To what extent does physical activity explain the associations between neighborhood environment and depressive symptoms in older adults living in an Asian metropolis?

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ABSTRACT

Purpose: This study aimed to examine physical activity (PA) as a mediator of both neighborhood environment-depressive symptoms associations and the moderating effects of living arrangements on these associations.
Methods: 909 Hong Kong Chinese older adults aged 65 + years and living in pre-selected communities stratified by walkability and socio-economic status participated in this cross-sectional observational study. Exposure variables were objectively-quantified neighborhood attributes. The outcome measure was presence of depressive symptoms. Scores on validated Chinese versions of international PA questionnaires were examined as mediators of environment-depressive symptoms associations and of the moderating effects of living arrangements (living alone vs. living with others) on these associations.
Results: Neighborhood connectivity, prevalence of public transport, and pedestrian infrastructure were positively related to depressive symptoms; and frequency of walking for transport was identified as a suppressor of these positive associations. Living arrangements moderated the associations of a considerable number of measures of access to destinations of daily living with depressive symptoms, and most of these moderating effects were partially mediated by frequency of walking for transport.
Conclusions: Ultra-dense, well-connected, pedestrian-friendly, destination-rich neighborhoods may contribute to lowering the risk of depressive symptoms in Hong Kong older adults by enabling them to frequently walk to local destinations of daily living and, thus, maintain their independence and bond with the community. These potential pathways of influence appear to be particularly important for older adults living alone. Future studies need to identify mechanisms other than PA that contribute to unexplained environment-depression relationships.

1. Introduction

The global prevalence of depressive disorders in 2015 was highest for older adults (WHO, 2017a) and likely to be underestimated (Arokiasamy et al., 2017). Although effective treatments for depression are available, barriers such as lack of resources and social stigma result in fewer than half of those suffering from depression receiving treatment (WHO, 2017b). Considering the substantial projected increases in the total number and population proportion of older adults in most

countries, an understanding of population-level modifiable factors influencing depression is needed.

According to socio-ecological models of health, individual, social, and environmental factors all contribute to health, including mental well-being (Stokols, 1992). In this respect, the WHO stresses the importance of creating physical and social environments that promote the maintenance of good health in older adults (WHO, 2012). Due to increased physical dysfunction and limited mobility, older adults tend to spend more time in their local areas. As such, the effects of

neighborhood social and physical environmental attributes on the levels of depression in this cohort may be more pronounced than in younger age groups.

Neighborhood environments that provide opportunities for mental-health-enhancing activities, such as socializing and physical activity (PA) (Adamson; Yang, & Motl, 2016; Ku, Steptoe, Liao, Sun, & Chen, 2018), may have protective effects against depression. A recent systematic review and meta-analysis reported a substantial amount of evidence for negative associations of neighborhood socio-economic status, neighborhood collective efficacy, and personal/crime-related safety with older adults' depression or depressive symptoms (A. Barnett, Zhang, Johnston, & Cerin, 2017). However, the review also revealed that very few studies had investigated the potential effects of physical attributes of the neighborhood environment (e.g., access to parks, environmental aesthetics, pedestrian infrastructure, and access to services) on older adults' depressive symptoms. Also, over half of the examined neighborhood physical attributes were not sufficiently studied to permit reaching robust conclusions about their potential effect on depression or depressive symptoms.

To address the above knowledge gap, we examined the associations of a wide range of objectively-assessed environmental attributes and depressive symptoms in a large community sample of mobile (i.e., able to walk) Hong Kong older adults living in low and high walkable neighborhoods stratified by socio-economic status (Zhang et al., 2018). We observed a very high overall level of access to destinations and services accompanied by a relatively low prevalence of depressive symptoms, and only a few significant environmental correlates. These findings suggest that the neighborhood physical environment across the whole territory of Hong Kong may provide sufficient opportunities for PA and social activities to reduce the risk of depressive symptoms in Hong Kong older adults. However, we also found that neighborhood attributes that are typically supportive of older adults' PA, including street connectivity, pedestrian infrastructure, and availability of public transport stops (Cerin, Nathan, van Cauwenberg, Barnett, & Barnett, 2017; D. W.; Barnett, Barnett, Nathan, Van Cauwenberg, & Cerin, 2017; Van Cauwenberg, Nathan, Barnett, Barnett, & Cerin, 2018), were associated with a higher risk of depressive symptoms. These unexpected associations might have been due to the fact that Hong Kong neighborhoods with high levels of these three environmental attributes are typically extremely dense and accompanied by high levels of traffic-related noise and air pollution (Zhang et al., 2018). While polluted and highly-trafficked ultra-dense neighborhoods with good pedestrian infrastructure and access to public transport may still promote transportation PA (Cerin, Nathan et al., 2017), they may not be conducive to participation in leisure-time PA, including walking for recreation (Cerin et al., 2013a). Specifically, the unexpected environment-depressive symptoms associations may be explained by the fact that structured exercise and leisure-time PA, rather than transportation PA, are usually associated with better mental health (Catalan-Matamoros, Gomez-Conesa, Stubbs, & Vancampfort, 2016; Cerin, Leslie, Sugiyama, & Owen, 2009; Teychenne, Ball, & Salmon, 2008), and air pollution and noise (to which older adults engaging in transportation PA would be exposed to) have been linked to a higher risk of depression (Lim et al., 2012). Hence, one of the aims of this paper was to conduct cross-sectional mediation analyses to examine the extent to which engagement in leisure-time PA and transportation PA might be potential mechanisms responsible for the observed environment-depressive symptoms associations in Hong Kong older adults.

