCs, we recruited approximately 30% of the sample (n=258) from elderly community centres with no formal provision of medical and health services. No significant differences between participants from the two types of centres were observed in age, physical health, marital status, living arrangements, type of neighbourhood of residence, type of housing and car in the household. Participants from the EHC tended to be more educated (P=0.018) and more likely to be men (P=0.010) than their counterparts.

Potential participants attending an EHC or community centre were invited to partake in the study and assessed for eligibility (Cantonese-speaking older adults aged ≥65 years, cognitively intact, able to walk without assistance for at least 10m and having lived in preselected TPUs for at least 6 months). Nine hundred and nine older adults were recruited (response rate: 71%). Men, residents of less walkable TPUs and members of EHCs (all Ps<0.001) were more likely to refuse to participate in the study than their counterparts. On recruitment, participants provided written consent for participation in the study. Further details of recruitment procedures are available elsewhere.^{28 31}

Measures and procedures

Exposures: neighbourhood attributes

Objective neighbourhood environmental attributes were assessed using GIS and environmental audits. GIS data

were sourced from the Census and Statistics, Lands, and Planning Departments, HKSAR. Participant residential buffers, approximating neighbourhood boundaries, were created by tracing from the participants' residential addresses through their unique street networks in all directions for 400m and 800m (see online supplementary table for definitions). GIS-derived environmental attributes were generated for each participant and each buffer size using Esri's ArcGIS software (online supplementary table). Environmental audits, conducted infield by trained auditors, were used to quantify environmental attributes that were not assessable via GIS (eg, presence of people), and also where the available GIS data were outdated or incomplete. We used 400m and 800m residential buffers to delineate participants' neighbourhoods because these are considered to be walkable distances and appropriate geographical scales for older adults living in high-density environments.^{35 39 40}

Environmental audits were conducted using items from the Environment in Asian Scan Tool – Hong Kong (EAST-HK).⁴¹ These items assessed the presence or absence of the environmental attributes listed in the online supplementary table in each sampled street segment. A street segment was defined as a section of a street between intersections. To identify street segments for auditing, 400m crow-fly buffers surrounding each participant's residential address were created, and all segments of major roads/streets that were accessible to pedestrians were selected. If the number of selected major roads/street segments in a specific buffer was smaller than 25% of the total number of segments included in that buffer, additional segments (from minor roads) were randomly selected. A validation study of the EAST-HK suggested that 25% street segments were sufficient to obtain representative estimates of various environmental attributes in Hong Kong neighbourhoods.⁴¹ Environmental audits were limited to 400m crow-fly buffers due to budgetary constraints. It should be, however, noted that in our previous study⁴¹ a 400m crow-fly distance corresponded to a network distance from 400 to ~900 m.

Trained auditors were instructed to assess both sides of selected street segments and record destinations visible from the street. When assessing the presence of destinations in multifloor, mixed-use buildings, they consulted the directory of services in the building. Environmental attributes were measured by single or multiple EAST-HK items and aggregated by participant buffers. Scores on single-item measures denoted the percentage of audited street segments within a buffer with that particular attribute, while scores on multiple-item measures represented the percentage of the maximum obtainable score averaged across audited street segments within a buffer.²³ For example, a buffer consisting of three audited street segments with respective scores on 'presence of people' (assessed by four items) of 4 (representing 100% of the maximum obtainable score), 3 (75%) and 3 (75%) was assigned an aggregate score of 83.3% (ie, the sum of 100%, 75% and 75% divided by three).²³ In addition, a

diversity score was computed for recreational destinations indicating the number of different types of recreational destinations present in a participant's residential buffer.

Outcome: depressive symptoms

Depressive symptoms were measured via interviewer administration of the four-item Geriatric Depression Scale (GDS) with a yes/no response format.⁴² Two items were inversely scored, and the number of depressive symptoms was represented by the sum of the scores on the four items (ranging from 0 to 4). The GDS⁴³ has been widely used for the assessment of depressive symptoms in older adults. This study employed a short, validated four-item version of the GDS to minimise participants' burden.⁴⁴

Covariates

Information on the participants' age, sex, educational attainment, marital status, living arrangement, housing type, availability of car in the household and the number of current diagnosed chronic health problems was collected via an interviewer-administered survey and medical records. These variables together with area-level SES and type of recruitment centre (EHC and elderly community centre) were included as covariates in the regression models.

Patient and public involvement

This study did not involve patients. Participants were community dwellers who, after participating in the study, received individualised feedback on their health-related lifestyle behaviours. The findings from this study will be disseminated to the wider public via local media and non-government organisations.

Data analyses

Descriptive statistics were computed for all variables. Generalised additive mixed models (GAMMs) were used to estimate confounder-adjusted associations of objectively assessed neighbourhood environmental attributes with depressive symptoms. GAMMs can model outcomes with various distributional assumptions, spatially correlated data and curvilinear relationships of unknown form.⁴⁵ In this study, a large number of participants ($n=574$, 63%) reported no depressive symptoms. Therefore, we evaluated two sets of GAMMs. A set of GAMMs modelled the odds of reporting any versus no depressive symptoms. These GAMMs used binomial variance and logit link functions and yielded ORs. Another set of GAMMs with negative binomial variance and logarithmic link functions modelled the number of non-zero depressive symptoms and produced antilogarithms of regression coefficients representing the proportional difference in mean outcome (the number of non-zero depressive symptoms) associated with a 1-unit increase in the predictor.

