Understanding the associations between the perceived built environment and Chinese older adults' accelerometer-assessed physical activity and sedentary time

by

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Author declaration

I, David William Barnett, certify that this thesis contains:

a) No material published elsewhere or extracted in whole or in part from a thesis by which I have qualified for or been awarded another degree or diploma;

b) No other person's work has been used without due acknowledgement in the main text of the thesis; and

c) That all research procedures reported in this thesis received the approval of the relevant ethics/safety committees.

Signed: ……………………………………..

Date: 21st August 2019

Statement of appreciation

I’d like to sincerely thank my two doctoral supervisors, Prof. Ester Cerin and A/Prof. Anthony Barnett. Only because of your honest and expert advice, patience, and inspiring work ethic have I been able to become a more competent scientist and navigate this PhD to its end. I’m proud of what we have achieved with this PhD research program, I hope you are too. I’m very grateful to have had the opportunity to learn from you both.

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“I hold a beast, an angel, and a madman in me, and my enquiry is as to their working, and my problem is their subjugation and victory, down throw and upheaval, and my effort is their self-expression.”

—Dylan Thomas

After finishing my Masters of Science thesis, I swore I would never put my mind through that kind of suffering ever again. Then, I signed up for a PhD degree…

This PhD journey has not been all rainbows and pots of gold, but I have always felt it worthwhile because I learned something at each hurdle. I think challenges, academic or otherwise, are part and parcel of a meaningful life and it’s only realistic that they have an element of suffering—whether that be late night reads on multilevel modelling, missing Christmas with my family, and/or acculturating to Australian humour! Far out! Overcoming these types of adversities, has, undoubtedly, made me a better person and, therefore, I’m extremely grateful for having had this opportunity to learn about myself in addition to honing my research skills. I was also lucky to learn more about Hong Kong and its people, a lovely place.

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And, Coops, you have a lot to answer for!

Gorau adnabod, d'adnabod dy hun.

Statement of dedication

This doctoral thesis is dedicated to my uncle, Tudor.

Abstract

Rationale

Moderate- to vigorous-intensity physical activity is important for older adults to achieve current physical activity recommendations. Moderate- to vigorous-intensity physical activity is more validly assessed using accelerometers than questionnaires. However, the most commonly-used accelerometer moderate- to vigorous-intensity physical activity cut-point (Freedson et al.'s: ≥1952 counts·min^{-1} [2]) is inappropriate for use in Chinese older adults. Additionally, emerging evidence suggests that sedentary behaviour is also a risk factor for health, yet it is unclear whether physical activity and sedentary behaviour are independent behaviours. Thus, identifying correlates of these behaviours is important for public health. Socio-ecological models posit that neighbourhood built environmental attributes may influence these behaviours.

Aims

(#1) Develop a moderate- to vigorous-intensity physical activity accelerometer cut-point specific to Chinese older adults;

(#2) Examine associations of neighbourhood attributes with accelerometer-assessed moderate- to vigorous-intensity physical activity (using the new *vs.* Freedson et al.'s cut-point [2]) and sedentary time and their socio-demographic/health moderators;

(#3) Investigate whether moderate- to vigorous-intensity physical activity mediates associations between sedentary time and neighbourhood attributes.

Results

(Aim #1) New moderate- to vigorous-intensity physical activity accelerometer cut-point: ≥1184 counts.min^{-1}.

(Aim #2) Moderate- to vigorous-intensity physical activity was positively associated with land-use mix, bridge/overpass connection access, and social disorder/littering and negatively associated with residential density. Generally, moderate- to vigorous-intensity physical activity defined using our new cut-point had stronger associations with neighbourhood

attributes than moderate- to vigorous-intensity physical activity based on Freedson's cut-point. Age (land-use mix) and the number of diagnosed medical conditions (aesthetics) moderated associations. Sedentary time was negatively associated with street connectivity, bridge/overpass connection access, and social disorder/littering and positively associated with presence of people in the streets. The number of diagnosed medical conditions moderated the effects of crowdedness and fences separating footpaths from traffic.

(Aim #3) Moderate- to vigorous-intensity physical activity fully-mediated associations of sedentary time with bridge/overpass connection access and social disorder/littering.

Conclusions

(Aim #1) New ≥1184 counts.min^{-1} moderate- to vigorous-intensity physical activity accelerometer cut-point was more appropriate than Freedson cut-point.

(Aim #2) Not-overly-dense neighbourhoods with higher land-use mix, bridge/overpass connection access, and social disorder/littering were associated with moderate- to vigorous-intensity physical activity. These latter two neighbourhood attributes were also associated with sedentary time and explained by moderate- to vigorous-intensity physical activity (Aim #3). Finally, some demographic sub-groups have a different relationship between neighbourhood attributes and moderate- to vigorous-intensity physical activity/sedentary time.

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List of abbreviations

ALECS	Active Lifestyle and the Environment in Chinese Seniors
BMI	Body mass index
CHAMPS	Community Health Activities Model Program for Seniors
CI	Confidence interval
CO_2	Carbon dioxide
df	Degrees of freedom
FFM	Fat free mass
GLM	Generalised linear model
GPS	Global positioning system
ICC	Intraclass correlation
ID	Identification number
IPAQ	International Physical Activity Questionnaire
IPAQ-E	International Physical Activity Questionnaire – Short version for the Elderly
IPAQ-LC	International Physical Activity Questionnaire – Long version in Chinese
IPAQ-S	International Physical Activity Questionnaire – Short version
IPAQ-CS	International Physical Activity Questionnaire – Short version in Chinese
LMM	Linear mixed model
MET	Metabolic equivalent
NEWS	Neighbourhood Environment Walkability Scale
O_2	Oxygen
PhD	Doctor of Philosophy
PRIMSA	Preferred Reporting for Systematic Reviews and Meta-Analyses
RMR	Resting metabolic rate
SD	Standard deviation
SES	Socio-economic status
SPPB	Short Performance Physical Battery
UK	United Kingdom of Great Britain and Northern Ireland
USA	United States of America
V_E	Expired ventilation
VO_2	Rate of oxygen consumption

Statement of candidate's contribution

Two sources of data were used to address the main aim and specific objectives of this PhD thesis: (1) primary data collection (experimental study – Chapter 4); and (2) secondary data analysis (epidemiological studies – Chapters 5 and 6).

Regarding the experimental study, the candidate, under the guidance and expertise of Prof. Ester Cerin (principal supervisor), Prof. Anna Timperio, Dr Nicola Ridgers (co-supervisors during the time at Deakin University, February 2014-January 2016), and A/Prof. Anthony Barnett had to (co-supervisor):

a) Apply for ethical approval;
b) Recruit research assistants that spoke Cantonese and Mandarin;
c) Recruit participants;
d) Collect data;
e) Manage data;
f) Design the statistical analysis plan;
g) Analyse data; and
h) Interpret data.

Regarding the epidemiological studies, the candidate, under the guidance and expertise of Prof. Ester Cerin, A/Prof. Anthony Barnett, and Dr Andrea Nathan (assistant supervisor during the time at the Australian Catholic University, January 2016-April 2018) had to:

a) Design the statistical analysis plan; and
b) Interpret data.

Note: As required by the Department of Health, Hong Kong Special Administrative Region (co-owner of the ALECS dataset), the analyses for the studies presented in Chapters 5 and 6 were conducted by Dr Anthony Barnett, a co-investigator on the Active Lifestyle and the Environment in Chinese Seniors (ALECS) study.

Chapter 1
Introduction

1.1. Demographic trends in the Asia-Pacific region: the ageing Chinese

Asia is the world's largest and most populous continent, with approximately 4.3 billion people, corresponding to 60% of the world's current population [3]. With a population of 1.3 billion individuals, China stands as the most populous nation in Asia and the world [4]. Older adults, here defined as individuals ≥65 years old [5], are a sizeable proportion of the population in Asia and the Pacific. Specifically, there are 300 million older adults in this region [6], with 178 million of those being Chinese [4]. Globally, the population of older adults is forecasted to grow exponentially to two billion (22% of the world's population [7]) by 2050[7]. This includes a trebling in size in Asia and the Pacific to 900 million individuals [6] and almost a doubling in size in China to 330 million individuals [8].

1.2. Morbidity in older adults: the economic burden

Older adults are the most morbid of any section of society which is partially attributable to the chronic nature of non-communicable disease progression [9, 10]. Thirty percent of China's population are expected to be aged ≥60 years by 2050, up from around 11% in 2010 [7], and morbidity in this demographic is highly prevalent with 47.6% reporting "some chronic disease" [11]. Nine out of ten of the most commonly-reported ailments were non-communicable diseases [12], namely: hypertension, renal lithiasis, chronic obstructive pulmonary disease, ischemic heart disease, chronic gastritis, cerebrovascular disease, lumbar disk disease, gallstones and diabetes [11]. As such, the economic implications on this middle-income developing economy [13], and its ageing population are of real concern [14]. China's economically active (i.e., working-age) population is forecast to decline rapidly [14]; and the associated insufficient labour force may, then, decrease China's export competitiveness [15]. Simultaneously, older adult-based healthcare expenditure will increase exponentially [16] and, thus, the burden of an ageing population will likely slow the economic growth rate [13]. Healthy ageing, therefore, will become an increasingly important economic consideration in China and, indeed, the world [5]. One cost- [17, 18] and clinically-effective [19, 20] strategy to reduce the burden of non-communicable diseases and their economic consequences that has received attention, has been the promotion of an active lifestyle (i.e., meeting physical activity recommendations for health).

1.3. Physical activity and sedentary behaviour: the health effects

1.3.1. Physical activity

Physical activity is defined as "*any bodily movement produced by the contraction of skeletal muscle that increases energy expenditure above the basal level*" [21]. Thus, it encompasses a wide variety of activities from sweeping the floor to washing the dishes, to gardening, to walking for transport. Robust scientific evidence shows that adequate levels of such physical activities in older age, particularly of at least moderate-intensity, have preventative and therapeutic roles with regard to a variety of health outcomes spanning physiological, psychological and psychosocial health paradigms [22-27].

Specifically, sufficient levels of physical activity (to current guidelines) have been shown to reduce the risk of all-cause mortality [25, 28, 29], cardiovascular events [30], type 2 diabetes mellitus [31, 32], cerebrovascular diseases such as stroke [33, 34], cancers of the breast [35] and colon [36], dementia progression [37], worsening cognition [38], depressive mood [39], and enhance feelings of independence, social interaction and social well-being [40, 41]. Participation in physical activity can also assist in the maintenance of physical functioning, which is fundamental to independent living [42]. That is, it allows the individual to be able to leave their home and access the community [43-45], the low occurrence of which (<1 per week) has been shown to significantly increase functional impairment in performing basic activities of daily living [45]. Impaired mobility predicts worsening disability and institutionalisation [46-48].

Although the majority of studies prospectively investigating the effect of physical activity 'dose' (i.e., frequency, intensity, and duration) on non-communicable disease have been conducted in predominantly White-European origin populations [49, 50], evidence suggests similar protective effects of physical activity in Chinese populations. A dose-dependent inverse relationship between physical activity and mortality risk in Taiwanese over 65's [51], reduced risk of cardiovascular and all-cause mortality in middle-aged Chinese women [52] and men [53], and incident type 2 diabetes mellitus [54] in middle-aged Chinese women have been reported. Thus, irrespective of ethnicity, older adults universally would benefit from health-enhancing levels of physical activity (i.e., meeting the physical activity guidelines).

1.3.2. Sedentary behaviour

Sedentary behaviour is defined as "*any waking behaviour characterised by an energy expenditure ≤1.5 METs while in a sitting or reclining posture*" [55]. Typical sedentary behaviours include television viewing, computer use, and sitting time [56]. In comparison with physical activity (energy expenditure >1.5 METS), sedentary behaviour has been understudied. However, evidence has linked increased levels of objectively- and subjectively-measured sedentary behaviour in older adults with significantly higher risk of all-cause- and cardiovascular-related-mortality [57-60], metabolic syndrome [61, 62], adverse insulin and glucose profiles [63], abdominal obesity [64, 65], weight gain [66], higher body mass index (BMI) [67, 68], and poor psychosocial well-being [69], and general mental health [70]. While there is no available information on the associations of sedentary behaviour with health outcomes in Chinese older adults, it is plausible that the same risks would be present. Therefore, understanding influences on sedentary behaviour in this population may have important implications for informing public health strategies.

1.4. Prevalence of older adults meeting physical activity and sedentary behaviour guidelines for health

Research has shown that physical activity in older life confers a multitude of benefits at a time when some degree of morbidity is almost inevitable [71]. Hence, Government-published recommendations prescribe undertaking at least 150 minutes of at least moderate-intensity physical activity per week [23, 27]. The number of people who are not meeting this weekly criterion is striking. In adults, recent evidence has shown that approximately 35% do not meet this physical activity target, the outcome of which is an estimated 5.3 million premature deaths annually (9% of all premature deaths worldwide), more than is caused by smoking [72]. With age, physical activity participation has been shown to decline, and older adults are generally the least active part of society (e.g., [73]). However, physical activity participation can differ considerably across countries and populations. For example, United Kingdom (UK) data showed that while 80.5% of older adults did not meet current physical activity recommendations [73], by comparison, Hong Kong data showed older adults, on average, participated in more than double current recommendations (331 min·wk^{-1} of recreational walking) [74, 75]. One limitation of these studies was the use of self-report measures to assess physical activity. This is an important consideration because these tools lack validity in assessing the dose of physical activity compared with objective alternatives (discussed in

Chapter 2) and brings into question whether, for example, the high estimates of Hong Kong Chinese older adults were valid or a function of measurement error.

Regarding sedentary behaviour in older adults, less research has been undertaken on this behaviour than physical activity, and there are currently no Government-published guidelines on how much sedentary time is detrimental to health [76, 77]. However, various researchers have made suggestions based on their findings. For example, limiting television time to <7 hrs·day^{-1} [78] or frequently breaking up prolonged bouts of sitting [79] may be particularly pertinent for the older adult population as they have been shown to spend 80% of their objectively-measured waking day sedentary [80]. Due to limited research, it is unclear how much time Chinese older adults spend in sedentary activities.