Attributes of the neighborhood physical environment that support engagement in PA and socializing may be especially important to groups of older adults that are at higher risk of depression, such as, for example, those living alone (Dean, Kolody, Wood, & Matt, 1992; Oh et al., 2015; Shin & Sok, 2012). Dean et al. (1992) found that the influence of living alone on depression was independent of the level of support and interaction with friends, undesirable life events, disability and financial strain. In our recent study, we found that Hong Kong older

adults living alone were more likely to report depressive symptoms than older adults living with others, and were especially likely to do so if living in neighborhoods with poorer access to services and lower levels of crowdedness, pollution, and prevalence of people in the street (Zhang et al., 2018). For older adults living alone in particular, having good access to destinations and people in the neighborhood may help offset the negative effects of solitude on mental health and well-being by providing opportunities for socializing and engagement in a variety of activities. In this case, of all forms of PA, walking for transport within the neighborhood may be the most significant mechanism responsible for the moderating effects of living arrangements on the associations of depressive symptoms with access to services and presence of people in the neighborhood. This is because older adults living alone are likely to be more self-reliant in performing activities of daily living, which, in turn, can be facilitated by a supportive neighborhood environment. In line with this hypothesis, the second aim of this study was to investigate the mediating role of different measures of PA (including walking for transportation) in explaining the moderating effects of living arrangements on environment-depressive symptoms associations found in a recent study on Hong Kong older community dwellers (Zhang et al., 2018). As noted earlier, studies on neighborhood physical environmental correlates of depressive symptoms in older adults are rare, and those examining mediators of these associations and their moderators even rarer. Hence, this study makes a significant and novel contribution to the research field of environmental determinants of lifestyle behaviors (PA) and mental health in older adults.

We hypothesized that the positive associations of street connectivity, pedestrian infrastructure and availability of public transport stops with the presence of depressive symptoms observed in Hong Kong older adults (Zhang et al., 2018) would be due to these neighborhood characteristics being associated with lower levels of non-walking PA and walking for recreation, which, in turn, would be predictive of a higher likelihood of reporting depressive symptoms. We also hypothesized that the negative associations between measures of destination accessibility and depressive symptoms found in Hong Kong older adults living alone would be explained by walking for transportation. Specifically, we expected higher destination accessibility to be associated with more walking for transport in older adults living alone, and more walking for transport to be predictive of a lower likelihood of reporting depressive symptoms.

2. Method

2.1. Study design and participants

This study used data from the Active Living and Environment in Chinese Seniors (ALECS) project that investigated relationships of neighborhood environmental characteristics with PA, depressive symptoms, and quality of life in Hong Kong Chinese elderly community-dwellers (Barnett et al., 2016, Cerin et al., 2016). The ALECS project was approved by the ethics committee of the Department of Health (Hong Kong Special Administrative Region, HKSAR) and the University of Hong Kong Research Ethics Committee for Non-Clinical Faculties (EA270211). It adopted a two-stage sampling method to enroll participants residing in pre-selected areas stratified by socio-economic status (SES, represented by census area-level median household income) and transport-related walkability (a composite index consisting of area-level standardized net residential density, street intersection density and land-use mix). To maximize variability in environmental exposures, all 289 tertiary planning units (TPUs), the smallest administrative area units in the HKSAR linked to census data, were ranked by SES and walkability, and then classified into four area types: high SES – high walkability, high SES – low walkability, low SES – high walkability, and low SES – low walkability. Participants were recruited from Elderly Health Centres (EHCs) and elderly community centres located in pre-selected TPUs across these four area types as detailed elsewhere

(Barnett et al., 2016; Cerin et al., 2016; Zhang et al., 2018). Eligibility criteria were being at least 65 years of age, Cantonese-speaking, cognitively-intact, able to walk without assistance for at least 10m, and having resided in pre-selected TPUs for at least six months. All eligible participants provided written informed consent prior to taking part in the study. A sample of 909 older adults from 124 TPUs (across four area types) were included in this study (response rate: 71%). Further details on the study design and participant recruitment have been reported in the study protocol and related publications (Barnett et al., 2016; Cerin et al., 2016; Zhang et al., 2018).

2.2. Measures

2.2.1. Exposures: neighborhood attributes

Geographic Information Systems (GIS) and environmental audits were used to objectively assess neighborhood environmental attributes. GIS data were sourced from the Census and Statistics, Lands, and Planning Departments of HKSAR. Participant residential buffers, delineating individual neighborhood boundaries, were created by tracing from participants' residential addresses through the unique street-network in all directions for 800 m, a walkable distance considered appropriate for older adults living in high density environments (Zhang et al., 2018). GIS-based environmental attributes were computed for each participant's residential buffer. They included number of parks and densities (units/km^2) of residential households, street intersections, public transport stops and civic/institutional, retail, entertainment, recreational, and food-related destinations.

Environmental audits, conducted by trained assessors, quantified the environmental attributes which were not accessible in GIS or for which information from the GIS database was outdated or incomplete. Items from the Environment in Asian Scan Tool – Hong Kong (EAST-HK) were used to assess the 17 environmental features in each audited street segment (Cerin, Chan, Macfarlane, Lee, & Lai, 2011). These included aspects of pedestrian infrastructure, aesthetics, personal and traffic safety and various types of destinations (see Supplementary Table S1 for definitions and scoring). Due to budget restrictions, a 400m crow-fly rather than an 800m street-network buffer centered at each participant's residence (commensurate with a network-distance from 400 to ~900 m) was used to identify areas for environmental audits. All major street segments accessible to pedestrians within individual buffers were included. Additional street segments (from minor streets) were randomly selected if all major street segments amounted to less than 25% of total segments in buffers (Cerin, Chan, et al., 2011). Prior to data collection, novice auditors were trained in class and in the field until 95% agreement between their ratings and those of experienced auditors was reached. If during data collection auditors were unsure how to rate a specific audit item, they consulted other experienced auditors in real time (i.e., shared street-segment photos and questions/comments via mobile phone) and recorded a consensual rating. Data collection was conducted on weekdays during daylight.