We first estimated the multivariable associations of all covariates and living arrangements with the two depressive symptom outcomes. A second set of main effect GAMMs estimated the dose-response relationships of single environmental attributes with the two outcomes,

adjusted for all covariates and living arrangements. Curvilinear relationships of environmental attributes with the outcomes were assessed with thin-plate smooth terms in GAMMs. Smooth terms failing to provide sufficient evidence of curvilinearity, defined as a 5-unit difference in Akaike information criterion, were replaced by linear terms.⁴⁵

Moderating effects of environmental attributes on the associations between living arrangements and depressive symptoms were estimated by adding a two-way interaction term to the main effect GAMMs. Significant interactions ($P<0.05$) were probed using Johnson-Neyman procedures,⁴⁶ whereby we estimated the range of values of the environmental attributes (also known as regions of significance) for which the effects of living arrangements (living alone vs living with others) on the depression outcomes were statistically significant.

All significant single environmental attributes and interaction terms were entered in multiple environmental attribute GAMMs adjusted for all covariates. Environmental attributes that were strongly correlated ($r>0.50$) were combined into composite variables as appropriate. Only those environmental attributes and interaction terms that showed a significant independent effect on the outcomes ($P<0.05$) were retained in the final multiple environmental attribute models. All analyses were conducted in R using the packages 'mgcv'⁴⁷ and 'gmodels'.⁴⁸

RESULTS

Table 1 reports the descriptive statistics for all variables relevant to this study. More than half of the sample were women, married or cohabiting with a partner, living in private housing and with less than secondary education. Nearly a quarter of participants reported living alone. The majority of the sample did not report any depressive symptoms (63.2%). Substantial levels of variability across residential buffers were observed for most of the examined environmental characteristics, with the exception of signs of crime/disorder. Overall, the presence of signs of crime/disorder and stray dogs/animals was low. On average, residential buffers scored relatively high on residential density, traffic safety, pedestrian infrastructure, presence of people, pollution and some measures of destination density/prevalence.

Older adults who were female (OR=2.294; 95% CI 1.616 to 3.257; $P<0.001$), living alone or with more current diagnosed health problems showed higher odds of having any depressive symptoms than their counterparts (**table 2**). The number of health problems was also positively associated with the number of non-zero depressive symptoms. Also, compared with those with no formal or postsecondary education, participants with secondary school education reported higher odds of having any versus no depressive symptoms but, on average, fewer symptoms among those with any symptoms. The type of recruitment centre was unrelated to depressive symptom outcomes.

Table 1 Sample characteristics (n=909)

Variables	Statistics	
	Mean (SD)	Median (IQR)
Sociodemographic and health-related characteristics (theoretical range)		
Age (years)	76.5 (6.0)	76.6 (8.8)
Number of current diagnosed health problems (0–10)	3.2 (2.0)	3.0 (3.0)
	%	
Sex, females	66.3	
Educational attainment		
No formal education	20.8	
Primary school	35.5	
Secondary school	30.5	
Postsecondary school	13.2	
Marital status		
Married or cohabiting	59.5	
Widowed	32.7	
Other	7.8	
Housing		
Public and aided	43.1	
Private (purchased)	51.3	
Renting	5.6	
Living alone	23.1	
Household with car	28.5	
Neighbourhood type		
Low walkable, low SES	22.0	
Low walkable, high SES	24.8	
High walkable, low SES	28.3	
High walkable, high SES	25.0	
Outcomes: depressive symptoms (theoretical range)		
Number of depressive symptoms (total score on GDS-4) (0–4)	0.5 (0.8)	0.0 (1.0)
Number of non-zero depressive symptoms ^{1–4}	1.5 (0.7)	1.0 (1.0)
	%	
No depressive symptoms	63.2	
Environmental attributes (theoretical range)		
Gross residential density (households/km ²) – 400 m buffer (GIS)	15813.2 (11196.4)	12286.4 (13759.1)
Gross residential density (households/km ²) – 800 m buffer (GIS)	14295.1 (8443.9)	12935.2 (11373.1)
Street intersection density (intersections/km ²) – 400 m buffer (GIS)	119.9 (58.0)	112.5 (73.3)
Street intersection density (intersections/km ²) – 800 m buffer (GIS)	91.5 (40.0)	86.7 (55.6)
Connectivity (score) (EA) (0–100)	40.6 (7.4)	38.9 (10.4)