The findings presented above suggest that: a) Chinese older adults may be highly active; and b) older adults are highly sedentary. Research gaps remain as to whether the intensity level of Chinese older adults' physical activity and the amount of sedentary time they engage in are appropriate to benefit health.

1.5. Models of physical activity and sedentary behaviour

Numerous models of health behaviour, for example, the Transtheoretical Model [81], the Health Belief Model [82], and the Social Cognitive Theory [83] have been implemented in physical activity and sedentary behaviour research to help explain these behaviours. Such models target only individual/intrapersonal and interpersonal level factors (e.g., [81, 82]) or are limited in their capacity to account for multi-level influences and interactions therein (e.g., between built and social environments) [83]. Conversely, ecological models posit that domain-specific, complex, and dynamic interrelations at the individual/intrapersonal level and within the physical and social environment shape physical activity and sedentary behaviour [84]. Therefore, unlike other behaviour change theories, they consider environmental- and policy-level factors along with individual and interpersonal factors [85]. Findings based on these models can have a substantial public health impact in comparison to those from the models targeting only individual/intrapersonal and interpersonal level factors. Public health effects depend on effect size, the number of people exposed, and duration of exposure. In the context of neighbourhood-related attributes, weak effect sizes are magnified by high exposure and the fact that people are exposed to these factors over their lifetime.

While the focus of this section will involve introducing the neighbourhood built environmental-level correlates of older adults' physical activity and sedentary behaviours, there are other correlates within the ecological theoretical framework that needs to be acknowledged. Specifically, ecological models posit that physical activity and sedentary behaviours are potentially influenced by individual, interpersonal, proximal-environmental (home and neighbourhood), meso-environmental (regional and national policy level), and distal environmental factors (global level) and their interactions (Figure 1). At the individual level, we find biological factors (e.g., age [86], ethnicity [87], sex [88] and health status [89]); demographic factors (e.g., household income [90], educational attainment [91]); and psychological factors (e.g., self-efficacy [90], attitudes toward physical activity [92]). Interpersonal level factors include social support from family [93] and friends [94], acculturation [95] and social cohesion [96]. At the proximal-environmental level, we find home and neighbourhood social, built and natural environmental attributes. At the regional or national policy level (meso-environmental), we find transport systems, urban planning and architecture, parks and recreation sector, health sector, education and schools sector, organised sports sector, national physical activity plans, national physical activity advocacy and the corporate sector. Finally, factors such as economic development, global media, global product marketing, urbanisation, global advocacy, and social and cultural norms fall under the category of distal-environmental factors and represent global-level influences on behaviours. While these factors are important, this PhD thesis will focus on the association between the neighbourhood physical (built) environment and older adults' physical activity and sedentary behaviour.

1.6. Neighbourhood built environment and physical activity and sedentary behaviour

The built environment refers to the physical form of communities [97]. This includes how land is used (land-use mix), specific destinations or buildings such as shops, walk-friendly infrastructure (e.g., pavements), aesthetics-related features (e.g., greenery) and transport-related infrastructure (e.g., roads and public transport availability). These urban designs, transportation systems and land-use planning may affect engagement in physical activity and sedentary behaviour in urban, rural, and suburban communities [98, 99].

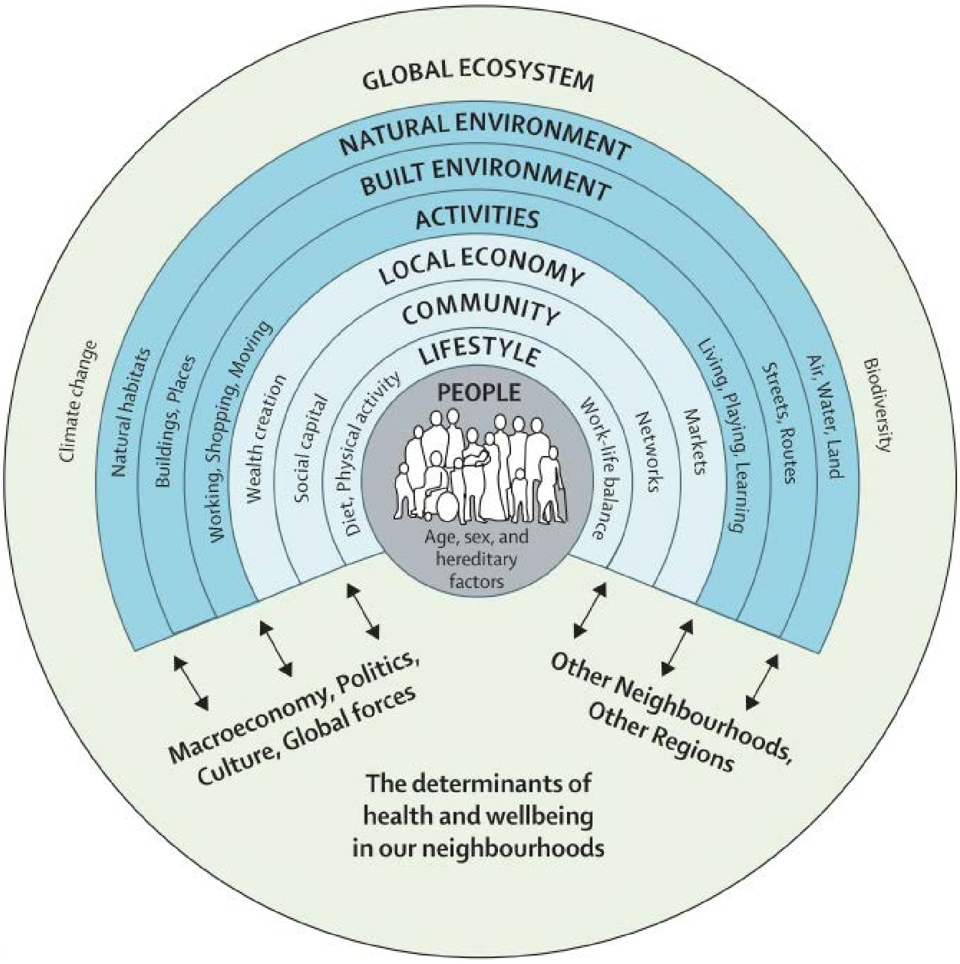

Figure 1. An ecological model of a local human habitat [1]

The most frequently cited definitions of "neighbourhood" in the literature are 15-20 minutes' walk from home and a 400-500 metre buffer around one's home [100-102]. One's neighbourhood may play a particularly crucial role in older adults' active living as neighbourhood walking is the most prevalent form of physical activity in this population [103-105]; partially attributable to most older adults being retired and likely to spend more time in their community. Indeed, evidence suggests that neighbourhood-level built and social environmental factors are related to active living in older adults [101, 106, 107], although this line of research is limited in comparison to studies on youth [108] and adults [109]. In comparison to younger generations, older adults possess unique physiological and psychosocial barriers/characteristics that may impact on their physical activity and sedentary behaviour and its association with neighbourhood-level attributes. The detrimental effects of a physically challenging environment (e.g., inclines, uneven surfaces) can be exacerbated by older adults' diminished physical capacity [110], which may yield to increased fear of venturing outside the home [111]. Such unwillingness to walk in the neighbourhood due to environmental barriers has been linked to increased mobility disability [112] which, if it means older adults leave the house less frequently, may increase depressive symptoms and functional impairment [113, 114], while simultaneously decreasing daily physical activity [115, 116] and independent living [117].

The neighbourhood built environment likely plays an important role in facilitating Chinese older adults' physical activity and sedentary behaviours. Understanding the association between specific built environmental attributes (i.e., correlates) and these behaviours may provide important information for public health strategists wanting to increase physical activity and reduce sedentary behaviour in this demographic.

1.7. Thesis structure

This thesis comprises seven chapters. Following the current introductory chapter *(Chapter 1), Chapter 2* reviews the current evidence concerning older adults' physical activity and sedentary behaviour measurement and then the built environmental correlates of these behaviours. The information of *Chapters 1 and 2* provide the background and rationale for the underpinning research questions of this thesis.

Chapter 3 describes the general methodology of an epidemiological study conducted in Hong Kong. This section includes information on participant and neighbourhood recruitment strategies, physical activity, sedentary behaviour and environmental attribute measures, data collection procedures, data management, and accelerometer data reduction. Methodological procedures specific to a validation study conducted in Melbourne, Australia, and the individual studies based on data collected in Hong Kong are detailed in their respective chapters *(Chapters 4, 5, and 6).*

Chapter 4 provides the methods and results of a methodological investigation concerned with developing an accelerometer cut-point for Chinese older adults' moderate-intensity physical activity.

Chapters 5 and 6 present the results of an epidemiological study into identifying built environmental correlates of older adults' accelerometer-assessed total physical activity and sedentary time.

Finally, *Chapter 7* provides a summary and discussion of this thesis' findings and overall emerging themes. Moreover, potential implications of this work on the research field and future research directions are discussed.

1.8. Thesis aim and objectives

The overarching aim of this thesis is to contribute to the understanding of how the built environment influences Chinese older adults' physical activity and sedentary behaviour. To achieve this, the first objective was to review the literature pertaining to physical activity and sedentary behaviour measurement and the built environmental correlates of these behaviours *(Chapter 2)*. The remaining objectives, underpinned by the information provided in *Chapters 1 and 2*, were to:

1) Develop a moderate- to vigorous-intensity physical activity accelerometer cut-point specific to Chinese older adults;
2) Examine associations of neighbourhood attributes with accelerometer-assessed moderate- to vigorous-intensity physical activity (using the new *vs.* Freedson et al.'s cut-point [2]) and sedentary time and their socio-demographic/health moderators; and
3) Investigate whether moderate- to vigorous-intensity physical activity mediates associations between sedentary time and neighbourhood attributes.

Chapter 2

Literature review

This chapter details information about physical activity and sedentary behaviour measurement in older adults and its relevance in defining associations with the built environment. The chapter then reviews the current literature related to the built environmental correlates of physical activity and sedentary behaviour in older adults.

2.1. Measurement methods of older adults' physical activity and sedentary behaviour: the evidence

Appropriate measurement tools are required to accurately assess time spent in physical activity and sedentary behaviours, that is, to determine energy expenditure and whether or not older adults meet physical activity guidelines. Older adults' physical activity levels can be assessed using both subjective (e.g., self-report questionnaires) and objective measures (e.g., accelerometry) – each approach having their respective advantages and disadvantages. Accordingly, research questions should underpin the selection of which measure to use. The following sections will discuss both self-report and objective measurement methods of physical activity and sedentary behaviour because part of this thesis is concerned with the validity of physical activity measurement in the older adult demographic.

2.1.1 Self-reported physical activity and sedentary behaviour in older adults

Self-report physical activity and sedentary behaviour measures are tools that require the respondent to report information on their overall dose, domain and/or setting. Self-report questionnaires assessing these behaviours have been the main source of information in older adult-based research, with a greater body of evidence examining physical activity than sedentary behaviours [80, 118-120]. However, given older adults spend the majority of their day sedentary [80, 121-123], it is important to accurately assess this behaviour to gain a better understanding of how it may affect healthy ageing. To date, thirty six different questionnaires have been used to try to validly assess these behaviours in older adults (Appendix 1).

2.1.1.1 Validity of self-report measurement methods of physical activity and sedentary behaviour in older adults

Twenty four identified articles validated questionnaires with physical activity outcomes against a given criterion [124-147], three articles examining sedentary behaviour outcomes [148-150], and nine articles assessed both behaviours as outcomes [151-159] (Appendices 2 and 3). The most frequently used questionnaire validating time spent in physical activity and sedentary behaviours was the International Physical Activity Questionnaire (IPAQ) (all versions; physical activity outcomes: total physical activity minutes [151, 153] and moderate-intensity physical activity minutes [154, 155]) (4 articles). The most popular criterion measure was accelerometry for physical activity (22 articles) [127, 128, 130, 135, 137-145, 149, 151, 152, 154-159], and sedentary time (9 articles) [148, 150-152, 154-157, 159]. For both behaviours, the ActiGraph accelerometer (all versions) was the most implemented for physical activity outcomes (12 articles [127, 137, 139, 142-144, 151, 154-157, 160]; ActiGraph-related physical activity outcomes: total physical activity minutes [156, 158], total counts per day [142, 143, 157], mean counts per minute [127, 137, 139, 142, 143, 154, 155], moderate-intensity physical activity minutes [144, 151, 154, 155, 157], and moderate- to vigorous-intensity physical activity minutes [139, 142, 143, 151, 156]); and sedentary time outcomes (6 articles [148, 150, 151, 154-157]; ActiGraph-related sedentary behaviour outcomes: total sedentary time minutes [148, 150, 151, 154, 156, 157], and mean counts per minute [155]). Other criterion measures were used in five studies or less (e.g., doubly-labelled water method [125, 132, 141]).

Twenty eight of thirty questionnaires were associated with validity results that had a wide range and were moderate at best, regardless of the criterion measure used (.07-.75) [125, 127, 135, 137, 139, 141, 143, 144, 150, 153, 155, 157, 158] (Appendix 2). This highlights the difficulty in accurately assessing energy expenditure (e.g., [125, 134, 141, 145, 147, 149, 152, 159]) and time spent in these specific/intensity of behaviours (e.g., moderate-intensity physical activity [125, 128, 144, 149, 153-155]; moderate- to vigorous-intensity physical activity [126, 134, 142, 143, 156]; total walking [129, 139, 142, 155]; and total physical activity [125, 135, 142, 143, 149, 151-153, 155]) when using self-reported tools in this population. When doubly-labelled water method, the gold standard in estimating energy expenditure [161, 162], was the criterion, directly comparable outcomes (i.e., total daily energy expenditure or energy expenditure of daily physical activity) from five questionnaires were found to have moderate-at-best validty estimates ranging from .32 to .46 [125, 141]. Two questionnaires produced moderate to high validity estimates of .68 [132] and .83 [145]. The Schuit et al. study results may be interpreted with caution because of a small sample size (n=21) [132]. The Yamada et al. questionnaire, Simplified Physical Activity Record, has seldom been used in older adult-based research, including validation research, and thus limits comparability across studies [145]. Regarding sedentary behaviour, one study reported high correlations between a questionnaire (television hr·week^{-1}) and accelerometry as the criterion (≥.78) (Appendix 3) [159]. The Matton et al. [159] study result associated with the Flemish Physical Activity Computerized Questionnaire should be interpreted with caution. Specifically, the outcome reported was time spent in moderate- to vigorous-intensity physical activity and the RT3 accelerometer has previously been shown to underestimate time spent in moderate- to vigorous-intensity physical activity and thus overestimate less intense behaviours, including sedentary ones [163]. Moreover, time spent viewing television was the only behaviour assessed and does not assess all behaviours which may affect total energy expenditure and sitting time estimates (e.g., sitting for meals) [164]. The remaining eleven questionnaires produced estimates that had a wide range and were moderate at best against a variety of criterions (.06-.67) [148-158, 165]. Collectively, these data tell us that the majority of questionnaires are inadequate in assessing energy expenditure associated with older adults' physical activity and sedentary behaviours.