2.2.2. Outcome: presence of depressive symptoms

A short, validated 4-item version of the Geriatric Depression Scale (GDS-4) was used to measure older adults' depressive symptoms through face-to-face interviews. The GDS has been widely used for the assessment of depressive symptomatology in older adults (D'Ath, Katona, Mullan, Evans, & Katona, 1994; Yesavage & Sheikh, 1986). We used the short, 4-item version of the scale to reduce participants' burden (Barnett et al., 2016;; Cerin et al., 2016; Van Marwijk et al., 1995). Due to a large number of participants (N = 574, 63%) reporting no depressive symptoms (Zhang et al., 2018), the outcome variable in this study was presence of depressive symptoms (any vs. no symptoms; dichotomous outcome, thereafter 'depressive symptoms'), rather than number of symptoms.

2.2.3. Mediator: physical activity (PA)

Weekly frequency and minutes of total non-walking moderate-to-vigorous PA and within- and outside-neighborhood walking were assessed using the interviewer-administered, Chinese versions of International Physical Activity Questionnaire – Short (IPAQ-SC) (Deng et al., 2008) and the Neighborhood Walking Questionnaire for Chinese Seniors (NWQ-CS) (Cerin, Barnett et al., 2011), respectively. These have been validated in Chinese older adults and have been found to be sufficiently reliable and valid (Cerin, Barnett et al., 2011; Deng et al., 2008). The NWQ-CS asked participants to report weekly frequency and duration of walking within and outside their neighborhood (defined as an area up to 15-min walk from home) for transportation and recreational purposes separately. For the purpose of this study, continuous (e.g., minutes per week) rather than categorical (e.g., meeting the PA guidelines) measures of PA were considered as possible mediators for three main reasons. First, continuous measures permit the assessment of dose-response (curvilinear) relationships between the environment, PA and the odds of experiencing depressive symptoms (Cerin, Nathan et al., 2017). Second, the categorization of continuous variables leads to loss of information that, in turn, reduces the power to detect associations (Altman & Royston, 2006). Third, the categorization of PA measures into, for example, meeting the PA guidelines is more appropriate for measures that capture total PA, while the measures used in this study focused on total non-walking PA and walking for different purposes within the neighborhood only. We examined frequency and duration of PA separately because there is some evidence that they may show different associations with environmental factors (Cerin, Nathan et al., 2017; D. W.; Barnett et al., 2017) as well as depressive symptoms (Teychenne et al., 2008) and other aspects of mental well-being (Cerin et al., 2009). We did not consider measures of outside-neighborhood walking as mediators of neighborhood-depressive symptom associations because neighborhood characteristics are unlikely to impact PA behaviors outside the neighborhood (Cerin, Mitáš et al., 2017).

2.2.4. Covariates: socio-demographic and health-related variables

All analyses included age, sex, educational attainment, marital status, living arrangements (living alone vs. living with others), housing type, household car ownership, the number of current diagnosed health problems, area-level SES, and types of recruitment center as covariates. Living arrangements was also treated as a potential moderator of neighborhood environment and depressive symptoms associations.

2.3. Analytical approaches

Descriptive statistics were computed for all variables. To examine whether PA cross-sectionally mediated the associations of objectively-assessed neighborhood environmental attributes with depressive symptoms, and the moderating effects of living arrangements on these associations, we used the joint-significance test (MacKinnon & Luecken, 2008). Mediation analyses were conducted only for neighborhood environment attributes that showed significant (p < .05) main or interaction effects (with living arrangements) on depressive symptoms (θ path in Fig. 1). In previous analyses of the ALECS project, three attributes (connectivity, prevalence of public transport stops and pedestrian infrastructure) showed significant main effects and nine attributes (civic/institutional, retail, food-related destinations and public transport densities; prevalence of eating outlets and health clinics/services; crowdedness, presence of people, and pollution) interacted with living arrangements (Zhang et al., 2018).