Continued

Table 1 Continued

Variables	Statistics	
	Mean (SD)	Median (IQR)
Civic and institutional density (destinations/km ²) – 400 m buffer (GIS)	88.2 (53.8)	81.6 (69.8)
Civic and institutional density (destinations/km ²) – 800 m buffer (GIS)	69.7 (36.5)	64.2 (44.7)
Retail density (destinations/km ²) – 400 m buffer (GIS)	45.4 (37.2)	43.3 (57.5)
Retail density (destinations/km ²) – 800 m buffer (GIS)	32.0 (19.0)	30.2 (27.1)
Prevalence of non-food retail and services (number in buffer) (EA)	15.9 (16.5)	11.0 (19.0)
Entertainment density (destinations/km ²) – 400 m buffer (GIS)	11.8 (16.9)	7.3 (16.1)
Entertainment density (destinations/km ²) – 800 m buffer (GIS)	6.9 (5.2)	6.2 (6.2)
Recreation density (destinations/km ²) – 400 m buffer (GIS)	21.2 (23.2)	17.5 (30.5)
Recreation density (destinations/km ²) – 800 m buffer (GIS)	22.5 (15.2)	20.1 (13.6)
Recreational destination diversity (number of types in buffer) (EA) (0–6)	1.3 (1.2)	1.0 (2.0)
Food-related destination density (destinations/km ²) – 400 m buffer (GIS)	44.8 (37.7)	42.7 (59.8)
Food-related destination density (destinations/km ²) – 800 m buffer (GIS)	31.5 (18.7)	29.8 (27.3)
Prevalence of food-related shops (number in buffer) (EA)	10.2 (8.6)	9.0 (13.0)
Prevalence of eating outlets (number in buffer) (EA)	13.6 (13.1)	9.0 (18.0)
Public transport density (transit points/km ²) – 400 m buffer (GIS)	14.1 (16.8)	9.1 (20.9)
Public transport density (transit points/km ²) – 800 m buffer (GIS)	11.6 (8.5)	10.3 (11.9)
Prevalence of public transport stops (number in buffer) (EA)	8.1 (4.7)	7.0 (5.0)
Number of parks – 400 m (GIS)	1.2 (1.5)	1.0 (2.0)
Number of parks – 800 m (GIS)	4.4 (4.0)	3.0 (6.0)
Prevalence of health clinics/ services (number in buffer) (EA)	3.9 (4.2)	3.0 (4.0)
Pedestrian infrastructure (score) (EA) (0–100)	62.7 (9.4)	62.5 (12.5)

Continued

Table 1 Continued

Variables	Statistics	
	Mean (SD)	Median (IQR)
Sitting facilities (score) (EA) (0–100)	20.5 (20.1)	17.0 (31.0)
Crowdedness (score) (EA) (0–100)	9.8 (8.8)	7.7 (12.5)
Presence of people (score) (EA) (0–100)	64.5 (21.6)	69.2 (19.2)
Traffic safety (score) (EA) (0–100)	69.9 (15.0)	73.3 (18.7)
Greenery/natural sights (score) (EA) (0–100)	36.9 (16.7)	45.5 (25.6)
Signs of crime/disorder (score) (EA) (0–100)	0.3 (0.9)	0.0 (0.0)
Stray dogs/animals (score) (EA) (0–100)	5.9 (9.9)	0.0 (9.0)
Litter/decay (score) (EA) (0–100)	22.9 (4.1)	21.4 (4.4)
Pollution (score) (EA) (0–100)	42.3 (33.2)	40.0 (61.2)
Number of street segments audited (in buffer) (EA)	21.4 (17.5)	16.0 (13.0)

EA, environmental audits; GDS, Geriatric Depression Scale; GIS, geographic information systems; SES, socioeconomic status.

Table 3 summarises the associations of single neighbourhood environmental attributes with depressive symptoms in older adults. No significant associations were observed between GIS-derived environmental attributes and the two depressive symptoms outcomes. Among the attributes measured using environmental audits, three significant linear associations were observed. Specifically, higher levels of pedestrian infrastructure, connectivity and prevalence of public transport stops were associated with increased odds of reporting one or more depressive symptoms.

The moderating effects of neighbourhood environmental attributes on the associations between living arrangements and depressive symptoms are summarised in table 4, where we report the ranges of values of the environmental attributes for which the associations between living arrangements and depressive symptoms were significant at the probability levels of 0.05, 0.01 or 0.001 (as appropriate). As expected, when compared with participants living with others, those living alone were more likely to report (any) depressive symptoms when living in neighbourhoods with poorer access to civic/institutional destinations, retail, food/eating outlets, public transport stops and health clinics/services, lower levels of crowdedness and fewer people on the streets (table 4). They were also more likely to experience depressive symptoms when living in areas with lower levels of perceptible pollution (noise and odours). For example, among residents of neighbourhoods with a (relatively low) pollution score of 21.4, the odds of reporting any depressive symptoms in those living alone were 109% higher than the odds observed in those living with others (table 4). However,

for higher levels of pollution (>43.7 points), there was no significant difference in the odds of reporting any versus no depressive symptoms between those living alone and those living with others. At high levels of access to public transport stops (≥ 59.7 transit points per km²), health clinics/services (≥ 18.8 destinations in residential buffers) and crowdedness (~ 2 standard deviations above average), participants living alone were significantly less likely to report any depressive symptoms than their counterparts. The same was observed with regards to the effects of public transport density on the number of depressive symptoms among those reporting any. In contrast, those living alone tended to report more depressive symptoms than those living with others, if residing in neighbourhoods with high levels of connectivity.