2.1.1.2 Advantages of self-report measures of older adults' physical activity and sedentary behaviour

Questionnaires are cheap and easy to administer in large-scale epidemiological studies [166, 167] and can provide potentially important information concerning behaviour domains, contexts and settings. Contextual physical activity and sedentary behaviour data (i.e., *where* the behaviour occurs), for example, are particularly important to identify modifiable environmental correlates (e.g., within neighbourhood *vs.* outside of neighbourhood [168]). Understanding the *domain* (e.g., leisure or transportation) in which physical activity [169] and sedentary behaviour [170] takes place may also be important as environmental correlates may differ by domain and how they relate to specific health outcomes [171]. For example, leisure physical activity was more strongly associated with mental health than active transport [172]. Better understanding the complexity of physical activity and sedentary behaviours (i.e., the context and domains of behaviour) may allow for more efficient public health strategies targeting these behaviours.

2.1.1.3 Disadvantages of self-report measures of older adults' physical activity and sedentary behaviour

Self-reported tools are more prone to recall and social desirability bias [173], and influenced by mood, depression, anxiety, cognition, and disability [174]. It may also be that older adults face unique challenges in precisely answering self-report questions because their interpretation of intensity of activity (e.g., "moderate") depends on their tolerance and fitness levels, which are affected by age, health status, and level of physical function [175]. Impaired cognition, memory difficulties [175] and/or questionnaire phrasing/timeframes (e.g., 'usual week' *vs.* 'previous week') may also detrimentally influence the accurate recall of intensity and other dimensions such as time spent in different intensities of behaviour [139, 176]. Particularly when assessing sedentary behaviours, given their low intensity, ubiquitous, prolonged, and often incidental nature, these behaviours are better assessed from a short, recent timeframe [176, 177]. Less predictable behaviour patterns of older adults against young adults' due to a lack of occupational routine may also compound difficulties in assessing these behaviours [178, 179]. Any of these issues may induce measurement error and, therefore, yield erroneous dose-response relationship between physical activity and sedentary behaviour and health outcomes [180, 181] and/or help explain why most questionnaires have not conferred any high validity estimates versus a criterion (e.g., physical activity outcomes: total physical activity [127, 137, 139, 142, 143, 154-158], time spent in moderate-intensity physical activity [144, 151, 154], and moderate- to vigorous-intensity physical activity [142, 151, 156]).

These limitations of self-report measures of behaviour may have biased the findings of studies on correlates of physical activity and sedentary behaviour based on these measures. Hence a need to collect objective data on these behaviours in older adults to compensate for the lower level of validity of the self-report alternatives.

2.1.2 Objective assessment of older adults' physical activity and sedentary behaviour

Objective measures of physical activity and sedentary behaviours include instruments, tools and procedures that do not rely on self-reports and provide estimates of time spent in different intensities of behaviour, energy expenditure, posture, type of behaviour a person engages in or ambulatory activities. While objective measures do not rely on self-report, there is a subjective element in data analysis and interpretation (i.e., researcher-chosen epochs, cut-point equations to estimate the intensity of activity). Although researchers have also used other objective measures of physical activity and sedentary behaviour, namely: direct observation, heart rate monitoring, indirect calorimetry, inclinometers, and pedometry, this section will focus on accelerometry, the most commonly used objective measure.

2.1.2.1 Accelerometry and older adults' physical activity and sedentary time

Accelerometers have gained acceptance as the most effective way to quantify the dose of ambulatory-based physical activities in populations of all ages [182, 183]; with the ActiGraph accelerometer being the most widely-used in physical activity research [182, 184] (Tables 1 and 2). Accelerometer technology started with older generation devices using a horizontal, weighted cantilevered beam that flexed and compressed a piezoelectric crystal when subjected to a vertical acceleration. A resultant voltage was consequently generated proportional to the acceleration made [185, 186]. Newer devices use inbuilt chip sensors that have a seismic mass sitting directly over a piezoelectric element [185, 186]. Raw acceleration signals are then converted to analogue/digital, filtered, rectified and summarised (typically as 'accelerometer counts') into researcher-specified epochs [185, 187]. While interest in pattern recognition is emerging [188], delineating accelerometer counts using regression cut-points remains, arguably, the most meaningful method to interpret accelerometer data [187, 189, 190]. For example, the Freedson et al. cut-point classifies at least moderate-intensity physical activity as any activity generating ≥1952 accelerometer counts·min^{-1} from an ActiGraph accelerometer worn on the hip [2].

Accelerometers also require minimal input from the participant, but for the standardising of device placement (usually the mid-axillary line about the right hip in physical activity-based research) [184, 187, 191]. While some recent physical activity studies (e.g., National Health and Nutrition Examination Survey [192]) have opted for wrist-worn accelerometry to increase compliance, it is unclear whether this approach produces data as accurate as that recorded about the hip [193, 194]. In sedentary behaviour-based research, a recent systematic review has reported that accelerometer placement on the thigh is most appropriate; albeit the hip is preferable when researchers intend to report both physical activity *and* sedentary behaviour data collected from same epoch [195-197].

2.1.2.2 Validity of accelerometry measures of older adults' physical activity and sedentary time

Ten identified articles [141, 163, 198-204] have investigated the validity of accelerometer-based estimates of older adults' physical activity against a reference standard, and ten other studies with sedentary time as the outcome [196, 205-212] (Tables 2 and 3). The majority of studies investigated older adults specifically (i.e., mean age ≥65 years old) and both sexes [141, 163, 196, 198-205, 209, 210, 212-214]. Six studies implemented direct observation [196, 199, 200, 203, 204, 208] and six used indirect calorimetry [163, 201, 202, 207, 212, 214] as the criterion, three studies with the *activ*PAL™ inclinometer [205, 210, 211], two studies using log books [206, 209], and one study each for the other two criteria [141, 198].

For both physical activity- [141, 203, 204] and sedentary time-based validation studies [196, 205, 207-211], the most commonly evaluated accelerometer was the ActiGraph (all versions; 11 articles), followed by the Caltrac (three studies) [163, 201, 202]. The most valid accelerometer in assessing total energy expenditure in older adults was the ActiGraph [GT1M] conferring a validity correlation estimate of .60 against doubly-labelled water [141] (Table 3). The ActiGraph [GT3X+] also performed well against direct observation in classifying time spent in sedentary behaviours [196]. The lowest validity estimate of total energy expenditure between an accelerometer (Caltrac) and doubly-labelled water method as the criterion was .37 (n=17 participants) [202]. These data tell us that accelerometers, generally, assess older adults' time spent in different intensities of behaviour and energy expenditure more accurately than self-report measures. Moreover, the most widely-used accelerometer in physical activity and sedentary behaviour research, the ActiGraph, was the most valid accelerometer in assessing energy expenditure and performed well against direct observation in classifying time spent in sedentary behaviour. However, the correlation in terms of energy expenditure was moderate, and this may be partly explained by accelerometer-related methodological issues associated with classifying different intensities of older adults' physical activity and thus its associated energy expenditure – discussed below (section 2.1.2.4).

2.1.2.3 Advantages of accelerometry measures of older adults' physical activity and sedentary time

Accelerometers overcome recall and social desirability bias associated with self-report measures along with potential cognitive issues that have been highlighted in older adult populations [215]. Indeed, accelerometer data have been shown to be more strongly associated with energy expenditure [141] (aforementioned) but also behavioural correlates (e.g., age and sex) [216] than self-reported data and more valid upon the assessment of volume, intensity and total time spent in ambulatory movement [80, 141, 175, 180, 187, 217, 218]. The accurate measurement of ambulatory movement is particularly important because walking is the most common physical activity amongst older adults [80, 104, 105] and it accounts for the largest portion of daily energy expenditure [219]. Moreover, while accelerometers are not as valid as inclinometers for assessing sitting and standing behaviour, they are the most appropriate measurement tool to investigate both the intensity of physical activity and time spent in sedentary behaviour using the same device (specifically the ActiGraph accelerometer) [197]. Therefore, accelerometry may provide a valid alternative to self-report methods for assessing older adults' physical activity dose and sedentary time, but not behaviour.

2.1.2.4 Disadvantages of accelerometry measures of older adults' physical activity and sedentary time

While the evidence thus far suggests that accelerometry is a more valid means of assessing levels of older adults' physical activity and sedentary behaviour than self-report measures, they cannot offer potentially important information on the context and type of these behaviours [148, 220]. This kind of information may be necessary for the identification of intervention targets and public health messages [221]. Also, aforementioned, accelerometers are less valid tools for objectively assessing sitting and standing behaviour than inclinometers [197] – albeit no validation studies using inclinometers have been conducted in older adults. Therefore, depending on research aims, adopting a mixed-methods approach may help offer a clearer picture of older adults' physical activity and sedentary behaviours and their associated health outcomes.

Table 1. List of commonly-used accelerometers in older adults' physical activity and sedentary behaviour studies

Accelerometer name	Manufacturer	Size and weight	Type	Placement	Epoch length/ sampling frequency	Memory (using 1 min epoch)	Measurements
Actical	Mini-Mitter, Sunriver, OR, USA	2.8 x 2.7 x 1.0 cm 17.5 g	Uniaxial; omni-directional	Wrist, ankle, hip	15 sec to 1 min	45 days	Activity counts, step counts, EE
ActiGraph 7164 (formerly CSA, MTI)	ActiGraph LLC, Pensacola, FL, USA	5.1 x 4.1 x 1.5 cm 45.5 g	Uniaxial	Hip, ankle/wrist	5 sec to 1 min	22 days	Activity counts, EE
ActiGraph GT1M	ActiGraph LLC, Pensacola, FL, USA	3.8 x 3.7 x 1.8 cm 27 g	Biaxial	Hip, waist	1 sec to several min	378 days	Activity counts, step counts, EE
ActiGraph GT3X	ActiGraph LLC, Pensacola, FL, USA	3.8 x 3.7 x 1.8 cm 27 g	Triaxial	Hip, waist, thigh, ankle, wrist	1/30 sec to 4 min	365 days	Activity counts for each plane, EE
ActiGraph GT3X+	ActiGraph LLC, Pensacola, FL, USA	3.8 x 3.7 x 1.8 cm 27 g	Triaxial	Hip, waist, thigh, ankle, wrist	30-100 Hz	42.50 days (30 Hz) 12.50 days (100 Hz)	Activity counts for each plane, EE, ambient light
Caltrac	Hemokinetics Inc., Madison, WI, USA	- 78 g	Uniaxial	Hip, waist	1 min	41 days	Activity counts
Dynaport	McRoberts Inc., The Netherlands	6.4 x 6.2 x 1.3 cm 78 g	Triaxial	Hip, waist	100 Hz	7 days	Activity min
GENEActiv	Activinsights Ltd., Kimbolton, UK	4.3 x 4.0 x 1.3 cm 16 g	Triaxial	Thigh	10-500 Hz	0.5Gb	Activity min
IDEEA	Minisun, Fresno, CA, USA	Each sensor 0.1 x 0.1 x 0.04 cm 200 g	Triaxial	5 sensors; 2 at upper legs, 2 on feet, 1 on sternum	-	7 days	Kcal
Lifecorder	Suzuken Co. Ltd., Nagoya, Japan	0.6 x 0.4 x 0.2 cm 42 g	Uniaxial	Waist	4 sec	-	Kcal
MotionWatch8	CamNtech, Cambridge, UK	3.6 x 2.8 x 9.4 cm 9.1 g	Triaxial	Wrist	3-11 Hz or 1, 2, 5, 15, 30, 60 sec	120 days	Activity counts, activity min
RT3-Triaxial Research Tracker (formerly R3D)	StayHealthy Inc., Monrovia, CA, USA	7.1 x 5.6 x 2.8 cm 65.2 g	Triaxial	Hip, waist	1 sec to 1 min	7 days	Activity counts for each plane, EE
Tritrac	Reining Ltd., Madison, WI, USA	1.2 x 0.6 x 0.2 cm 35 g	Triaxial	Waist	1 min	45 days	Kcal

Table 2. Characteristics of studies assessing the validity of accelerometer-based measures of older adults' physical activity and sedentary time