Mediation analyses consisted of two steps. First, we estimated the covariate-adjusted main effects of the relevant neighborhood attributes, and/or the interaction effects of neighborhood attributes by living arrangements, on PA variables (α regression coefficients; see Fig. 1). This was done using random-intercept generalized linear mixed model with negative binomial variance and logarithmic link functions accounting for TPU-level clustering effects and the positive skewness of the
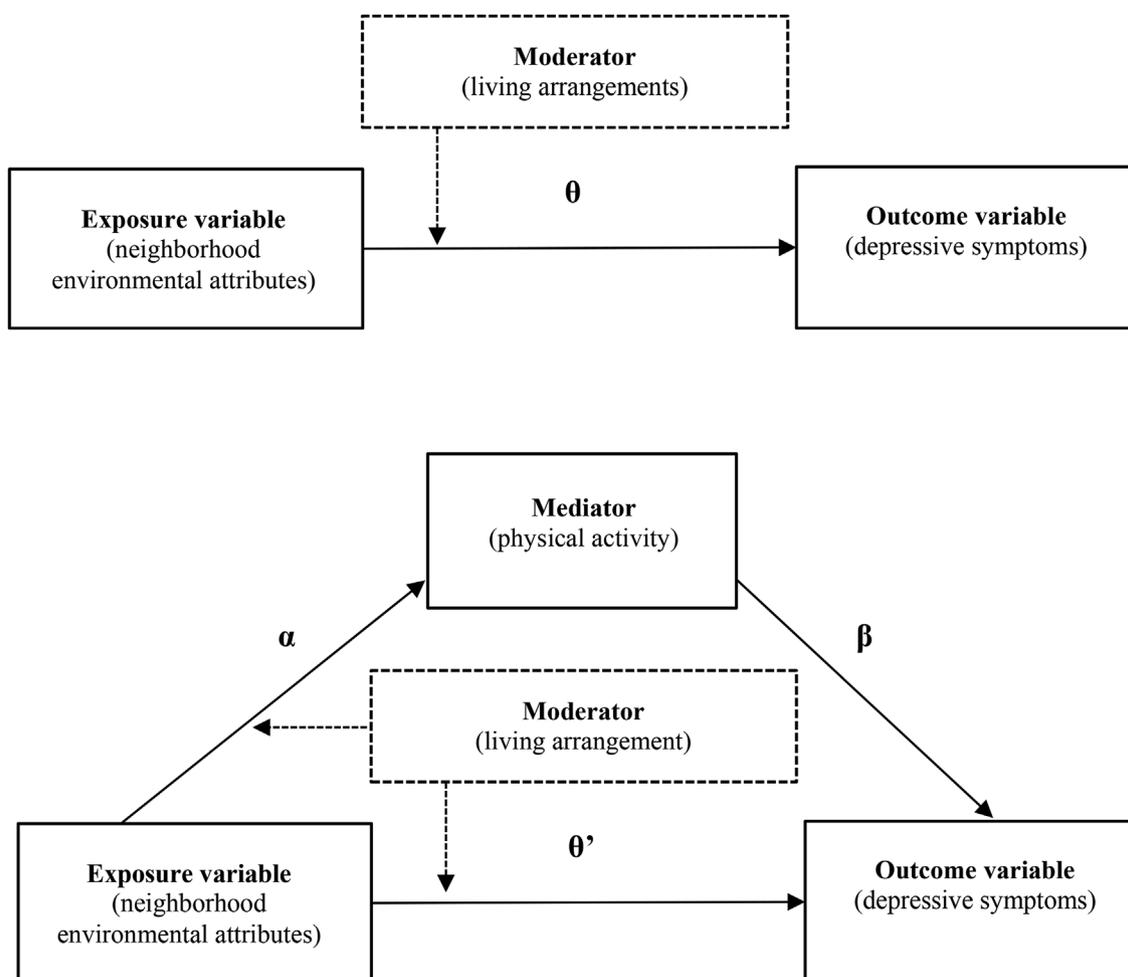
Fig. 1. Diagram for the analysis of the main and moderated effects of neighborhood environmental attributes on depressive symptoms mediated by physical activity.

outcome variables. α path coefficients were estimated for single- and multiple-environmental-attribute models. The latter models included all neighborhood environmental attributes and interaction terms with *p*-values < .05 in the single-environmental-attribute models. Multiple 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 a PA variable were retained in final multiple-environmental-attribute models.

The second step involved the estimation of the associations between the PA variables and depressive symptoms, controlled for neighborhood attribute(s) main effects and, where appropriate, interactions between neighborhood attributes living arrangements (β path coefficients; Fig. 1). This step also provided estimates of the direct (i.e., non-mediated by a specific PA variable) main and/or interaction effects of neighborhood attributes on depressive symptoms (θ' path coefficients; Fig. 1) (Cerin, 2010). Step 2 was undertaken only for PA variables that were significantly related to neighborhood attributes or their interaction with living arrangements, given that, according to the join-significant test, a specific PA variable can be considered a mediator of a neighborhood-attribute main or interaction effect on depressive symptoms if both relevant α and β path coefficients are statistically significant ($p < .05$). Random-intercept logistic regression models were used in step 2 of the mediation analyses. Separate sets of mediation analyses were performed for each PA variable because some of these variables were strongly positively correlated (e.g., weekly frequency and minutes of within-neighborhood walking for transport). All analyses were conducted in Stata 13.0.

3. Results

Table 1 summarizes the sample's sociodemographic and health-related characteristics, objectively-assessed neighborhood environmental attributes (relevant to this study), PA, and presence of depressive symptoms. Two-thirds of participants were female and nearly a quarter reported living alone. Over a third of the sample reported depressive symptoms. On average, participants reported very high levels of PA and resided in areas with relatively high levels of pedestrian infrastructure and some destination-related variables. Participants self-reported a mean of 752 min/week of total PA encompassing the sum of weekly minutes of non-walking PA, within- and outside-neighborhood walking for transport and for recreation. Older adults reporting any depressive symptoms were less likely to be men (OR = 0.436, 95% *CI* 0.307, 0.619, $p < .001$) and more likely to be living alone (OR = 1.497, 95% *CI* 1.021, 2.195, $p = .032$).

Table 2 reports estimates of single neighborhood attribute main effects, and single neighborhood attribute by living arrangement interaction effects on PA variables (α paths, Fig. 1) significant at a probability level of 0.05. The remaining estimates ($p > .05$) are given in Supplementary Table S2.

Within-neighborhood walking for transport (weekly frequency or both weekly frequency and minutes) was the type of PA most consistently associated with neighborhood environmental correlates of depressive symptoms, and neighborhood attributes by living arrangements interactions. It was positively related to neighborhood connectivity, pedestrian infrastructure, and several measures of destination prevalence/density but only, or more strongly, in older adults living

Table 1
Sample characteristics (N = 909).