In models of multiple neighbourhood environmental attributes (table 5), connectivity and prevalence of public transport stops remained positively associated with the odds of reporting any depressive symptoms. Presence of people (OR=0.982; 95% CI 0.966 to 0.999; P=0.036) and a composite destination index (consisting of sum of z-scores of variables related to access to civic and institutional and retail destinations, food/eating outlets, health clinics/services, and public transport stops; OR=0.921; 95% CI 0.854 to 0.994; P=0.034) were the only significant moderators of the associations between living arrangements and the odds of any depressive symptoms. Specifically, participants living alone were more likely to report depressive symptoms in neighbourhoods with poor access to multiple destinations and fewer people on the street, compared with those living with others. Among those with any depressive symptoms, the moderating effects of connectivity ($e^b=1.017$; 95% CI 1.001 to 1.003; P=0.032) and public transport density of 800m buffer ($e^b=0.985$; 95% CI 0.971 to 0.999; P=0.035) remained significant. Participants living alone tended to report more depressive symptoms in neighbourhoods with high levels of connectivity (above average) and less depressive symptoms in neighbourhoods with better access to public transports (≥ 9.2 transit points per km²) than their counterparts.

DISCUSSION

The main aim of this study was to quantify the associations of depressive symptoms with a wide range of objectively assessed neighbourhood attributes in Hong Kong Chinese older adults. Only 3 of the 21 examined categories of neighbourhood environmental attributes were found to be significantly associated with depressive symptoms in the whole sample. This lack of associations may be explained by the fact that Hong Kong is generally characterised by a well-developed public transport system and high levels of density and access to retail/services,³⁵ which are known to promote a physically⁴⁹ and socially active lifestyle.⁵⁰ Also, 75% of the sample reported living with others. Hence, the proportion of participants potentially suffering from loneliness (a major contributor to depression)⁵¹ due to social

Table 2 Associations of sociodemographic and health-related characteristics with depressive symptoms

Characteristics	Any versus no depressive symptoms (n=909)		Number of non-zero depressive symptoms (n=335)	
	OR (95% CI)	P values	e ^b (95% CI)	P values
Age	0.988 (0.961 to 1.015)	0.370	0.993 (0.983 to 1.003)	0.156
Sex				
Female*	–	–	–	–
Male	0.436 (0.307 to 0.619)***	<0.001	0.981 (0.855 to 1.127)	0.786
Education attainment				
No formal education*	–	–	–	–
Primary school	1.302 (0.862 to 1.966)	0.210	0.949 (0.814 to 1.107)	0.506
Secondary school	1.575 (1.010 to 2.456)*	0.045	0.833 (0.710 to 0.977)*	0.025
Postsecondary school	0.900 (0.508 to 1.597)	0.719	0.987 (0.797 to 1.221)	0.901
Marital status				
Married or cohabiting	0.962 (0.549 to 1.688)	0.894	1.032 (0.843 to 1.263)	0.758
Widowed	0.877 (0.494 to 1.559)	0.653	1.028 (0.838 to 1.261)	0.789
Other†	–	–	–	–
Housing				
Public and aided†	–	–	–	–
Private (purchased)	0.962 (0.699 to 1.324)	0.811	0.970 (0.867 to 1.086)	0.599
Renting	1.045 (0.542 to 2.015)	0.895	1.124 (0.891 to 1.419)	0.322
Living arrangement				
Living with others†	–	–	–	–
Living alone	1.497 (1.021 to 2.195)*	0.039	1.044 (0.913 to 1.195)	0.526
Household with car				
No†	–	–	–	–
Yes	1.009 (0.735 to 1.386)	0.956	0.927 (0.825 to 1.042)	0.204
Area-level socioeconomic status				
Low†	–	–	–	–
High	1.283 (0.925 to 1.779)	0.135	0.937 (0.843 to 1.041)	0.222
Recruitment centre				
Elderly community centre†	–	–	–	–
Elderly Health Centres	1.001 (0.691 to 1.450)	0.996	1.035 (0.912 to 1.174)	0.592
Number of current diagnosed health problems	1.095 (1.016 to 1.180)*	0.018	1.039 (1.013 to 1.066)**	0.004

*P<0.05.

**P<0.01.

***P<0.001.

†Reference group. e^b is interpreted as the proportional increase (if >1) or decrease (if <1) in depressive symptoms associated with a 1-unit increase in the environmental attribute.