Accelerometer name	Reference (first author, year)	Sample characteristics					Primary outcome (interpretability)
		Country	Sample size	Age (years)	Sex	Other demographics	
Physical activity							
ActiGraph 7164	Storti, 2008 [204]	USA	34	≥65	M & F	Caucasian, able to walk without assistance	Steps
ActiGraph GT1M	Colbert, 2011 [141]	USA	56	≥65	M & F	Able to walk unassisted, predominantly Caucasian	$Kcal \cdot d^{-1}$
ActiGraph GT3X	Webber, 2014 [203]	Canada	35 [non-walking aid users, n=22; walking aid users, n=13)	≥65	M & F	Convenience sample of community-dwelling older adults living in an apartment complex, could walk 100 m without a person's assistance, predominantly Caucasian	Steps
Caltrac	Choquette, 2009 [202]	Canada	17	60-78	M & F	Of good health but sedentary (i.e., no regular participation in structured exercise and no more than two weekly sessions of light activities, such as walking), predominantly Caucasian [1]	$Kcal \cdot d^{-1}$
Caltrac	Fehling, 1999 [163]	USA	86	71 ± 4	M & F	Healthy older adults, predominantly Caucasian	Activity counts
Caltrac	Leaf, 1995 [201]	USA	20	65-78	M & F	Community-dwelling, sedentary, predominantly Caucasian	EE
DynaPort	Taylor, 2014 [200]	New Zealand	22	≥80	M & F	Either living independently or as part of long-term within a retirement village, able to walk independently with or without a walking aid, predominantly Caucasian	$Activity \cdot min^{-1}$
IDEEA	Marsh, 2007 [199]	USA	29	70-85	M & F	Living independently but at risk of mobility disability, predominantly Caucasian	Steps
Tritrac	Kochersberger, 1996 [198]	USA	80 (sample 1 = 30; sample 2 = 40; sample 3 = 10)	71-77	M & F	Sample 1 = nursing home residents; sample 2 = frail community-dwellers participating in a nonaerobic strengthening exercise program; sample 3 = active community-dwellers participating in an aerobic exercise program, predominantly Caucasian	Activity $units \cdot min^{1}$ (vector $magnitude \cdot min^{-1}$)
Tritrac	Fehling, 1999 [163]	USA	86	71 ± 4	M & F	Healthy older adults, predominantly Caucasian	Activity counts
Sedentary time							
Actical	Hutto, 2013 [206]	USA	200	63.5 ± 8.3	M & F	Healthy older adults, community-dwelling, predominantly Caucasian	Sedentary $time \cdot min^{-1}$
ActiGraph GT3X	Bai, 2016 [207]	USA	194	75.4 ± 7.7	F	Healthy older adults, community-dwelling, predominantly Caucasian	EE

	Evenson, 2015 [208]	USA	200	75.5 ± 7.7	F	Healthy older adults, community-dwelling, predominantly Caucasian	Sedentary time·min^{-1}
ActiGraph GT3X+	Aquilar-Farias, 2014 [205]	Australia	37	73.5 ± 7.3	M & F	Convenience sample, healthy older adults, community-dwelling, predominantly	Sedentary time·min^{-1}
	Chudyk, 2017 [209]	USA	62	78.4 ± 5.7	M & F	Low income, healthy older adults, community-dwelling, predominantly Caucasian	Sedentary time·min^{-1}
	Koster, 2016 [210]	USA	62	78.4 ± 5.7	M & F	Low income, healthy older adults, community-dwelling, predominantly Caucasian	Sedentary time·min^{-1}
	Rosenberg, 2017 [211]	USA	39	69.4	F	Convenience sample, healthy older adults, community-dwelling, predominantly Caucasian	Sedentary time·min^{-1}
	Sasaki, 2016 [196]	USA	35	70.8 ± 4.9	M & F	Convenience sample, healthy older adults, community-dwelling, predominantly Caucasian	Sedentary time·min^{-1}
GENEActiv	Wullems, 2017 [212]	UK	40	73.5 ± 6.3	M & F	Convenience sample, healthy older adults, community-dwelling, predominantly Caucasian	EE
MotionWatch8	Landry, 2015 [214]	Canada	23	70.0 ± 6.6	M & F	Convenience sample, healthy older adults, community-dwelling, predominantly Caucasian	EE

Notes: M: Male; F: Female; d: day; EE: energy expenditure; kcal: kilocalorie

Table 3: Validity estimates of accelerometer-based measures of older adults' physical activity and sedentary time

Accelerometer name	Reference (first author, year)	Criterion/ comparison method	Accelerometry criterion/ comparison intensity threshold	Validation duration/ protocol	Validity variables tested	Validity results	
						Correlation coefficient/s & agreement (if given) [a]	*p*-value [b]
Physical activity							
ActiGraph 7164	Storti, 2008 [204]	DO	N/A	-	Total sample steps (Acc) – steps (DO)	LoA = -7.1%	-
					Slow gait steps (Acc) – steps (DO)	LoA = -19.1%	-
					Middle-speed gait steps (Acc) – steps (DO)	LoA = -5.7%	-
					Fast gait steps (Acc) – steps (DO)	LoA = -0.7%	-
ActiGraph GT1M	Colbert, 2011 [141]	DLW	N/A	10 days	Kcal·d^{-1} (Acc: Crouter) – PAEE (DLW)	.60	.01
					Kcal·d^{-1} (Acc: Freedson) – PAEE (DLW)	.49	.01
					Activity CPM (Acc) – PAEE (DLW)	.56	.01
					Steps·d^{-1} (Acc) – PAEE (DLW)	.59	.01
ActiGraph GT3X	Webber, 2014 [203]	DO	N/A	100 m walk	Steps (Acc) – steps (DO)	Absolute error: left hip = 23.2% (mean), 8.6% (median)	-
						right hip = 23.1% (mean), 7.2% (median)	-
Caltrac	Choquette, 2009 [202]	InD	N/A	7 days	PAEE (Acc) – TEE (InD)	.37	Ø
					PAEE (Acc) – RMR (InD)	.51	.05
					PAEE (Acc) – PAEE (InD)	.30	Ø
Caltrac	Fehling, 1999 [163]	InD	N/A	Treadmill walking; stepping exercise	EE (Acc) – EE (InD)	Treadmill: LoA = +10-53%	.05
						Stepping: LoA = -19-28%	.05
Caltrac	Leaf, 1995 [201]	InD	N/A	Treadmill protocol	EE (Acc) – EE (InD)	.32	Ø
Dynaport	Taylor, 2014 [200]	DO (video)	-	Scripted and	Sitting (Acc) – sitting (DO)	85.2% (78.7-91.5)	-
					Standing (Acc) – standing (DO)	56.1% (34.8-81.2)	-
						89.9% (80.8-94.7)	

				unscripted activities	Locomotion (Acc) – locomotion (DO) Lying (Acc) – lying (DO)	98.0% (73.8-100) (overall agreement)	- -
IDEEA	Marsh, 2007 [199]	DO	N/A	-	Steps (Acc) -- steps (DO)	LoA = -2.6%	-
Tritrac	Fehling, 1999 [163]	InD	N/A	Treadmill walking; stepping exercise	EE (Acc) – EE (InD)	Treadmill: LoA = -12-37% Stepping: LoA = -58-60%	.05 .05
Tritrac	Kochersberger, 1996 [198]	N/A	ActiGraph 7164	3-7 days	Activity units·min^{-1} (Acc: Tritrac) – activity units·min^{-1} (Acc: ActiGraph)	.77	<.001
Sedentary time							
Actical	Hutto, 2013 [206]	Paper log/diary	N/A	7 days	Sedentary time·min^{-1} (Acc) – sedentary time·min^{-1} (log)	60-min: 618 ± 81 90-min: 649 ± 88 120-min: 667 ± 97 150-min: 675 ± 98 180-min: 679 ± 101	-
ActiGraph GT3X	Bai, 2016 [207]	InD	N/A	7 min per activity	Activity counts, vertical axis (Acc) – EE (InD)	Normal filter: AUC: 0.86 Low frequency filter: AUC: 0.91	-
	Evenson, 2015 [208]	DO	N/A	7 min per activity	Activity counts, vertical axis (Acc) – sedentary time·min^{-1} (DO)	Normal filter: AUC: 0.73 Sensitivity: 91% Specificity: 62% Low frequency filter: AUC: 0.79 Sensitivity: 79% Specificity: 81%	-
ActiGraph GT3X+	Aguilar-Farias, 2014 [205]	*activ*PAL™ inclinometer	N/A	7 days	Sedentary time·min^{-1} (Acc) – sedentary time·min^{-1} (*activ*PAL™)	Vertical axis: <1 count·s^{-1}: AUC: 0.67 Sensitivity: 92% Specificity: 43% Correctly classified: 74% <10 counts·s^{-1}: AUC: 0.70	-

						Sensitivity: 84% Specificity: 65% Correclty classified: 79% <25 counts·min^{-1}: AUC: 0.79 Sensitivity: 83% Specificity: 75% Correclty classified: 80%	
	Chudyk 2017 [209]	Paper log/diary	N/A	7 days	Sedentary time·min^{-1} (Acc) – sedentary time·min^{-1} (log)	-4.4-37.5 min (mean difference across different processing options)	-
	Koster, 2016 [210]	*activ*PAL™ inclinometer	N/A	7 days	Sedentary time·min^{-1} (Acc) – sedentary time·min^{-1} (*activ*PAL™)	Vertical axis counts, <100 CPM (60-s epoch): Sensitivity: 94% Specificity: 58% (mean difference: -114.3 min·d^{-1}) Vertical axis counts, <22 CPM (60-s epoch): AUC: 0.85 Sensitivity: 85% Specificity: 74% (mean difference: 2.5 min·d^{-1})	-
	Rosenberg, 2017 [211]	*activ*PAL™ inclinometer	N/A	7 days	Sedentary time·min^{-1} (Acc) – sedentary time·min^{-1} (*activ*PAL™)	Sitting: Sensitivity: 89% Specificity: 91%	-
	Sasaki, 2016 [196]	DO	N/A	30 sec – 5 min	Sedentary time·min^{-1} (Acc) – sedentary time·min^{-1} (DO)	Correctly classified: Lab-based: Hip: 92% Wrist: 97% Ankle: 92% Free-living:	-

						Hip: 82% Wrist: 75% Ankle: 87%	
GENEActiv	Wullems, 2017 [212]	InD	N/A	4 min per activity	Sedentary time·min^{-1} (Acc) – EE (InD)	Cut-point algorithms: Sensitivity: 99.3-99.9% Specificity: 99.7% Accuracy: 99.5-99.8% Random Forest machine learning: Sensitivity: 99.9% Specificity: 99.2% Accuracy: 99.6%	-
MotionWatch8	Landry, 2015 [214]	InD	N/A	5 min per activity	Sedentary time·min^{-1} (Acc) – EE (InD)	AUC: 0.81 Sensitivity: 78% Specificity: 70% Accuracy: 70%	-

Notes: See Table 1 for accelerometer characteristics. [a] Limits of agreement (LoA), *r* and *rho* are sometimes given with 95% confidence intervals (lower, upper); [b] < unless otherwise stated; LoA; EE: energy expenditure. DO: direct observation; Acc: accelerometer; LoA: Limits of agreement; kcal: kilocalories; d: day; PAEE: physical activity energy expenditure; CPM: counts·min^{-1}; DLW: doubly-labelled water: InD: indirect calorimetry; TEE: total energy expenditure; Ø: not statistically significant; RMR: resting metabolic rate

Accelerometry may also be associated with population-specific (i.e., ethnicity and age) methodological issues that need consideration to more accurately quantify these behaviours. Ethnicity befits a specific physiology profile that may differ (e.g., Caucasian *vs.* Asian) and, for example, impact on resting metabolic rate (RMR) [222-224]. Table 2 shows that there is currently no accelerometer validation research on older Asian (Chinese) adults and a study population bias toward older Caucasians [141, 163, 198-204]. Ageing is another factor that impacts on physiology, RMR and gait patterns [225-229]. Yet most accelerometer cut-points used in older adult physical activity research have been developed in younger adults with a different RMR [118]. This includes the most commonly-used Freedson et al. moderate-intensity physical activity cut-point [2, 118], which has been arbitrarily applied to older adults aged, for example, ≥70 years [80] despite being developed in 23-25-year-olds. This brings into question the validity of classifying the intensity of older adults' physical activity using such cut-points. Thus, research needs to address ethnicity- and age-related issues that may help elucidate a more valid assessment of Chinese older adults' physical activity and sedentary time and, subsequently, appropriate physical activity guidelines. Moreover, it would ensure that the defined relationships between exposures (e.g., built environmental attributes) and outcomes (e.g., accelerometer-assessed moderate-intensity physical activity) were valid [230].

2.2 Built environmental correlates of older adults' physical activity: the evidence

As part of the PhD program of research, the candidate has recently published a systematic review and meta-analysis of 1553 individual findings from 100 articles investigating built environmental correlates of older adults' physical activity (full manuscript: Appendix 4) [101] and its supplementary material (Appendices 5 and 6). While the methodology used in the systematic review and meta-analysis is described in detail in the published article [101], a brief account of the procedure to derive the findings reported in this section is given here.

2.2.1 Selection criteria

Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines were followed for the literature search of potential articles from 1st January 2000 to 3rd September 2016 [231]. Search terms accounted for grey literature, experimental research, a greater variety of built environmental attributes, and older adults' physical activity specifically. Article eligibility was independently screened by three reviewers based on the following inclusion criteria: (1) article published in English; (2) a quantitative study; (3) a cross-sectional, longitudinal, or quasi-experimental study design; (4) a sample with a mean age of ≥65 years; (5) investigated the association between any objective or perceived attribute of the built environment and objectively measured or self-reported physical activity and/or walking that was not specific to a single physical activity domain; (6) did not exclusively focus on clinical populations (e.g., overweight, disabled, or institutionalised participants); and (7) did not investigate associations between physical activity and the built environment with an ill-defined aggregated environmental measure that, for example, combined weakly correlated attributes such as access to/availability of recreational facilities and traffic/pedestrian safety.

2.2.2 Data extraction

Two reviewers independently extracted the following data from included articles: study name (if any), first author and publication year, participant information – sample size, study setting (e.g., urban or rural), mean age, percentage of females, study response rate, community dwellers or not, geographical location; study design – sampling method for clusters (areas or neighbourhoods) and individuals, stratification of recruitment site by environmental attribute/s (if any), neighbourhood definition (if any); list of covariates (if any); physical activity outcome information – type of measurement (objective or self-reported), instrument or device used and whether or not it was validated, how outcome measures were operationalised (e.g., continuously or categorically); environmental exposure information – type of measurement (objective or perceived), name of measure, environmental attributes as named in study and category of environmental attribute according to the classification used in the review; moderator information (if any); analytical approach information; findings; and additional comments important for the assessment or interpretation of the study (if any).