Variables [theoretical range]	*Statistics*
Socio-demographic and health-related characteristics	
Age, years, *M* (*SD*)	77 (6)
Sex, female, %	66
Educational attainment, %	
No formal education	21
Primary school	35
Secondary school	31
Post-secondary school	13
Marital status, %	
Married or cohabiting	59
Widowed	33
Other	8
Housing, %	
Public and aided	43
Private (purchased)	51
Renting	6
Living alone, %	23
Household with car, %	29
Neighborhood type, %	
Low walkability, low SES	22
Low walkability, high SES	25
High walkability, low SES	28
High walkability, high SES	25
Number of current diagnosed health problems [0-10], *M* (*SD*)	3 (2)
Outcome	
Presence of depressive symptoms, %	37
Mediator: physical activity	
Total non-walking – frequency (times/week), *Median* (*IQR*)	6 (7)
Total non-walking – duration (minutes/week), *Median* (*IQR*)	210 (420)
Within-neighborhood walking for recreation – frequency (times/week), *Median* (*IQR*)	0 (7)
Within-neighborhood walking for recreation – duration (minutes/week), *Median* (*IQR*)	0 (210)
Within-neighborhood walking for transport – frequency (times/week), *M* (*SD*)	8 (8)
Within-neighborhood walking for transport – duration (minutes/week), *Median* (*IQR*)	120 (180)
Exposures: neighborhood environmental variables	
Connectivity (score) – EA [0–100], *M* (*SD*)	41 (7)
Civic and institutional density (destinations/km^2) – GIS, *M* (*SD*)	70 (37)
Retail density (destinations/km^2) – GIS, *M* (*SD*)	32 (19)
Food-related destination density (destinations/km^2) – GIS, *M* (*SD*)	32 (19)
Prevalence of eating outlets (number in buffer) – EA, *Median* (*IQR*)	9 (18)
Public transport density (transit points/km^2) – GIS, *Median* (*IQR*)	10 (12)
Prevalence of public transport stops (number in buffer) – EA, *M* (*SD*)	8 (5)
Prevalence of health clinics/services (number in buffer) – EA, *Median* (*IQR*)	3 (4)
Pedestrian infrastructure (score) – EA [0–100], *M* (*SD*)	63 (9)
Crowdedness (score) – EA [0–100], *Median* (*IQR*)	8 (13)
Presence of people (score) – EA [0–100], *M* (*SD*)	65 (22)
Pollution (score) – EA [0–100], *Median* (*IQR*)	40 (61)
Number of street segments audited (in buffer) – EA, *Median* (*IQR*)	16 (13)

Notes: SES = socio-economic status; *SD* = standard deviation; *IQR* = interquartile range; GIS = geographic information system; EA = environmental audits. Only environmental attributes relevant to this study are reported. Medians and IQR are reported for variables that were highly positively skewed (skewness > 1.00).

alone than in those living with others (Table 2). Insufficient evidence was found for PA variables as potential mediators of previously reported effects of prevalence of public transport stops, crowdedness, presence of people, and pollution on depressive symptoms (Zhang et al., 2018) (Table S2).

Table 3 summarizes the findings of the second step of single-environmental-attribute mediation analyses (β and θ′ paths in Fig. 1). This second step was undertaken only for the significantly interrelated pairs of environmental attributes and PA measures presented in Table 2. Only frequency of walking for transport emerged as a potential mediator. In fact, after adjusting for relevant environmental attributes, frequency of walking for transport was significantly negatively related with the odds

of reporting any depressive symptoms (Table 3). This PA variable partially explained the associations of environmental attributes with depressive symptoms, since most direct main and interactive effects of neighborhood environmental attributes on depressive symptoms (θ′ path coefficients) remained statistically significant.

Multiple-environmental-attribute mediation models were estimated for frequency of walking for transport and the environmental attributes in Table 3 (specified as main or interaction effects, as appropriate). For this purpose, a composite destination index consisting of the sum of the z-scores of five relevant destination variables (civic/institutional, retail, food-related destination densities and prevalence of eating outlets and health clinics/services) was created because they were strongly correlated (r > 0.50). In the final α path model, connectivity was positively related to frequency of walking for transport (e^b = 1.016; 95% *CI* 1.005, 1.026; *p* = .004) and living arrangements moderated the association between the destination index and this PA variable (e^b = 1.066; 95% *CI* 1.023, 1.112; *p* = .003), with those living alone showing a positive association (e^b = 1.081; 95% *CI* 1.040, 1.124; *p* < .001) and those living with others failing to do so (e^b = 1.031; 95% *CI* 0.993, 1.034; *p* = .194) (see Fig. 2). The β and θ′ path model indicated that frequency of walking for transport was negatively related to the likelihood of experiencing depressive symptoms (OR = 0.976; 95% *CI* 0.956, 0.996; *p* = .017) and, hence, could be considered a suppressor (i.e., inconsistent mediator) of the association between connectivity and depressive symptoms (θ′ path coefficient: OR = 1.044; 95% *CI* 1.017, 1.072; *p* = .001) and a partial mediator of the interaction effect of living arrangements and destinations on depressive symptoms (θ′ path coefficient: OR = 0.900; 95% *CI* 0.827, 0.979; *p* = .014) (Fig. 2).

4. Discussion

This study examined the extent to which various types of PA explained associations between objectively-assessed neighborhood attributes and depressive symptoms in Hong Kong older adults. As noted earlier, only three neighborhood attributes were identified as correlates of depressive symptoms in the whole sample (Zhang et al., 2018). The scarcity of main effects has been attributed to Hong Kong's widespread walkability and access to affordable public transport promoting a physically- and socially-active lifestyle that reduces the risk of depressive symptoms in older dwellers (Zhang et al., 2018). In fact, in this study, participants self-reported a mean of 752 min/week of total PA, which is substantially higher than that observed in older adults from other countries using similar PA measures (median ~100–150 min/week) (Grimm, Swartz, Hart, Miller, & Strath, 2012; Hurtig-Wennlof; Hagstromer, & Olsson, 2010).

Of the three environmental attributes found to be positively associated with depressive symptoms (Zhang et al., 2018), neighborhood connectivity and/or pedestrian infrastructure were positively related to PA and, specifically, frequency of walking for recreation, and amount and frequency of walking for transport. Higher frequency of walking for transport was associated with a lower likelihood of reporting depressive symptoms. This pattern of findings indicates that, in ultra-dense metropolises such as Hong Kong, neighborhood walkability may exert beneficial as well as detrimental effects on older residents' mental health via different mechanisms. On the one hand, neighborhood connectivity and good pedestrian infrastructure can facilitate and promote walking for transport, particularly in older dwellers with reduced mobility (Cerin, Nathan et al., 2017). The ability to easily access local destinations, participate in various activities, maintain independence, and age in place may lower the risk of experiencing depressive symptoms (A. Barnett et al., 2017). On the other hand, the exposure to common by-products of urban density and walkability, such as traffic-related noise, pollution, and stress, may increase the risk of depressive symptoms (Cutrona, Wallace, & Wesner, 2006). In Hong Kong, well-connected neighborhoods usually have a large number of street intersections, pedestrian overpasses, bridges, and tunnels. These are places

Table 2

Statistically significant main and interaction effects of neighborhood environmental attributes on physical activity variables (α path coefficients of single-environmental-attribute mediation analyses).