–, not applicable; e^b, antilogarithm of regression coefficient.

isolation stemming from living alone in a neighbourhood with limited opportunities for social contacts was relatively low. We also expected that access to parks and greenery would be negatively, and adverse neighbourhood conditions (ie, crime/disorder) positively, related to depressive symptoms. However, these hypotheses were not confirmed. Park quality rather than presence of parks may be a more important contributor to older adults' mental well-being.^{52 53} The failure to observe an

association between signs of crime/disorder and depressive symptoms in this study is likely due to the extremely low levels of crime/disorder found in the sampled street segments and, generally, in Hong Kong.^{30 41}

The three environmental attributes that were found to be associated with increased odds of reporting one and more depressive symptoms were the prevalence of public transport stops, street connectivity and pedestrian infrastructure. Although this small number of

Table 3 Associations of single neighbourhood environmental attributes with depressive symptoms

Environmental attributes (unit; measure approach)	Buffer	Any versus no depressive symptoms (n=909)		Number of non-zero depressive symptoms (n=335)	
		OR (95% CI)	P values	e ^b (95% CI)	P values
Gross residential density (1000 households/km ² ; GIS)	400m	0.998 (0.983 to 1.012)	0.749	0.997 (0.992 to 1.002)	0.318
	800m	0.994 (0.975 to 1.013)	0.536	0.997 (0.991 to 1.004)	0.425
Street intersection density (100 intersections/km ² ; GIS)	400m	1.097 (0.845 to 1.424)	0.486	0.929 (0.846 to 1.020)	0.121
	800m	0.999 (0.671 to 1.487)	0.995	0.971 (0.843 to 1.120)	0.689
Connectivity (score; EA)	–	1.039 (1.015 to 1.065)**	0.002	1.004 (0.996 to 1.012)	0.281
Civic and institutional density (1 location/km ² ; GIS)	400m	0.999 (0.996 to 1.002)	0.607	0.999 (0.998 to 1.000)	0.319
	800m	0.999 (0.995 to 1.004)	0.791	1.000 (0.998 to 1.001)	0.561
Retail density (1 location/km ² ; GIS)	400m	1.000 (0.996 to 1.004)	0.847	1.000 (1.000 to 1.001)	0.895
	800m	1.003 (0.995 to 1.011)	0.425	1.000 (0.998 to 1.003)	0.745
Prevalence of non-food retail and services (number in buffer; EA)	–	1.007 (0.996 to 1.019)	0.216	1.001 (0.997 to 1.004)	0.775
Entertainment density (1 location/km ² ; GIS)	400m	0.999 (0.990 to 1.009)	0.891	0.999 (0.996 to 1.002)	0.577
	800m	1.006 (0.978 to 1.036)	0.661	0.996 (0.987 to 1.006)	0.484
Recreation density (one location/km ² ; GIS)	400m	0.999 (0.992 to 1.005)	0.734	1.001 (0.999 to 1.003)	0.418
	800m	1.006 (0.996 to 1.016)	0.239	0.997 (0.994 to 1.001)	0.104
Recreational destination diversity (number of types in buffer; EA)	–	1.113 (0.981 to 1.261)	0.096	0.978 (0.936 to 1.021)	0.312
Food-related destination density (1 location/km ² ; GIS)	400m	1.000 (0.996 to 1.004)	0.923	1.000 (0.999 to 1.001)	0.937
	800m	1.003 (0.995 to 1.011)	0.472	1.000 (0.998 to 1.003)	0.745
Prevalence of food-related shops (number in buffer; EA)	–	1.004 (0.982 to 1.027)	0.739	1.000 (0.992 to 1.008)	0.955
Prevalence of eating outlets (number in buffer; EA)	–	1.016 (1.000 to 1.033)	0.057	1.002 (0.997 to 1.007)	0.492
Public transport density (1 location/km ² ; GIS)	400m	1.003 (0.994 to 1.012)	0.542	0.999 (0.996 to 1.002)	0.556
	800m	1.001 (0.984 to 1.019)	0.887	1.003 (0.997 to 1.009)	0.374
Prevalence of public transport stops (number in buffer; EA)	–	1.056 (1.012 to 1.102)*	0.012	1.008 (0.993 to 1.022)	0.290
Number of parks (1 location; GIS)	400m	0.971 (0.879 to 1.073)	0.562	0.991 (0.955 to 1.029)	0.640
	800m	1.006 (0.967 to 1.047)	0.756	0.992 (0.978 to 1.007)	0.297
Prevalence of health clinics/services (number in buffer; EA)	–	1.029 (0.989 to 1.071)	0.162	1.003 (0.990 to 1.016)	0.669
Pedestrian infrastructure (score; EA)	–	1.025 (1.007 to 1.044)**	0.008	0.999 (0.993 to 1.005)	0.662
Sitting facilities (score; EA)	–	1.000 (0.991 to 1.009)	0.981	1.001 (0.998 to 1.004)	0.449
Crowdedness (score; EA)	–	1.005 (0.987 to 1.024)	0.567	0.997 (0.992 to 1.003)	0.363
Presence of people (score; EA)	–	1.004 (0.997 to 1.013)	0.291	1.002 (0.999 to 1.004)	0.250
Traffic safety (score; EA)	–	1.005 (0.994 to 1.016)	0.402	1.002 (0.998 to 1.006)	0.273
Greenery/natural sights (score; EA)	–	1.008 (0.992 to 1.024)	0.339	1.000 (0.994 to 1.005)	0.944
Signs of crime/disorder (score; EA)	–	1.151 (0.967 to 1.371)	0.114	0.993 (0.941 to 1.048)	0.808
Stray dogs/animals (score; EA)	–	1.006 (0.990 to 1.022)	0.480	0.997 (0.992 to 1.003)	0.322
Litter/decay (score; EA)	–	0.966 (0.929 to 1.005)	0.084	0.994 (0.980 to 1.007)	0.346
Pollution (score; EA)	–	1.001 (0.996 to 1.006)	0.651	1.001 (0.999 to 1.003)	0.318