2.2.3 Data synthesis

Some of these data were then used to score article quality, the basis of the meta-analytical procedure, and weighted positive, nil, and negative findings accordingly. Any neighbourhood buffer size and/or moderator effects were also integrated into the meta-analysis and weighted findings. Each separate positive, negative, and nil association between a built environmental attribute and total physical activity was tallied and then stratified by physical activity measurement type (objective or perceived) for aforementioned reasons and by environmental attribute measurement type because differences in environment-physical activity associations have previously been reported when using different measurement types [232, 233]. A z-value was then assigned to each separate built environmental attribute and physical activity finding: 1.96

for a positive; -1.96 for a negative; and 0 for a nil finding [100]. We then calculated a summary two-tailed *p*-value using Rosenthal's approach [234], reporting a summary weighted z-value and it's associated two-tailed probability value as detailed in Cerin et al.'s recent systematic review and meta-analysis of built environmental correlates of active transport [100]. Tables 4 to 6 (below) report the weighted number of positive, negative, and nil associations extracted from the selected articles for each environmental attribute. *P*-values were interpreted as follows: .05 to .01 – evidence of an association; <.01 – strong evidence of an association; and <.001 – very strong evidence of an association [235].

2.2.4 Total physical activity and the built environment

There was very strong evidence that neighbourhood walkability (p <.001), overall access to destinations and services (p <.001) and recreational facilities (p <.001) and crime-related personal safety (p <.001) were positively associated (i.e., more time spent in) with older adults' total physical activity (Table 4). Moreover, there was strong evidence of positive associations between total physical activity and access to both parks/public open space (p =.002) and shops/commercial destinations (p =.006), the presence of greenery and aesthetically pleasing scenery (p =.004) and walk-friendly infrastructure (p =.009). In addition, there was evidence that access to public transport was positively associated with total physical activity (p =.016). No other significant associations were found in relation to built environmental attributes and total physical activity.

2.2.5 Total physical activity by measurement type (objective and self-reported)

Irrespective of the physical activity measurement type used, neighbourhood walkability (both p <.001) and overall access to destinations and services (both p <.01) were positively associated with older adults' total physical activity (Table 5). Seven other positive associations between attributes of the built environment and physical activity were physical activity-measurement dependent. Five positive associations were specific to self-reported total physical activity, namely: greenery and aesthetically pleasing scenery (p =.001), access to shops/commercial destinations (p =.002), parks/public open space (p =.002), recreational facilities (p =.002) and public transport (p =.006). Two positive associations were in relation to objectively assessed total physical activity only, specifically: walk-friendly infrastructure (p =.031) and destination diversity (land-use mix) (p =.019).

Table 4: Associations of environmental attributes/correlates with older adults' total physical activity [101]

Environmental attribute	Total physical activity[1]				
	P	Ø	N	p_a	D_a
Walkability	12.33	6.67	0	**<.001**	**P**
Residential density/urbanisation	11.53	33.50	12.97	.394	Ø
Street connectivity	8.80	26.06	2.14	.094	Ø
Access to/availability of destinations and services					
Overall access to destinations and services	12.55	38.15	0.50	**<.001**	**P**
Land-use mix—destination diversity	5.68	19.32	2	.148	Ø
Shops/commercial	9.96	57.04	0	**.006**	**P**
Food outlets	0.72	21.28	1	.932	Ø
Government/finance services	0.33	11.67	0	.834	Ø
Education	0.31	11.69	0	.765	Ø
Health and aged care	4.61	26.39	1	.275	Ø
Religious	0	8	0	1.00	Ø
Public transport	7.50	25.50	1	**.016**	**P**
Parks/public open space	11.29	47.54	0.17	**.002**	**P**
Recreational facilities	13.34	39.66	0	**<.001**	**P**
Social recreational facilities	4.15	25.95	0	.105	Ø
Other destinations	0	3	0	1.00	Ø
Infrastructure and streetscape					
Overall access to cycle/walk-friendly infrastructure	1	9	0	.612	Ø
Walk-friendly infrastructure	9	21.49	1.51	**.009**	**P**
Cycle-friendly infrastructure	0	5	0	1.00	Ø
No physical barriers (e.g., hills)	5	20.40	2.60	.208	Ø
Pavement/footpath quality	3	6	1	.155	Ø
Street lighting	3	6	0	.059	Ø
Greenery and aesthetically pleasing scenery	13.01	45.49	0.5	**.004**	**P**
Pollution (air)	0	5	0	1.00	Ø
Safety					
Traffic/pedestrian safety	7	47	3	.463	Ø
Crime/personal safety	20.52	50.48	4	**<.001**	**P**

Notes: [1] Objective and self-report total physical activity findings combined. P: positive association; Ø: nil association; N: negative association; *p*: *p*-value; D: direction of association supported by the data; subscript "a:" fully adjusted (for sample size and article quality). In **bold** font: statistically significant evidence of a directional association that has been sufficiently studied (i.e., ≥5 findings reported on specific combinations of environmental exposure and physical activity variables)

2.2.6 Total physical activity by environmental measurement type (objective and perceived)

For nine out of 18 environmental exposures, associations with total physical activity differed by environmental measurement type (Table 6). Perceptions of crime-related personal safety (p <.001), access to/availability of recreational facilities (p <.001), access to/availability of parks/public open space (p =.003), greenery and aesthetically pleasing scenery (p =.003), and destination diversity (land-use mix) (p =.002) were all positively associated with total physical activity, whereas objectively assessed measures of these attributes were not. Objectively assessed access to/availability of shops/commercial destinations (p =.006) and public transport (p =.004), presence of walk-friendly infrastructure (p =.028), and absence of physical environmental barriers (e.g., hills) (p =.048) were all positively associated with total physical activity, whereas associations with these attributes were not significant when using perceived exposure measures.

Table 5: Associations of environmental attributes/correlates with older adults' physical activity by physical activity measurement method (objective and self-report) [101]

Environmental attribute	Total physical activity									
	Objective					Self-report				
	P	Ø	N	p_a	D_a	P	Ø	N	p_a	D_a
Walkability	5.96	2.04	0	**<.001**	**P**	6.37	4.63	0	**<.001**	**P**
Residential density/urbanisation	1	7	0	.377	Ø	10.53	26.50	12.97	.240	Ø
Street connectivity	3	7.86	0.14	.262	Ø	5.71	18.20	2	.215	Ø
Access to/availability of destinations and services										
Overall access to destinations and services	3.89	8.31	0	**.005**	**P**	8.66	29.84	0.50	**.004**	**P**
Land-use mix—destination diversity	3.17	8.83	0	**.019**	**P**	2.51	12.49	2	.884	Ø
Shops/commercial	1.38	26.62	0	.507	Ø	8.58	29.42	0	**.002**	**P**
Food outlets	0	13	0	1.00	Ø	0.72	8.28	1	.884	Ø
Government/finance services	0.34	5.66	0	.377	Ø	0	6	0	1.00	Ø
Education	0.17	6.83	0	.818	Ø	0.14	4.86	0	.845	Ø
Health and aged care	1	18	0	.612	Ø	3.61	8.39	1	.206	Ø
Religious	0	5	0	1.00	Ø	0	3	0	1.00	Ø
Public transport	1	12	0	.520	Ø	6.50	13.50	1	**.006**	**P**
Parks/public open space	1.75	14.25	0	.296	Ø	9.54	33.29	0.17	**.002**	**P**
Recreational facilities	4.29	16.71	0	.056	Ø	9.05	22.95	0	**.002**	**P**
Social recreational facilities	2.65	12.35	0	.118	Ø	1.50	13.50	0	.432	Ø
Infrastructure and streetscape										
Overall access to cycle/walk-friendly infrastructure	1	5	0	.529	Ø	0	4	0	1.00	Ø
Walk-friendly infrastructure	3	3	0	**.031**	**P**	6	18.49	1.51	.059	Ø
No physical barriers (e.g., hills)	3	5	1	.135	Ø	2	15.40	1.60	.631	Ø
Greenery and aesthetically pleasing scenery	1.50	15	0.50	.741	Ø	11.51	30.49	0	**.001**	**P**
Safety										
Traffic/pedestrian safety	2	14	0	.408	Ø	5	33	3	.737	Ø
Crime/personal safety	3	8	0	.063	Ø	17.52	42.48	4	**.001**	**P**

Notes: P: positive association; Ø: nil association; N: negative association; *p*: *p*-value; D: direction of association supported by the data; subscript "a:" fully adjusted (for sample size and article quality). In **bold** font: statistically significant evidence of a directional association that has been sufficiently studied (i.e., ≥5 findings reported on specific combinations of environmental exposure and physical activity variables)

Table 6. Associations of environmental attributes/correlates with older adults' total physical activity by environmental measures (objective and perceived) [101]

Environmental attribute	Total physical activity[1]				
	P	Ø	N	p_a	D_a
Walkability					
Objective	9.05	6.95	0	<.001	P
Perceived	3	0	0	.003	P
Residential density/urbanisation					
Objective	10	18.50	11.50	.388	Ø
Perceived	1.53	15	1.47	.855	Ø
Street connectivity					
Objective	2.80	14.20	1	.366	Ø
Perceived	6	11.86	1.14	.076	Ø
Access to/availability of destinations and services					
Overall access to destinations and services					
Objective	3.76	12.24	0	.003	P
Perceived	8.79	25.91	0.50	.008	P
Land-use mix—destination diversity					

Objective	1.17	10.83	2	**.504**	**Ø**
Perceived	4.51	8.49	0	**.002**	**P**
Shops/commercial					
Objective	8.25	34.75	0	**.006**	**P**
Perceived	1.71	21.29	0	**.475**	**Ø**
Food outlets					
Objective	0.72	14.28	0	.685	Ø
Perceived	0	7	1	.521	Ø
Education					
Objective	0.31	8.69	0	.727	Ø
Perceived	0	3	0	1.00	Ø
Health and aged care					
Objective	4	24	1	.382	Ø
Perceived	0.61	2.39	0	.290	Ø
Public transport					
Objective	6.50	12.50	0	**.004**	**P**
Perceived	1	13	1	**.918**	**Ø**
Parks/public open space					
Objective	4.42	28.58	0	**.083**	**Ø**
Perceived	6.87	18.96	0.17	**.003**	**P**
Recreational facilities					
Objective	4.58	21.42	0	**.092**	**Ø**
Perceived	8.76	18.24	0	**<.001**	**P**
Social recreational facilities					
Objective	3.50	14.50	0	.094	Ø
Perceived	0.65	11.45	0	.687	Ø
Infrastructure and streetscape					
Walk-friendly infrastructure					
Objective	5	9	0	**.028**	**P**
Perceived	4	12.49	1.51	**.137**	**Ø**
No physical barriers (e.g., hills)					
Objective	5	8.40	1.60	**.048**	**P**
Perceived	0	12	1	**.629**	**Ø**
Greenery and aesthetically pleasing scenery					
Objective	3	18	0	**.252**	**Ø**
Perceived	10.01	27.49	0.50	**.003**	**P**
Safety					
Traffic/pedestrian safety					
Objective	1	13	3	.407	Ø
Perceived	6	34	0	.126	Ø
Crime/personal safety					
Objective	4	5.50	2.50	**.510**	**Ø**
Perceived	16.52	44.98	1.50	**<.001**	**P**

Notes: [1] Objective and self-report total physical activity (including total walking) combined. P: positive association; Ø: nil association; N: negative association; *p*: *p*-value; D: direction of association supported by the data; subscript "a:" fully adjusted (for sample size and article quality). In **bold** font: evidence of a difference between environmental measures of an association between a sufficiently studied exposure and physical activity variable (i.e., ≥3 articles' reported findings on specific combinations of environmental exposure and physical activity variables)

2.3 Strengths and limitations of this review and meta-analysis

This systematic review and meta-analysis has several strengths. It addressed publication bias by including both peer-reviewed scientific articles and grey literature. It provided a quantitative synthesis of associations based on non-standardised environmental and physical activity measurement instruments and stratified findings by measurement types. It incorporated an extensive article quality assessment into the meta-analytical procedure and, therefore, adjusted the synthesis of evidence for study methodology quality. Limitations include not accounting for potentially correlated findings from the same article, an inability to account for potential moderating effects of neighbourhood size and definition, and including only articles published in English.

2.4 Built environmental correlates of older adults' sedentary behaviour: the evidence

A review of the literature identified nine articles examining the association between built environmental attributes and sedentary behaviour in older adults. A meta-analysis of these nine articles' findings was not conducted due to the lack of reported findings, particularly on objective physical activity-based research (see Table 8). The table below shows tallied positive, negative, or nil findings only.

2.4.1 Built environmental correlates of older adults' sedentary behaviour

2.4.1.1 Total sedentary behaviour and the built environment

Most individual associations (121/140; 86%) between built environmental attributes and total sedentary behaviour were nil (Table 7). The highest overall amount of findings were reported for greenery and aesthetically pleasing scenery (20 findings) [236-241] and crime/personal safety (14 findings) [236, 237, 239-241], with the remaining articles reporting nine findings or less.

2.4.1.2 Sedentary behaviour by measurement methods (objective and self-report)

Stratifying total sedentary behaviour by measurement methods revealed that only two studies [240, 242] investigated the association between built environmental attributes and accelerometer-assessed sedentary time (Table 8). Thirty-four of 36 individual findings (94%) reported in these articles based on objectively-assessed total sedentary behaviour were nil. Similarly, regarding self-reported total sedentary behaviour, the majority of individual findings were nil (87/104 individual findings; 84%).