Environmental attribute [independent variable]	Physical activity [mediator; outcome in α path models]	Effect type	e^b (95% CI) [α path coefficients]	p
Main effects				
Connectivity (EA)	WNWT (times/week)	Main	1.018 (1.007, 1.028)**	.001
	WNWT (min/week)	Main	1.019 (1.003, 1.036)*	.017
Prevalence of public transport stops (EA)	None associated	–	–	–
Pedestrian infrastructure (EA)	WNWR (times/week)	Main	1.005 (1.000, 1.010)*	.048
	WNWT (times/week)	Main	1.012 (1.004, 1.019)**	.002
	WNWT (min/week)	Main	1.015 (1.004, 1.027)**	.009
Interaction effects				
Civic/institutional density (GIS) by Living arrangements	WNWT (times/week)	Interaction	1.007 (1.002, 1.012)**	.006
		in LO	1.001 (0.999, 1.003)	.384
		in LA	1.008 (1.003, 1.013)**	.001
Retail density (GIS) by Living arrangements	WNWT (times/week)	Interaction	1.012 (1.002, 1.021)*	.016
		in LO	1.005 (1.001, 1.009)*	.016
		in LA	1.017 (1.008, 1.026)***	< .001
Food-related destination density (GIS) by Living arrangements	WNWT (times/week)	Interaction	1.011 (1.002, 1.021)*	.029
		in LO	1.005 (1.001, 1.010)*	.013
		in LA	1.016 (1.007, 1.025)***	< .001
Prevalence of eating outlets (EA) by Living arrangements	WNWT (times/week)	Interaction	1.018 (1.005, 1.031)**	.005
		in LO	1.001 (0.992, 1.010)	.871
		in LA	1.019 (1.066, 1.032)**	.003
Public transport density (GIS) by Living arrangements	None associated	–	–	–
Prevalence of health clinics/services (EA) by Living arrangements	WNWT (times/week)	Interaction	1.047 (1.005, 1.090)*	.029
		in LO	1.005 (0.984, 1.027)	.649
		in LA	1.052 (1.013, 1.092)**	.008
Crowdedness (EA) by Living arrangements	None associated	–	–	–
Presence of people (EA) by Living arrangements	None associated	–	–	–
Pollution (EA) by Living arrangements	None associated	–	–	–

Notes. All environmental attributes that showed significant main or interaction effects on depressive symptoms are listed in this table. WNWT = within-neighborhood walking for transport; WNWR = within-neighborhood walking for recreation; e^b = antilogarithm of regression coefficient; CI = confidence intervals; p = p-value; EA = environmental audits; GIS = geographic information systems; in LO = in those living with others; in LA = in those living alone. e^b is interpreted as the proportional increase in physical activity associated with a 1-unit increase in the environmental attribute. All estimates were adjusted for age, sex, educational attainment, household with car, marital status, housing type, living arrangement, area-level socio-economic status, type of recruitment center, and number of current diagnosed health problems. Only physical activity variables with α path coefficients significant at a 0.05 probability level are reported. Physical activity variables with non-significant α path coefficients are reported in Supplementary Table S2. *p < .05; **p < .01; ***p < .001.

with an excellent pedestrian infrastructure, but also with high volumes of traffic, noise, pollution, and no public space for socializing (Highways Department, 2017; Zhang et al., 2018). It is likely that the observed non-mediated positive relationship between neighborhood connectivity and depressive symptoms was primarily due to exposure to environmental stressors (Zhong, Cai, & Bloss, 2016). Future studies will need to objectively measure these potential antagonistic mechanisms of influence and establish how older adults perceive their impact on mental health.

Living arrangements moderated the associations of a considerable number of measures of access to destinations of daily living (retail, health services, public transport, eating outlets, and food stores) with depressive symptoms, and most of these moderating effects were partially mediated by frequency of walking for transport. Specifically, better access to destinations was associated with a lower likelihood of reporting depressive symptoms and with higher frequency of walking for transport in older adults living alone but not in those living with others. Good access to services may be more important to older adults living alone who receive less personal assistance from family members, are more self-reliant in performing activities of daily living (Kooshiar, Yahaya, Hamid, Abu Samah, & Sedaghat Jou, 2012), and, hence, more likely to walk to local destinations for various purposes if these destinations are available. It is interesting that within-neighborhood walking did not explain the moderating effects of living arrangements on the associations of presence of people and public transport density with depressive symptoms. These two types of neighborhood attributes may respectively facilitate socializing and engagement in activities outside the neighborhood (Cerin et al., 2013b), which are potential mechanisms of environmental influence on depressive symptoms that were not

captured in this study. Engagement in social activities may have also been in part responsible for the 'direct' moderating effects of living arrangement on destination-depressive symptoms associations not explained by walking for transport, since socializing helps maintain strong bonds with the community and strengthen one's resilience to negative affectivity (A. Barnett et al., 2017; Cohen et al., 2008). Further, older adults living alone may benefit more from the same amounts of social contacts with community dwellers than those living with others. Another possible reason for observing partial rather than full mediation pertains to the relatively high measurement error common to self-report measures of PA, which may attenuate the associations between PA and depressive symptoms (Cerin, 2010; Cerin, Barnett et al., 2011).