e^b is interpreted as the proportional increase (if >1) or decrease (if <1) in depressive symptoms associated with a 1-unit increase in the environmental attribute. All estimates adjusted for age, sex, educational attainment, household with car, marital status, housing type, living arrangement, area-level socioeconomic status, type of recruitment centre and number of current diagnosed health problems.

*P<0.05.

**P<0.01.

–, not applicable; e^b, antilogarithm of regression coefficient; EA, environmental audits; GIS, Geographic Information Systems.

Table 4 Associations between living arrangements (reference group: living with others) and depressive symptoms at region-of-significance threshold values of neighbourhood environmental attributes (moderators) – single neighbourhood environmental variable models

Moderator: neighbourhood environmental attribute	Any versus no depressive symptoms (n=909)			Number of non-zero depressive symptoms (n=335)		
	P level	RoS values of environmental moderator	OR (95% CI)*	P level	RoS values of environmental moderator	e ^b (95% CI)*
Connectivity (EA)	-	-	-	0.05	≤23.1 points	0.738 (0.545 to 1.000)
	-	-	-	0.05	≥49.8 points	1.194 (1.000 to 1.424)
Civic and institutional density – 800 m buffer (GIS)	0.01	≤56.3 destinations/km ²	1.682 (1.132 to 2.497)	-	-	-
	0.05	≤69.8 destinations/km ²	1.467 (1.001 to 2.150)	-	-	-
Retail density – 800 m buffer (GIS)	0.01	≤25.8 destinations/km ²	1.686 (1.134 to 2.507)	-	-	-
	0.05	≤32.9 destinations/km ²	1.466 (1.001 to 2.148)	-	-	-
Food-related destination density – 800 m buffer (GIS)	0.01	≤25.4 destinations/km ²	1.683 (1.132 to 2.500)	-	-	-
	0.05	≤32.3 destinations/km ²	1.466 (1.001 to 2.147)	-	-	-
Prevalence of eating outlets (EA)	0.01	≤7.8 outlets/buffer	1.705 (1.137 to 2.555)	-	-	-
	0.05	≤13.7 outlets/buffer	1.466 (1.002 to 2.146)	-	-	-
Public transport density – 800 m buffer (GIS)	0.01	≤9.7 transit points/km ²	1.679 (1.135 to 2.485)	0.05	≤5.5 transit points/km ²	1.163 (1.000 to 1.353)
	0.05	≤12.5 transit points/km ²	1.467 (1.000 to 2.150)	0.05	≥28.9 transit points/km ²	0.756 (0.572 to 1.000)
	0.05	≥59.7 transit points/km ²	0.149 (0.022 to 1.000)	-	-	-
Prevalence of health clinics/services (EA)	0.001	≤0.4 destination/buffer	2.209 (1.378 to 3.542)	-	-	-
	0.01	≤2.8 destinations/buffer	1.666 (1.131 to 2.455)	-	-	-
	0.05	≤3.8 destinations/buffer	1.481 (1.012 to 2.169)	-	-	-
	0.05	≥18.8 destinations/buffer	0.254 (0.065 to 0.999)	-	-	-
Crowdedness (EA)	0.001	≤3.7 points	2.088 (1.347 to 3.237)	-	-	-
	0.01	≤7.7 points	1.670 (1.132 to 2.463)	-	-	-
	0.05	≤10.0 points	1.468 (1.001 to 2.154)	-	-	-
	0.05	≥35.1 points	0.361 (0.130 to 1.000)	-	-	-
Presence of people (EA)	0.001	≤49.8 points	2.158 (1.365 to 3.412)	-	-	-
	0.01	≤60.9 points	1.671 (1.132 to 2.468)	-	-	-
	0.05	≤66.6 points	1.466 (1.000 to 2.147)	-	-	-
Pollution (EA)	0.001	≤21.4 points	2.089 (1.347 to 3.239)	-	-	-
	0.01	≤35.6 points	1.669 (1.132 to 2.463)	-	-	-
	0.05	≤43.7 points	1.469 (1.002 to 2.155)	-	-	-

Note: only significant (P<0.05) interaction terms between living arrangement and specific neighbourhood environmental attributes are shown.

e^b is interpreted as the proportional increase (if >1) or decrease (if <1) in depressive symptoms associated with a 1-unit increase in the environmental attribute. All estimates adjusted for age, sex, educational attainment, household with car, marital status, housing type, area-level socioeconomic status, type of recruitment centre and number of current diagnosed health problems.

*OR or e^b estimate at region-of-significance threshold values of environmental attribute.