2.5 Summary of this literature review and identified gaps

The characterisation of physical activity and sedentary behaviour is a function of the assessment tools that are utilised by researchers. This includes the extent to which individuals meet physical activity recommendations and the defined associations between such

Table 7. Associations of environmental attributes/correlates with older adults' total sedentary behaviour

Environmental attribute	**Total sedentary behaviour**[1]		
	P	Ø	N
Walkability	-	2	-
Residential density/urbanisation	1	6	2
Street connectivity	-	3	-
Access to/availability of destinations and services	-	-	-
Overall access to destinations and services	1	5	-
Land-use mix—destination diversity	-	1	-
Shops/commercial	-	9	-
Food outlets	-	4	-
Government/finance services	-	1	-
Health and aged care	-	3	-
Religious	2	1	-
Public transport	-	3	4
Parks/public open space	-	9	-
Recreational facilities	-	7	1
Social recreational facilities	-	4	-
Infrastructure and streetscape	-	-	-
Overall access to cycle/walk-friendly infrastructure	-	1	-
Walk-friendly infrastructure	-	9	1
Cycle-friendly infrastructure	-	1	-
No physical barriers (e.g., hills)	-	7	-
Pavement/footpath quality	-	3	-
Street lighting	-	3	1
Greenery and aesthetically pleasing scenery	-	18	2
Pollution (air and noise)	1	3	-
Safety	-	-	-
Traffic/pedestrian safety	1	5	1
Crime/personal safety	-	13	1

Notes: [1]All sedentary behaviour outcomes combined. P: positive association; Ø: nil association; N: negative association

behaviours and the built environment. The evidence reviewed thus far *(Chapter 1)* suggests that higher levels of physical activity, particularly moderate-intensity physical activity, and lower levels of sedentary behaviour promote physiological, psychological, and psychosocial health in older adults. However, the questionable metric characteristics of self-reported physical activity and sedentary behaviour measures in this population may infer that findings of previous studies on physical activity and sedentary behaviour correlates, exclusively based on self-report data, were biased due to methodological limitations associated with these outcome measures. While self-reported physical activity and sedentary behaviour assessments offer potentially important information on activity/behaviour type and context/domain, accelerometers can potentially provide more valid data on the dose. Thus, while both types of information are key to the identification and better understanding of correlates of older adults' physical activity and sedentary behaviours, accelerometry more accurately assesses physical activity dose and sedentary time. There remains, however, a gap in knowledge on the extent to which ethnicity and age may impact the classification of older adults' moderate-intensity

Table 8. Associations of environmental attributes/correlates with older adults' total sedentary behaviour by measurement method

Environmental attribute	Total sedentary behaviour[1]					
	Objective			Self-report		
	P	Ø	N	P	Ø	N
Walkability	-	2	-	-	-	-
Residential density/urbanisation	-	2	1	1	4	1
Street connectivity	-	2	-	-	1	-
Access to/availability of destinations and services	-	-	-	-	-	-
Overall access to destinations and services	-	4	-	1	1	-
Land-use mix—destination diversity	-	1	-	-	-	-
Shops/commercial	-	1	-	-	8	-
Food outlets	-	1	-	-	3	-
Government/finance services	-	1	-	-	-	-
Health and aged care	-	-	-	-	3	-
Religious	-	-	-	2	1	-
Public transport	-	1	1	-	2	3
Parks/public open space	-	5	-	-	4	-
Recreational facilities	-	2	-	-	5	1
Social recreational facilities	-	1	-	-	3	-
Infrastructure and streetscape	-	-	-	-	-	-
Overall access to cycle/walk-friendly infrastructure	-	-	-	-	1	-
Walk-friendly infrastructure	-	1	-	-	8	1
Cycle-friendly infrastructure	-		-	-	1	-
No physical barriers (e.g., hills)	-	1	-	-	6	-
Pavement/footpath quality	-	-	-	-	3	-
Street lighting	-	-	-	-	3	1
Greenery and aesthetically pleasing scenery	-	3	-	-	15	2
Pollution (air and noise)	-	-	-	1	3	-
Safety	-	-	-	-	-	-
Traffic/pedestrian safety	-	1	-	1	4	1
Crime/personal safety	-	5	-	-	8	1

Notes: [1]All sedentary behaviour outcomes combined. P: positive association; Ø: nil association; N: negative association

physical activity using accelerometry, although a few methodologically-weak studies have determined specific accelerometer cut-points for older adults [208, 243, 244]. The practice of arbitrarily applying cut-points developed from young adults with a different RMR to older adults likely underestimates time spent in this behaviour. If so, this would mean a lesser perceived achievement of physical activity guidelines and influence defined associations between built environmental attributes (exposure variables) and physical activity of that intensity. Data resulting from such an investigation may help to underpin future accelerometer-based research in older adults.

The physical activity-based meta-analysis results showed that safe, walkable, and aesthetically pleasing neighbourhoods, with access to destinations and services, specifically, recreational facilities, parks/public open space, shops/commercial destinations and public transport facilitated older adults' participation in physical activity [101]. The review also highlighted that 1) perceived built environmental attributes were more strongly associated with older adults' physical activity behaviour than were objectively measured environmental attributes; and 2) that there is a paucity of research on the built environment and accelerometer-assessed physical activity, particularly from Asia. This knowledge gap warrants investigation because Asian cities (e.g., Hong Kong) may present unique environmental characteristics (e.g., ultra-denseness, crowdedness, an efficient public transport network, indoor places for walking) that may directly or interactively affect physical activity and sedentary behaviour [245, 246] in different ways (i.e., correlates may differ) than those documented by 'Western'-based research. Also, cohorts from previous Hong Kong-based studies on this research topic were not representative of the population in terms of health (generally healthier) and mobility (highly functional) (e.g., [74, 75, 247]. There is a need to investigate the association between the built environment and accelerometer-assessed physical activity in a more demographically generalisable cohort from Hong Kong. This is important because greater variability in physical function and health in a sufficiently-sized sample will increase the power of detecting associations between built environmental attributes and older adults' physical activity (i.e., lowering type II error rate), since low physical function and poorer health are related to lower levels of physical activity and likelihood of going outside of the home [43-45, 116, 248]. An investigation of these issues will provide a better insight into how the physical activity behaviour of older adults is influenced by the built environment. This evidence may then inform future urban planning strategies aimed at improving public health through increased physical activity levels and add important information to a growing evidence base.

The scoping review on built environmental correlates of sedentary behaviour showed that far less research had been conducted on this behaviour compared to physical activity. For example, only two articles were identified that studied the association between accelerometer-assessed sedentary time and built environmental attributes, one of which was based in Asia (Hong Kong). Given the dearth of evidence, there is a clear need for further investigation in this research area. Such information may, again, help to inform the development of urban planning initiatives aimed at improving public health, but through *reducing* older adults' sedentary behaviour levels.

Chapter 3
Methodology

3.1 Research plan and chapter aim

This PhD thesis consists of three quantitative studies to address three specific research objectives (*Chapter 1,* section1.8); one employing an experimental research design (objective 1) and two an observational design (objectives 2; and 3). The methodologies for the experimental study determining an accelerometer cut-point for the assessment of Chinese older adults' moderate-intensity physical activity are explained in *Chapter 4,* while this chapter provides an overview of the Active Lifestyle and the Environment in Chinese Seniors (ALECS) epidemiological study that provided data for the studies presented in *Chapters 5 and 6*.

3.1.1 Active Lifestyle and the Environment in Chinese Seniors study

3.1.1.1 Ethics approval

Ethical approval for the ALECS study was obtained from The University of Hong Kong's Human Research Ethics Committee for Non-Clinical Faculties (Project ID: EA270211) (Appendix 7).

3.1.1.2 Research design and methodology

ALECS is an observational, cross-sectional study. Previously described in detail [249], it examined the associations between attributes of the built and social environment, and psychosocial factors with physical activity, quality of life and depressive symptoms in older adults (n=909) aged ≥65 years living in preselected Hong Kong neighbourhoods. For this thesis, the analysed data were from a sub-group within the ALECS study, with accelerometer-assessed physical activity and sedentary time data (n=402). The following description of the research methodology will reflect this.

3.1.1.3 Participant and neighbourhood sampling strategy

A two-stage stratified sampling strategy was adopted whereby 416 Hong Kong older adults were recruited from urban areas in Hong Kong stratified based on their "walkability" characteristics and socio-economic status (median household income) into high walkable/high socio-economic status, high walkable/low socio-economic status, low walkable/high socio-economic status, and low walkable/low socio-economic status (Table 9). The stratified sampling strategy was chosen to maximise the variability in environmental exposures (aspects of walkability) and outcomes (self-reported and objectively-assessed physical activity). Thirty-one Tertiary Planning Units, the smallest administrative units with Census data in Hong Kong, were selected to represent each of the four strata. Approximately 3-4 older adults were recruited from each Tertiary Planning Units (≈104 per quadrant; n=416). Assuming a maximal cluster effect equivalent to an ICC of 0.10 (.048 observed in a previous study on adults and .069 observed in a different study on older adults conducted by The University of Hong Kong research team), it was estimated that a sample of 416 participants living in 124 Tertiary Planning Units would be sufficient to detect a 2% change in explained variance (small effect usually observed in environmental studies of physical activity) with a power of 0.80 under conditions of an alpha level of 0.05, two-tailed significance tests, and 12 covariates in a regression model.

Table 9. Walkability and socio-economic status strata

	Low walkability	High walkability
Low SES	31 TPUs	31 TPUs
	Average N=3-4 per TPU	Average N=3-4 per TPU
High SES	31 TPUs	31 TPUs
	Average N=3-4 per TPU	Average N=3-4 per TPU

Notes: SES: socio-economic statusTPU = Tertiary Planning Unit

The selection of Tertiary Planning Units was based on a multi-dimensional "walkability" index (Figure 2). For each Tertiary Planning Unit, the walkability index was derived as a function of net residential density, land use mix and intersection density [250, 251]. Walkability variables were selected based on previous literature and were computed from land-use data and street centreline files [252]. This type of walkability index has been found to be related to walking in older adults [253] and adults [91]. Tertiary Planning Units were ranked and divided into deciles based on their walkability. The top four and bottom four deciles were labelled "high walkability" and "low walkability," respectively. Similarly, the median household income data for each Tertiary Planning Unit was deciled. The bottom four deciles constituted the "low SES" category, and the top four deciles made up the "high SES" category. Candidate

Tertiary Planning Units were identified and final selections made by investigators after in-person visits.

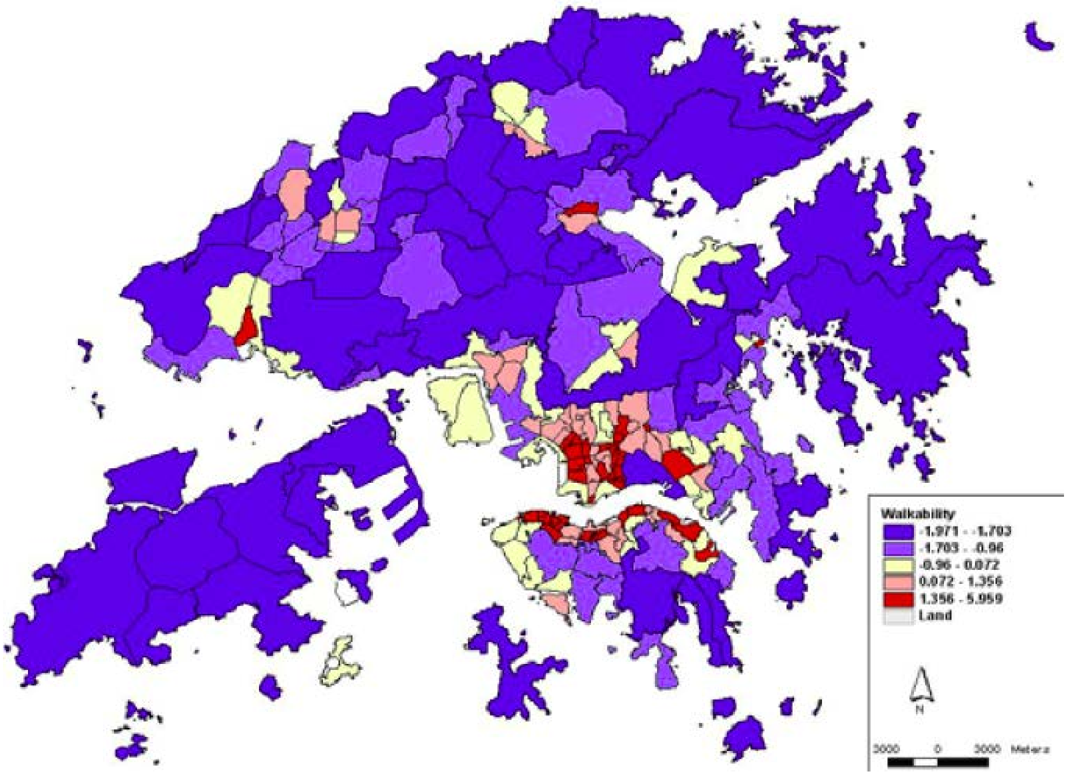

Figure 2. Walkability index for Tertiary Planning Units in Hong Kong (red: highest walkability; dark purple: lowest walkability)

3.1.1.4 Participants and inclusion criteria

Participants were residents of Hong Kong (≈3-4 per each of 124 pre-selected Tertiary Planning Units). Inclusion criteria were being/having: (1) ≥65 years old; (2) Cantonese-speaking and able to communicate verbally; (3) lived in one of the selected residential buildings for ≥6 months; (4) able to walk unassisted for ≥10 metres; and (5) cognitively intact. Participants were recruited from eight out of 18 Elderly Health Centres established by the Department of Health of the Government of Hong Kong Special Administrative Region to provide comprehensive primary care services for Hong Kong residents ≥65 years old; and from elderly community centres and housing estates with the help of staff from the Sao Po Centre on Ageing (The University of Hong Kong) with strong, established community links. The response rate was 71%.

A modest incentive and participation certificate was provided for completing the survey (HK$50) and 7-day accelerometer component (additional HK$50). All participants entered a draw to win one of the three gift certificates valued at HK$2,000.