It is noteworthy that only frequency of within-neighborhood walking for transport emerged as a significant mediator of environment-depressive symptoms associations. The number of times older adults, especially those living alone, break periods of time spent alone at home seems to be more important that the total time they spend walking for transport in their communities. Unexpectedly, non-walking PA and walking for recreation did not mediate the observed associations. This might be due to the measure of non-walking PA encompassing participation in leisure-time as well as household activities (Deng et al., 2008), and recreational walking being a discretionary activity mainly determined by personal factors (habits, attitude to PA) and, to a lesser extent, by environmental factors (Van Cauwenberg et al., 2018).

Table 3

Environmental-attribute-adjusted associations of physical activity variables with, and direct main and interaction effects of neighborhood environmental attributes on, the presence of depressive symptoms (β and θ' path coefficients of single-environmental-attribute mediation analyses).

Model	Path coefficient	OR (95% CI) [any vs. no depressive symptoms]	p
Environmental attributes with main effects on depressive symptoms			
Connectivity (EA) via WNWT (times/week)	β: WNWT (times/week)	0.974 (0.955, 0.994)*	.010
	θ': Connectivity	1.046 (1.019, 1.073)**	.001
Connectivity (EA) via WNWT (min/week)	β: WNWT (min/week)	0.999 (0.998, 1.000)	.166
	θ': Connectivity	1.043 (1.016, 1.070)**	.001
Pedestrian infrastructure (EA) via WNWR (times/week)	β: WNWR (times/week)	1.014 (0.976, 1.053)	.448
	θ': Pedestrian infrastructure	1.027 (1.008, 1.050)**	.007
Pedestrian infrastructure (EA) via WNWT (times/week)	β: WNWT (times/week)	0.975 (0.956, 0.995)*	.013
	θ': Pedestrian infrastructure	1.029 (1.009, 1.049)**	.004
Pedestrian infrastructure (EA) via WNWT (min/week)	β: WNWT (min/week)	0.999 (0.999, 1.000)	.165
	θ': Pedestrian infrastructure	1.028 (1.008, 1.048)**	.006
Environmental attributes with interaction effects on depressive symptoms			
Civic/institutional density (GIS) by Living arrangements via WNWT (times/week)	β: WNWT (times/week)	0.982 (0.962, 1.000)+	.054
	θ': Civic/institutional density by Living arrangement	0.991 (0.981, 1.000)*	.049
	θ': in LO	1.002 (0.997, 1.007)	.388
	θ': in LA	0.993 (0.984, 1.001)+	.095
Retail density (GIS) by Living arrangements via WNWT (times/week)	β: WNWT (times/week)	0.979 (0.960, 0.999)*	.036
	θ': Retail density by Living arrangement	0.982 (0.964, 1.000)*	.045
	θ': in LO	1.009 (1.000, 1.019)+	.057
	θ': in LA	0.991 (0.975, 1.007)	.253
Food-related destination density (GIS) by Living arrangements via WNWT (times/week)	β: WNWT (times/week)	0.979 (0.960, 0.999)*	.035
	θ': Food-related destination density by Living arrangement	0.981 (0.963, 0.999)*	.044
	θ': in LO	1.009 (0.999, 1.019)+	.065
	θ': in LA	0.990 (0.974, 1.006)	.231
Prevalence of eating outlets (EA) by Living arrangements via WNWT (times/week)	β: WNWT (times/week)	0.980 (0.961, 0.999)*	.041
	θ': Prevalence of eating outlets by Living arrangement‡	0.977 (0.963, 1.001)+	.064
Prevalence of health clinics/services (EA) by Living arrangements via WNWT (times/week)	β: WNWT (times/week)	0.980 (0.961, 0.999)*	.044
	θ': Prevalence of health clinics/services by Living arrangement	0.985 (0.820, 0.976)*	.013
	θ': in LO	1.054 (1.011, 1.100)*	.014
	θ': in LA	0.944 (0.869, 1.024)	.165

Notes. Reference category: no depressive symptoms. WNWT = within-neighborhood walking for transport; WNWR = within-neighborhood walking for recreation; OR = odds ratio; CI = confidence intervals; p = p-value; EA = environmental audits; GIS = geographic information systems; in LO = in those living with others; in LA = in those living alone. All estimates were adjusted for age, sex, educational attainment, household with car, marital status, housing type, living arrangement, area-level socio-economic status, type of recruitment center, and number of current diagnosed health problems. +p < .10; *p < .05; **p < .01.

4.1. Strengths and limitations

The current study has several strengths and limitations. By quantifying the neighborhood environmental attributes using objective measures, we accounted for one of the sources of reverse causality – namely, the influence of depressive states on perceptions of the environment (Zhang et al., 2018). Other study strengths include the sampling strategy maximizing the variability in environmental exposures balanced by SES, the high response rate, and the wide range of environmental attributes and potential confounders measured. The cross-sectional nature of the study is one of the main limitations as it precludes the establishment of causal relationships. Older adults with depressive symptoms may engage in walking for transport less frequently than their counterparts, and those enjoying being physically active may choose to live in activity-friendly neighborhoods (residential self-selection) (Cerin, Nathan et al., 2017). However, the latter source of bias is unlikely to have a large impact on our study since nearly 40% of Hong Kong elders live in public housing, and their choice of residence is generally restricted by Hong Kong's exorbitant property prices (TransportandHousing Bureau, 2017). The inability to obtain more comprehensive sampling frames due to privacy ordinance restrictions is another study limitation. Finally, the use of self-report measures of PA known for having relatively large measurement errors might have resulted in an underestimation of PA-mediated effects of the environment on depressive symptoms. While the IPAQ-SC is one of the most reliable self-report measures for older adults (Forsen et al., 2010), no significant associations were found between non-walking PA as assessed by the IPAQ-SC and pedometer counts (Deng et al., 2008). Similar findings were reported with respect to the long version of the IPAQ when administered to Hong Kong older adults (Cerin et al., 2012). Apart from the notorious difficulties in reporting frequency and volumes of moderate-intensity PA other than walking, the fact that Hong Kong older adults tend to accumulate moderate-intensity PA mainly through domestic rather than leisure activities (Cerin et al., 2012) may have contributed to the inability to establish non-walking PA as a mediator of environment-depressive symptoms in the present study. Objective measures of PA (e.g., using accelerometers with cut-points appropriate for older adults) can provide more accurate estimates of PA but also lack context-specific details (e.g., PA type, purpose and location) that are important for clarifying the environment-behavior-mental health nexus and informing the design of efficacious environmental and behavioral interventions (D.W. Barnett et al., 2017). A combination of objective and self-report measures may be required to advance this field of research.