–, the interaction effect of living arrangements with a specific environmental attribute was not statistically significant and, thus, was not probed; EA, environmental audits; e^b, antilogarithm of regression coefficient; GIS, Geographic Information Systems; living with others as reference group; p level, significance level; RoS, regions of significance.

Table 5 Independent associations of multiple neighbourhood environmental attributes with depressive symptoms

Variables	Any versus no depressive symptoms (n=909)		Number of non-zero depressive symptoms (n=335)	
	OR (95% CI)	P values	e ^b (95% CI)	P values
Environmental attribute main effects				
Connectivity (EA)	1.036 (1.011 to 1.061)**	0.004	0.999 (0.990 to 1.008)	0.799
Composite destination index†	1.013 (0.966 to 1.061)	0.594	–	–
Public transport density – 800 m buffer (GIS)	–	–	1.006 (1.000 to 1.013)	0.067
Prevalence of public transport stops (EA)	1.054 (1.002 to 1.109)*	0.043	–	–
Presence of people (EA)	1.003 (0.992 to 1.015)	0.559	–	–
Interacting effects of living arrangement with environmental attribute‡				
Connectivity (EA)				
0.05 level: ≥41.2 points	–	–	1.223 (1.001 to 1.494)*	0.050
0.01 level: ≥45.2 points	–	–	1.308 (1.066 to 1.604)**	0.010
Composite destination index†				
0.001 level: ≤–4.0 points	6.604 (2.152 to 20.265)***	0.001	–	–
0.01 level: ≤0.3 points	4.643 (1.449 to 14.875)**	0.010	–	–
0.05 level: ≤3.6 points	3.542 (1.011 to 12.411)*	0.050	–	–
Public transport density – 800 m buffer (GIS)				
0.05 level: ≥9.2 transit points/km ²	–	–	0.532 (0.284 to 1.000)*	0.050
0.01 level: ≥22.5 transit points/km ²	–	–	0.434 (0.230 to 0.819)**	0.010
Presence of people (EA):				
0.01 level: ≤56.0 points	1.739 (1.142 to 2.647)**	0.010	–	–
0.05 level: ≤65.2 points	1.474 (1.001 to 2.170)*	0.050	–	–

Notes: only significant (P<0.05) interaction terms between living arrangement and specific neighbourhood environmental attributes were included in the regression models.

*P<0.05.

**P<0.01.

***P<0.001.

† The sum of z-scores of single destination-related variables that interacted with living arrangement in the single-environmental variable models, including civic and institutional density – 800 m buffer (GIS), retail density – 800 m buffer (GIS), food-related destination density – 800 m buffer (GIS), prevalence of eating outlets (EA), public transport density – 800 m buffer (GIS) and prevalence of health clinics/service (EA). ‡OR or e^b estimates were calculated at region-of-significance threshold values of environmental attribute; living with others as reference group. e^b is interpreted as the proportional increase (if >1) or decrease (if <1) in depressive symptoms associated with a 1-unit increase in the environmental attribute. All estimates adjusted for age, sex, educational attainment, household with car, marital status, housing type, area-level socioeconomic status, type of recruitment centre and number of current diagnosed health problems. The interacting effects of living arrangement with pollution, crowdedness and the main-effect of pedestrian infrastructure (significant in the single environmental variable models) were removed from the full model because they were not statistically significant at a 0.05 probability level.

–, not included in regression model because the specific main and/or interaction effect was not statistically significant; EA, environmental audits; e^b, antilogarithm of regression coefficient; GIS, Geographic Information Systems.

statistically significant associations (3 out of 70) might have arisen by chance, there are several plausible mechanisms that might explain them. High levels of public transport density are usually accompanied by higher levels of traffic-related noise and air pollution, especially in urban environments typified by a concentration of tall buildings.⁵⁴ Both excessive traffic-related noise and air pollution have been linked to stress, inability to psychologically restore and depression.^{55 56} One of the main features included in the measure of street connectivity used in this study was the presence of bridges, overpasses or tunnels. Pedestrian bridges and overpasses are highly prevalent in Hong Kong and commonly found in crowded, built-up areas with high

traffic volumes and lack of sitting facilities and public spaces to meet with others. These areas are also typically characterised by a developed pedestrian infrastructure with well-maintained pavements and indoor pedestrian passageways through buildings.⁵⁷ This may explain why a positive association between depressive symptoms and pedestrian infrastructure was observed in the single environmental variable but not in the multiple environmental variable models adjusted for street connectivity. Multisite studies expanding the level of variability in exposures may be needed to accurately characterise the dose–response relationships between characteristics of the neighbourhood environment and depressive symptoms in older adults.^{58 59}

The secondary aims of this study were to examine the association between depressive symptoms and living arrangements and to quantify the moderating effects of neighbourhood environmental attributes on this association. Older adults living alone showed a higher likelihood of reporting at least one depressive symptom compared with those living with family members or others, which was consistent with earlier studies.^{24 25} Living alone and loneliness are established risk factors for depression and depressive symptoms in older adults. These effects are thought to be due to lower levels of social support in those who live alone.⁶⁰ Although the association between living arrangements and depressive symptoms was in the expected direction, it was not strong. Previous studies on Northeast Asian populations noted that living with children and grandchildren may increase the level of stress and, hence, the risk of depression.²⁵ This is especially the case in modern Asian societies where respect for privacy and independence are becoming increasingly important values due to the assimilation of Western culture and lifestyles.⁶¹ Consequently, it is possible that, in this study, a certain percentage of older adults who reported living with family members or others might have been exposed to higher level of stress leading to experiencing depressive symptoms due to living in a crowded household with their children and grandchildren. Unfortunately, this study did not collect detailed data on household composition enabling the estimation of the effect of different categories of living arrangements on depressive symptoms among those who reported living with family members or others.