3.1.1.5 Data collection procedures

Research assistants (interviewers) were trained by investigators. All questionnaires (including the validated NEWS scale for Chinese Seniors [246], Appendix 8) were interviewer-administered to participants (maximum duration 2.5 hours, including a 15-minute break; minimum duration 40 minutes; average duration 1.25 hours). The scales included in the interview were randomised to prevent sequence effects. Participants were asked whether they would be willing to wear the accelerometer for one week and keep a log of wearing time. Accelerometer-assessed physical activity and sedentary time were collected over seven consecutive days in 416 Chinese older adults using the ActiGraph GT3X accelerometer. The ActiGraph has been validated for use among older adults and is among the most reliable and valid field measures of physical activity [69, 141] *(Chapter 2)*. Fourteen participants were excluded from the study because they did not provide valid accelerometry data giving a final sample size of 402.

3.1.1.6 Data management

A research assistant gave a detailed explanation of how to fill in the log with several examples and ascertained that the participants had understood the instructions. The project phone number was provided in case of questions during the week of monitoring. These participants received a daily phone call at a pre-determined time to motivate participation and verify compliance. ActiGraph data integrity was monitored during the study, and in the case of unusable data, participants were asked to continue participation in the study for an additional period of time. This was a successful approach employed in a previous study in Elderly Health Centre older adults [246]. After the completion of the 7-day monitoring period, the research assistant arranged a meeting with the participant to collect the accelerometer and log and verify the validity of the data. Participants with fewer than five valid (i.e., $\geq$10 hr·day^{-1}) days (including $\geq$1 weekend day) of ActiGraph data were asked to re-wear the accelerometer for a required number of days. Non-wear periods were considered as 100 minutes of consecutive zero counts with data programmed using a low-frequency filter to collect data in 60-second epochs, criteria appropriate for older adults [80, 86, 254].

3.2 Summary of the ALECS study

Chapter 3 provided a general overview of the methodology employed to address this thesis' specific objectives 2 and 3. (*Chapter 1*, section 1.8). This included the ALECS' study aim, the recruitment strategy that was undertaken, the measurement tools employed, and the data collection procedures followed. Specific protocols that took place after that to identify built environmental correlates of this behaviour and sedentary time (epidemiological studies) are outlined in *Chapters 5 and 6*, respectively.

Chapter 4
ActiGraph accelerometer cut-point for quantifying Chinese older adults' moderate- to vigorous-intensity physical activity

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4.1 Introduction

As detailed in *Chapter 1,* globally, a rapid and sustained increase in the numbers of older adults in society is set to impart high costs on public health services due to morbidity [5]. This prospect may have greater implications for China in comparison to other countries (e.g., Australia), given the rising number of people over the age of 60 from 2010 to 2050 – a projected increase from 160.2 to 440.7 million people in China versus 4.5 to 11.1 million in Australia [7]. Hence, strategic efforts to improve health outcomes in this demographic are needed [5]. Physical activity, of sufficient dose, has been identified as a modifiable lifestyle factor that can reduce the risk of chronic diseases, such as coronary artery [30], and cerebrovascular disease [255].

Physical activity recommendations specify intensity as a key parameter of activity dose (along with frequency and duration); where moderate-intensity physical activity is typically recommended as the minimum intensity to confer health benefits [19, 256]. Moderate-intensity physical activity is equal to 3.0-5.9 metabolic equivalents (METs), with a RMR of 3.5 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$ typically used to standardise 1 MET in adults (e.g., [256, 257]). Despite studies reporting lower RMRs in older adults (2.7-2.9 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$) [225-227, 258, 259], the 3 METs value based on a RMR of 3.5 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$ is also commonly used as the energy expenditure cut point when quantifying moderate-intensity physical activity in this age group (e.g., [260, 261]). This practice results in an underestimation of the time spent undertaking moderate- to vigorous-intensity physical activity and, therefore, in a sizeable proportion of sufficiently active older adults being incorrectly identified as not achieving the physical activity guidelines for health.

Accelerometers are popular instruments for estimating older adults' physical activity-related energy expenditure due to their validity, reliability, small size, and lightweight [141, 182, 216]. Accelerometers objectively, accurately and automatically (i.e., participants are not required to manage any device functions during data collection) record the intensity of ambulatory activities (e.g., walking and running) across time by detecting movements, in most cases, about the hip [141, 182, 216]. Thus, these devices are not affected by, for example, recall bias associated with subjective physical activity measures (e.g., questionnaires) [175]. These metric characteristics of accelerometers are important for older adult-based physical activity research because walking (an ambulatory activity) is the most common form of physical activity in this demographic [107] and memory may decline with age [262].

A variety of accelerometers are available to researchers and these devices' output, quantified as counts per minute, is used to classify intensity of physical activity. Determining intensities involves attributing specific accelerometer counts per minute to a given intensity (e.g., a cut-point for moderate-intensity physical activity). In older adult-based research, the most commonly-used accelerometer and associated moderate-intensity physical activity cut-point is the ActiGraph accelerometer and ≥1952 counts per minute [2, 118]. As noted earlier, a key issue is the development of this cut-point in adults aged 23-25 years and its arbitrary application to older adults who typically have a lower RMR [263, 264]. To undertake moderate-intensity physical activity based on this cut-point, older adults would be required to accumulate counts at a higher rate and, therefore, participate in the activity at a higher intensity than necessary. This brings into question the validity of previously determined associations between accelerometer-assessed physical activity and exposure variables (e.g., built environmental attributes [242, 265-276]) where this cut-point was used to classify older adults' moderate-intensity physical activity.

Further methodological considerations involve walking surface and gait patterns. Previous accelerometer calibration studies have relied on treadmill-based ambulation to determine cut-points [189, 226, 243, 244, 277], an approach that has been shown to overestimate adults' energy expenditure versus overground walking [278]. Coupled with evidence suggesting that gait patterns differ with age [228, 229], a factor that may also effect accelerometer-determined energy expenditure, these two considerations raise the need for the development of an age-specific cut-point based on overground walking. Indeed, a recent study by Barnett et al. [225] set out to address these concerns. This study found that the moderate-intensity physical activity cut-point in older adults (70.2 ± 7.0 years old) was considerably lower than the most commonly used cut-point from a sample of younger adults (≥1013 [225] *vs.* ≥1952 counts·min^{-1} [2]) and that there was considerable inter-individual variability associated with the cut-point. These findings suggest that the Freedson et al. cut-point [2] is too high a threshold and inappropriate for categorising older adults moderate-intensity physical activity. It may also suggest that individually-calibrated cut-points would be preferable to a group-derived cut-point for classifying moderate-intensity physical activity in older adults when assessing small, rather than larger, samples. Inter-individual cut-point variability has not been examined in Chinese older adults.

While Barnett et al. [225] developed a moderate-intensity physical activity cut-point for use in older adults employing a sound methodology to address limitations related to previous research, potential issues associated with ethnicity may also warrant investigation. In adult populations, absolute resting energy expenditure has been shown to differ across ethnic groups [222-224, 279, 280]. Differences in components of body mass related to ethnicity may partly explain these observations. While Asians (including ethnic Chinese) were found to have a lower absolute resting energy expenditure than Caucasians, there was no difference after adjusting for fat-free mass [223]. In contrast, Song et al. [224] found the RMR of Asian-Indian men was significantly lower than that of Chinese men even after adjusting for body weight, fat-free mass, and fat mass. However, the difference was not significant when adjusting for the mass of high-metabolic organs, which differed between the two ethnic groups. Two other studies have similar findings. When comparing African-Americans with white premenopausal women, Gallagher et al. [279] found the mass of high-metabolic organs was associated with ethnicity and was also a significant predictor of resting energy expenditure. Furthermore, resting energy expenditure and high-metabolic rate tissue was lower in African American than white women [281]. The findings of these three studies suggest that ethnicity-related differences in the mass of high-metabolic rate organs may, at least partly, explain ethnic-specific differences in resting energy expenditure. In contrast to the studies finding ethnic differences in adults' absolute resting energy expenditure, older adults were found to have a RMR relative to body weight within the range of 2.7 to 2.9 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$ reported in studies of older adults of white Caucasian or unidentified ethnicity [226, 258, 259]. The above supports further research to ascertain the possible need for ethnic-specific, in this case, Chinese-specific, moderate-intensity accelerometer cut-points for older adults.

4.2 Aim

The primary aims of this chapter were to establish ActiGraph accelerometer (vertical axis and vector magnitude displacement) count and walking speed cut-points to quantify Chinese older adults' moderate-intensity physical activity. The secondary aims of this chapter were to quantify the level of inter-individual variability in these cut-points and identify socio-demographic, biological and behavioural predictors of inter-individual differences in cut-points.

4.3 Methods

4.3.1 Ethics approval

Ethical approval for study 1 was obtained from Deakin University's Human Ethics Advisory Group (Project ID: HEAG-H 88_2014) (Appendix 9).

4.3.2 Research design and methodology

This study implemented an experimental research design.

4.3.3 Participants and inclusion criteria

Forty-three Chinese older adults living in Melbourne and able to walk unassisted were recruited to participate in this study. Similar calibration studies determining cut-points for accelerometers in other adult populations have relied on sample sizes of 28-38 participants (e.g., [243, 244, 282]). It was estimated that a sample of forty participants would allow for the determination of cut-points within 15% accuracy (see Appendix 10 for details on sample size calculations), which is more precise than the approximate 30% accuracy reported from a previous study [282]. Other cut-point calibration studies did not provide specific information on sample size calculations regarding their older adult participants [243, 244, 277]. Participant inclusion criteria were: (1) being ethnically Chinese (self-identified); (2) ≥60 years old; (3) able to walk unassisted; (4) able to attend a one-off data collection session at Deakin University (maximum duration of 1.5 hours); (5) having no diagnosis of cognitive impairment; and (6) able to understand and read English or Chinese. Exclusion criteria were: (1) suffering from any conditions that may prevent participants from walking unaided; and (2) being diagnosed with type 2 diabetes. It was important that participants were cognitively intact as they were required to complete a questionnaire on their demographic information, and free from type 2 diabetes because the fasting aspect of the experimental protocol had the potential to elevate hypoglycaemia risk [283].

4.3.4 Recruitment strategy

Participants were recruited via local media advertisements, flyers (Appendices 11 and 12) distributed to relevant organisations (e.g., clinics and community centres), and snowball sampling. Interested participants were asked to contact an English-, Cantonese- or Mandarin-speaking staff member via phone or email who recorded the contact details of the participants, verified their eligibility against the inclusion criteria, and, if eligible, sent them a copy of the Plain Language Statement and Consent Form (Appendix 13). A week after posting or emailing the Plain Language Statement and Consent Form (available in English, Traditional Chinese, and Simplified Chinese) to an interested volunteer, research staff phoned the participants to schedule a data collection session at Deakin University, Burwood Campus, if they still wished to participate.

4.3.5 Pre-calibration test data collection procedures

Participants visited the School of Exercise and Nutrition Sciences facilities at Deakin University, Burwood Campus, on one occasion. Upon arrival, participants were asked to provide written informed consent and reminded of the dietary and behavioural requirements of the experimental protocol. Once cleared, the participants, first, completed two interviewer-administered questionnaires (*Note:* if required, all materials were available in English and Chinese and, as appropriate, a Cantonese- or Mandarin-speaking research assistant was always present). The first questionnaire asked the participants' contact details, information on health status (e.g., medication usage) and on any physical ailment that may prevent them from walking unaided (Appendix 14); the second was a validated questionnaire [the International Physical Activity Questionnaire-Short version (IPAQ-S) [284] or IPAQ-S Chinese version (IPAQ-CS) [153] asking about their physical activity habits (Appendix 15). The English- and Chinese-version (7 items each) questionnaires ask participants to separately report on how many days within the last seven have they undertaken moderate- and vigorous-intensity physical activities (not including walking) and how many minutes per day of each were performed. In addition to these questions, participants were asked to report the average number of minutes of walking and sitting per day. Total minutes of physical activity were calculated by adding together the minutes per day from each type of activity, not including sitting. The information from the demographic and physical activity questionnaires outlined the characteristics of the population to which the study findings can be applied to. Also, information on age, sex, sitting time (min·day^{-1}), and total physical activity (min·day^{-1}) was used to examine whether these characteristics partially explained inter-individual differences in ActiGraph moderate-intensity physical activity cut-points.

4.3.6 Pre-test dietary and behavioural requirements

Prior to testing, participants were asked to adhere to the following five requirements to obtain a valid measure of RMR, from which the classification of moderate-intensity was determined: (1) fasting for the preceding five hours, at a minimum, because total thermic effect of feeding can increase metabolic rate and account for 7-9% of energy expended post eating – 91% of that effect reportedly expended at five hours [285]; (2) an abstinence of caffeine overnight because caffeine ingestion has been shown to increase RMR by 7-11% [286, 287] – while this metabolic effect was sustained at three hours [287] it was eliminated after fasting overnight [288]; (3) no smoking or alcohol ingestion for the preceding two hours because smoking cigarettes (specifically nicotine) can elevate RMR within the first ten minutes of first exposure, but RMR returns close to baseline two hours later [289, 290]. Drinking alcohol (specifically ethanol) can elevate RMR by 1.1-13.6% in participants but was markedly reduced after 90 minutes post ingestion in men [291] and women [292]; (4) not participating in moderate-intensity physical activity for the preceding two hours because performing activity at this intensity increases energy expenditure and elevates RMR – this metabolic effect was eliminated after 30-90 minutes [293-295]; and (5) not participating in vigorous-intensity physical activity for the preceding 14 hours before testing because some research has shown that baseline RMR remained elevated (100 kcal) 14.5 hours after participants conducted moderate- to vigorous-intensity exercise [296].

4.3.7 Anthropometric measurements

Once the two questionnaires had been completed, height and weight were measured three times and the mean calculated for each. Height was assessed using a portable stadiometer (220, Seca, Hamburg, Germany; to the nearest 0.1 cm) after asking participants to remove their footwear and stand with heals together and placing them and their calves, buttocks, and upper back against the scale [297]. The participants were then asked to take and hold a deep breath as the stadiometer measuring board was placed firmly on the head, crushing the hair as much as possible [297]. Body mass was measured using portable scales (UC-321, A&D, Tokyo, Japan; to the nearest 0.1 kg) after asking participants to remove any footwear, excessive clothing, and heavy objects from their pockets (e.g., mobile phone). The scale was placed on an even surface and zeroed before participants were asked to step on to it. Data on height and weight were also used to determine the BMI of participants which is a metric commonly used for categorising individuals into underweight, normal weight, or overweight and has been extensively used in health-based research as a risk factor for chronic disease [298]. Body mass (kg) was required as a component to determine RMR [299, 300], while BMI was used as a descriptor variable of the sample and as a predictor of inter-individual variability in ActiGraph moderate-intensity physical activity cut-points. Bioelectrical impedance (Tanita BC-418; Tanita Corp., Tokyo, Japan) assessed body composition of each participant; a valid method for estimating body composition in adults, including older adults [301-303].