5. Conclusions

In summary, this study suggests that ultra-dense, well-connected, pedestrian-friendly, destination-rich neighborhoods may contribute to lowering the risk of depressive symptoms in Hong Kong older adults by enabling them to frequently walk to local destinations of daily living and, thus, maintain their independence and bond with the community.
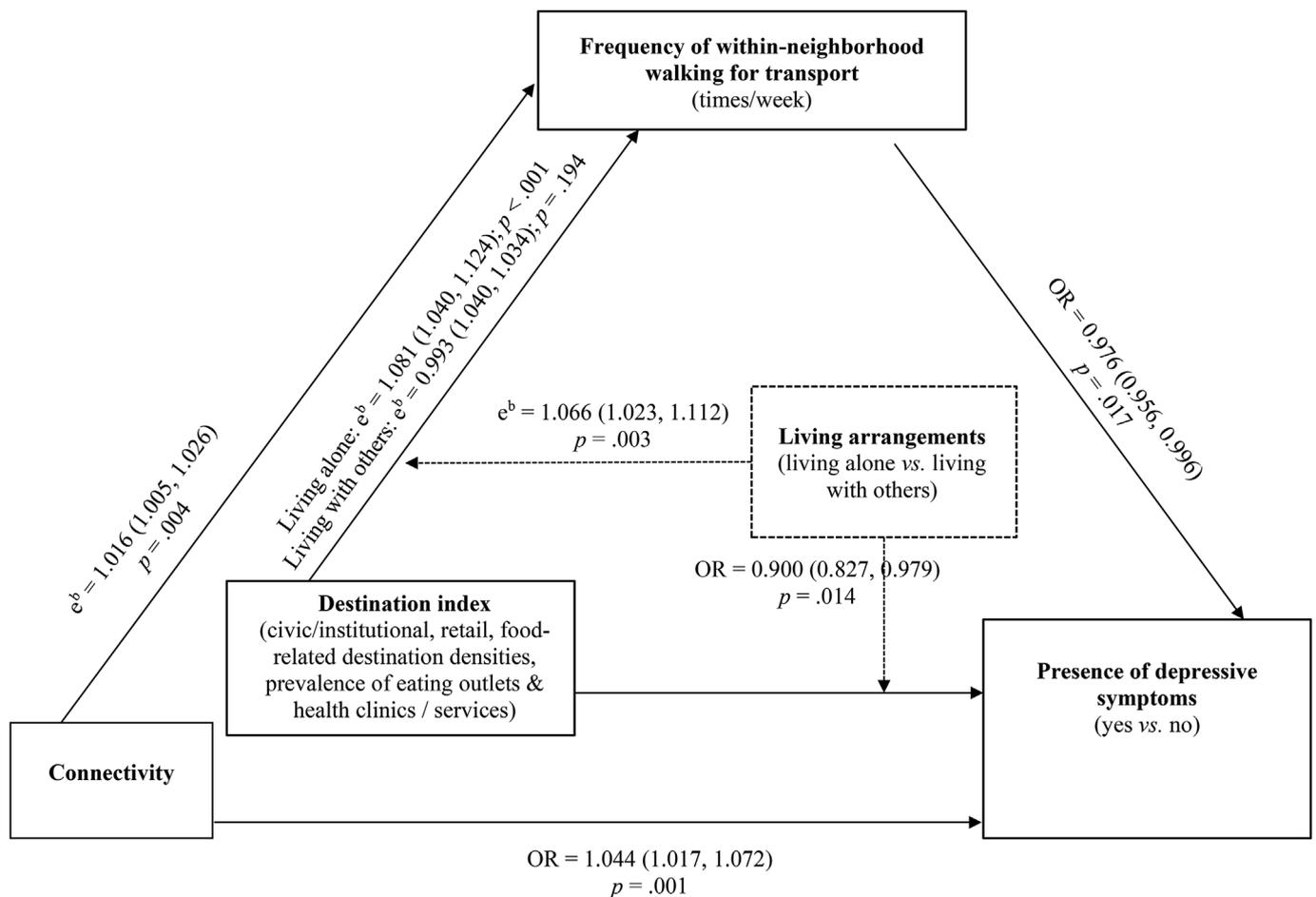
Fig. 2. Diagram of multi-environmental-variable mediation models of depressive symptoms in Hong Kong older adults.

These potential pathways of influence are particularly important for older adults living alone. However, our findings also suggest that ultra-dense, well-connected neighborhoods may also expose residents to environmental stressors (e.g., high traffic volumes) that have been linked to higher risk of depression (Cutrona et al., 2006). To advance our understanding of how neighborhood environments affect older adults' mental health, future studies will need to examine a wider range of potential antagonistic mediators of neighborhood correlates of physical activity and depressive symptoms. Specifically, it would be important to estimate the pros and cons of engaging in PA outdoors in noise and polluted environments in relation to depressive symptoms.

Conflict of interest declaration

The authors declare no conflicts of interest.

Declarations of interest

None.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.mhpa.2018.11.005.

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