An analysis of the moderating effects of neighbourhood environmental attributes on the associations between living arrangement and depressive symptoms revealed that, as expected, those living alone were more likely to report (any) depressive symptoms than their counterparts when residing in neighbourhoods with poorer access to destinations (eg, services and retail) and fewer people on the street. Having good access to destinations and people in the neighbourhood may help offset the negative effects of living alone by providing opportunities for socialising and engagement in a variety of activities. It is interesting that at higher levels of access to public transport and crowdedness, those living alone were less likely to report any depressive symptoms than those living with others. Older adults living in ultra-dense overcrowded urban environments with high levels of traffic-related noise and pollution may benefit from daily periods of restoration and quiet. These may be more easily attainable if living alone than if living in a small apartment with others, which is a common housing condition in Hong Kong.⁶² In fact, household crowding has been found to contribute to psychological distress.⁶³

Apart from being respectively negatively and positively associated with depressive symptoms, perceptible pollution and street connectivity also respectively attenuated and increased the deleterious effects of living alone. However, the moderating effect of pollution was

no longer significant in the multivariable model likely due, as explained above, to it being a by-product of high density of/access to destinations and presence of people. Street connectivity remained a significant moderator in the multivariable models. As mentioned above, the presence of pedestrian bridges/overpasses is common in ultra-dense neighbourhoods of Hong Kong with high volumes of traffic. The latter neighbourhood characteristic has been identified as a risk factor for depression.^{55 64}

This study has several strengths and limitations. Unlike previous investigations,¹⁹ we examined a large range of neighbourhood environmental attributes plausibly related to depressive symptoms. Also, we used objective approaches to quantify neighbourhood attributes that allowed us to partially control for potential reverse causality due to depressed individuals tending to exhibit negative cognitive bias resulting in negative thoughts and perceptions.⁶⁵ Residential self-selection bias is likely to be a trivial source of reverse causality in this study because Hong Kong's high levels of population density (6760 people/km²) and low percentage of developed land (less than 25%)⁶⁶ limit most residents' choice of accommodation and 37% of Hong Kong older adults live in public rental housing.⁶⁷ Given the satisfactory response rate and the level of similarity in depressive symptoms and sociodemographic characteristics of participants recruited from two types of recruitment centres, the findings from this study are likely to be generalisable to the population of Chinese Hong Kong older adults matching the study eligibility criteria and other populations of older adults living in similar ultra-dense metropolises of Southeast Asia. Yet, we need to consider that the lower response rates among residents of low-walkable neighbourhoods might have introduced some bias. If respondents with depressive symptoms are less likely to participate in surveys and low walkable neighbourhoods increase the risk of depressive symptoms,¹⁹ the observed associations between environmental attributes and depressive symptom outcomes may have been attenuated (biased downwards).

Limitations also include the cross-sectional nature of the study and inability to employ a more comprehensive sampling frame for participant recruitment due to privacy ordinance restrictions. Future research may need to focus on longitudinal studies and natural experiments that provide more robust estimates of causal influences of the neighbourhood environment on depressive symptoms. However, small changes in the neighbourhood environment across short time periods (<5 years) are a challenge in longitudinal research as they provide low statistical power to detect associations. Future studies may also benefit from the use of both objective and self-report measures of the environment allowing the examination of the mediating role of environmental perceptions in the relationships between objective measures of the environment and depressive symptoms.

Overall, our findings shed some light on the complex relationships between the neighbourhood characteristics of ultra-dense cities and older adults' depressive

symptoms in an Asian context. The level of access to destinations and social networks across Hong Kong neighbourhoods may be sufficiently high to reduce the risk of depressive symptoms attributable to social isolation in the general population of older adults. Traffic-related noise and air pollution associated with extreme levels of public transport density may increase the likelihood of depressive symptoms in residents of ultra-dense cities such as Hong Kong. Measures to reduce traffic-related air pollution and noise, such as the upgrade of bus fleets, policies promoting the reduction of car and bus idling and the installation of vegetative barriers may help attenuate this environmental risk factor. Particular neighbourhood attributes, such as access to destinations and presence of people on the street, may facilitate engagement in stress-buffering behaviours (eg, socialising with others⁶⁸ and engaging in physical activity)³⁵ in people living alone. Providing good access to facilities and public open spaces for socialising in neighbourhoods with high prevalence of older adults living alone should be considered as an important aspect of mental health promotion.

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