4.3.8 Assessing energy expenditure

To assess a participant's energy expenditure, a lightweight (total mass 1.40 kg), portable indirect calorimeter (MetaMax 3b system; Cortex, Leipzig, Germany) was used that comprises of a bidirectional digital turbine assembly, a 60-cm length of Nafion/Permapure® sampling tube, and a gas analyser-data telemetry module (base unit). This device has been validated for the assessment of adults' breath-by-breath oxygen uptake ($\dot{V}O_2$), carbon dioxide production (CO_2), and expired ventilation (V_E) [304]. During testing, the turbine assembly was attached to an otherwise air-tight facemask (Vmask™, Hans Rudolph Inc., Shawnee, KS; dead space 40-49 mL) and the base unit placed on a surface or fastened by a harness to a researcher close by, depending on the protocol stage [225]. The turbine assembly contains a Triple V breathing valve with an in-built lightweight (20 mg) fan flow meter that records the volume of expired air in proportion to the amount of air passing through the turbine [305, 306]. Fan revolutions are recorded by an infrared photodetector and flow taken from these recorded signals [305, 306]. Respired air during the complete exhalation (≈100 $mL \cdot min^{-1}$) is sampled from the mouthpiece and into a mixing chamber in the base unit through the Nafion/Permapure® tube for analysis of the fractions of O_2 and CO_2 [305, 306]. Oxygen is measured by an electrochemical (zirconium-oxide) cell kept at ≈400°C and CO_2 by an infrared sensor [305, 306]. Recorded data for each outcome was then stored in 5-second intervals on the device to be later downloaded on to a personal computer. Comma-separated values files were then exported from the device using the Metasoft 3 software, version 3.7.0 SR2, and data copied to a customised Microsoft Excel Spreadsheet® for data analysis.

Prior to testing, the MetaMax 3b system was turned on for at least 15 minutes and then calibrated according to the manufacturer's guidelines (Calibration Manual 931-00-

264/Revision a/2014-03-06, CORTEX Biophysik GmbH, Leipzig, Germany). First, the oxygen and the carbon dioxide analysers were calibrated against ambient air as well as a reference gas of known composition (5.2% CO_2, 16.0% O_2, and 78.8% nitrogen). Secondly, a volume calibration was undertaken using a 3.0-L syringe (5530 series, Hans Rudolph Inc., Shawnee, KS) to ensure accurate volume assessments. Lastly, to control for possible drift over multiple tests, the gas content of the ambient air was checked before each test. Oxygen uptake ($mL \cdot kg^{-1} \cdot min^{-1}$) was calculated using standard metabolic algorithms employing the Haldane transformation [307].

4.3.9 Determining resting metabolic rate

Following the completion of answering the questionnaires and gas analyser calibration, data were collected to determine participants' RMR. In a quiet room at a 22 °C temperature, participants laid at rest in a semi-recumbent position (30°) for 30 minutes of which oxygen uptake data was collected by the MetaMax 3b system for the final 10 minutes [308]. The MetaMax 3b base unit was securely placed on a surface nearby. The established RMR formed a component of the data used to determine moderate-intensity physical activity cut-point.

4.4 Determining physical functionality and the association between accelerometer counts and energy expenditure and walking speed

4.4.1 Monitor preparation for data collection

Each electronic monitor – one ActiGraph GT3X accelerometer, one global positioning system (GPS) unit without live display feedback (QStarz BT1000X GPS data logger; QStarz International Co., Taipei, Taiwan), and one GPS unit with live display feedback (Forerunner 305 GPS monitor; Garmin Ltd., Olathe, KS) – were all synchronised to atomic clock time. The ActiGraph accelerometer was programmed using ActiLife software v6.11.8 to measure count data (vertical axis and vector magnitude displacement) in 5-sec intervals; the QStarz GPS was programmed using Q Travel v1.48 to measure walking speed ($km \cdot hr^{-1}$) in 5-sec intervals; and the Garmin GPS was used to regulate speed ($km \cdot hr^{-1}$) during the different stages of the walking protocol and its distance (m) (live feedback).

4.4.2 Monitor placement

Participants affixed both the ActiGraph GT3X accelerometer (in-built belt feed) and QStarz GPS (placed into a pouch with in-built belt feed) at the mid-axillary line on the right hip with an elasticated – fitted – waist belt. This position, close to the body's centre of mass, is the most frequently used in physical activity research and provides accurate estimates without overburdening data processing techniques with regards data collected at, for example, the wrist [118, 309, 310] – a site where it remains unclear as to whether data collected will be as accurate as that collected at the hip [193, 194]. The Garmin GPS was held by the researcher walking beside the participant and has been shown to be accurate in monitoring speed over a given distance in a relatively small, open-sky environment [311]. All devices are small of size: ActiGraph accelerometer (4.6 cm x 3.3 cm x 1.5 cm), QStarz GPS (7.2 cm x 4.7 cm x 2.0 cm), and Garmin GPS (5.3 cm x 6.9 cm x 1.8 cm).

Hereafter, subheadings represent the order in which participants undertook each aspect of this part of the experimental protocol.

4.4.3 Determining physical functionality

Participants were asked to complete the Short Physical Performance Battery (3 items) (Appendix 16); a validated measure of physical function in older adults [312]. This scale asks the participant to complete three separate physical activities, specifically: (1) five repeated chair stands as quickly as possible – scored 0 points (unable to complete 5 stands or completed 5 stands in >60 sec), 1 point (≥16.7 sec), 2 points (13.7-16.6 sec), 3 points (11.2-13.6 sec), and 4 points (<11.1 sec).; (2) balance testing with increasing difficultly: participants asked to hold a side-by-side stand (feet together) for 10 sec if unable to perform a semi-tandem stand, otherwise the participant starts with trying to hold a semi-tandem stand (side of the heal of one foot touching the big toe of the other) for 10 sec, and finally, a tandem stand (heal of one foot in front and touching the toes of the other) for up to 10 sec – scored 0 points (side-by-side stand only 0-9 sec or unable), 1 point (side-by-side stand for 10 sec but semi-tandem <10 sec), 2 points (semi-tandem for 10 sec and tandem 0-2 sec), 3 points (semi-tandem for 10 sec and tandem 3-9 sec), and 4 points (tandem for 10 sec); and (3) a 4-metre walk as fast as possible – scored 0 points (unable), 1 point (>8.70 sec), 2 points (6.21-8.70 sec), 3 points (4.82-6.20 sec), and 4 points (<4.82 sec). The scores from each of these tests are then totalled and participants categorised as having: low physical function (0-4 points), intermediate-level function (5-7 points), or high physical function (8-12 points).

4.4.4 Walking protocol

Participants undertook a 1.2 km walking protocol, which was a modified version of the method devised by Barnett et al. [278]. It began with participants walking at their 'usual pace' for 200 metres, a process undertaken to ensure familiarisation with walking while wearing the face mask. Measuring older adults' energy expenditure in this manner has been shown to be reliable [313], and mask-wearing has been shown not to effect vertical axis count accumulation [278]. Throughout the entire walk, the researcher walked beside the participant wearing the gas analyser base unit as not to add weight to the participant. A 5-minute period of rest followed; allowing for both heart rate and metabolic rate to return to resting levels. Participants then completed the remaining 1 km incremental-speed walk protocol in stages, specifically: 100 m at 1.6 km·hr^{-1}; 200 m at 2.2 km·hr^{-1}; 200 m at 2.8 km·hr^{-1}; 200 m at 3.4 km·hr^{-1}; and 300 m at 4.0 km·hr^{-1}. Previous research has shown that this protocol is adequate in achieving 'steady-state' oxygen uptake [278]. Steady-state oxygen uptake ensures aerobic adenosine triphosphate production is taking place – and not anaerobic adenosine triphosphate – and that any oxygen deficit upon the onset of exercise, or transition to a higher intensity, is overcome [314]. Additionally, to control stage speed and distance, the researcher walking beside the participant held the Garmin GPS [311]. Regarding protocol stages, five different speeds, and not three [2, 189] or four [315], were assessed to maximise the accuracy of the calibration equation [225].

4.5 Statistical analyses

4.5.1 Data preparation

All datasets were exported in comma-separated values files to Microsoft Excel® Spreadsheets from their respective software programs, and corresponding time-matched data (per 5-sec) were manually transferred into a customised Microsoft Excel® Spreadsheet. Specifically, MetaMax gas analyser: VO_2 (L·min^{-1}) data for RMR and walking protocols. First, RMR was determined by multiplying the lowest VO_2 (L·min^{-1}) over the 10-min measurement period by 1000 (mL) and then dividing by body mass (kg). Then oxygen uptake (mL·kg^{-1}min^{-1}) per 5-seconds of the walking protocol was calculated using the same method. METs were then determined per 5-second interval by dividing oxygen uptake by RMR. The mean of the 'steady-state' final two minutes of oxygen uptake (mL·kg^{-1}min^{-1}) was then calculated for each stage of the protocol. The mean for corresponding time-matched final two minutes of data from the ActiGraph (vertical axis counts and vector magnitude displacement), and QStarz GPS (km·hr^{-1}) was also calculated.

4.5.2 Moderate-intensity physical activity cut-point

Linear mixed models (LMMs) were used to determine cut-points from the walking protocol data and estimate inter-individual variability in these. These models were chosen as they can handle data where the assumption of independency of observations is violated, as is the case in this study due to there being five sets of data points per person [225]. LMMs included random intercepts and slopes for linear and quadratic terms at the individual level; allowing for the assessment of between-individual variability in each specific cut-point as quantified by the standard deviation (SD) of the random intercept. The first set of models included ActiGraph counts as the outcome variable and energy expenditure (RMR-adjusted METs) as the predictor variable, and the second model had walking speed as the outcome. MET values were centred at 3.0 so that the average participant's vertical axis and vector magnitude ActiGraph counts and walking speed cut-points could be determined from the point estimates of the random intercept of the respective LMMs. For each outcome (ActiGraph vertical axis counts and vector magnitude displacement, and walking speed), several models of increasing complexity were estimated including examining evidence of curvilinear associations modelled using polynomials, namely:

(1) Random intercept with fixed slope for linear term model;
(2) Random intercept with fixed slopes for linear and quadratic terms model;
(3) Random intercept with random slope for linear term and fixed slope for quadratic term model;
(4) Random intercept and random slopes for linear and quadratic terms model;
(5) Variations in random intercept and random slopes for linear and quadratic terms model.

For each outcome, the final model was selected based on the likelihood ratio test where a significant difference in fit was detected from a base model to a more complicated model, represented by larger logLik estimates closer to zero and lower deviance estimates. Applying models of increasing complexity continued until the fit could no longer be improved. After establishing the best-fitting models for each outcome variable (i.e., moderate-intensity physical activity ActiGraph vertical axis and vector magnitude count and walking speed cut-points), specific predictor variables were then added to the models to investigate how much each independent variable explained variation in the intercept (i.e., individual cut-points), namely: sex, mean-centred age, BMI, the number of different medications taken per day, IPAQ-measured total weekly minutes of physical activity, fat-free mass (kg), and short performance physical battery score. Analysis was undertaken using R 3.2.3 [316] with package lme4 for LMM models [317].

4.6 Results

Participant characteristics are presented in Table 10. Mean RMR was 2.9 ± 0.5 mL O_2·kg^{-1}·min^{-1}. There were large inter-individual differences in RMR (1.6-4.4 mL O_2·kg^{-1}·min^{-1}) and a significant difference (p < .001) in RMR by sex: male (3.2 mL O_2·kg^{-1}·min^{-1}); and female (2.7 mL O_2·kg^{-1}·min^{-1}). Body mass index- and physical function-related data indicated that, on average, participants were of normal weight [318] and high in physical function [319].

Table 10.Participant demographic characteristics (N=43)

Characteristic	Mean ± SD	Median	Range
Age (years)	68.7 ± 6.6	65.0	60-85
Sex (female)	53%	-	-
Height (m)	1.62 ± 0.07	1.63	1.46-1.78
Weight (kg)	59.6 ± 10.0	58.2	43.7-75.8
Body mass index (kg·m^2)	22.7 ± 3.3	22.4	17.3-35.5
Resting metabolic rate (mL O_2·kg^{-1}·min^{-1})	2.9 ± 0.5	3.0	1.6-4.4
Fat-free mass (kg)	43.4 ± 8.0	43.6	32.7-57.1
Medications taken·day^{-1}	2 ± 2	1	0-7
Short Physical Performance Battery score	10.8 ± 1.2	11.0	8-12
Total self-reported physical activity (min·$week^{-1}$)	572.9 ± 795.8	297.5	10.0-4200.0

Notes: SD: standard deviation; Short Physical Performance Battery classifications: <6 = low physical function, 7-9 = moderate physical function, ≥10 = high physical function

Average speeds per stage of the walking protocol were 1.7 ± 0.1, 2.3 ± 0.1, 2.9 ± 0.1, 3.4 ± 0.1, and 4.1 ± 0.2 km·hr^{-1}. There were marked inter-individual intercept and slope variation for vertical axis counts per minute, vector magnitude displacement counts per minute, and speed as predicted by METS (Figures 3, 4, and 5). Table 11 reports the likelihood ratio tests for the different LMMs of increasing complexity. In so far as the more complex model improved the fit of outcomes data (i.e., largest log-likelihood closest to zero), the process of testing more complex models continued until the fit of the model could not be improved. Specifically, for ActiGraph vertical axis counts per minute, a model allowing for a random intercept, random slope for the linear component, and fixed slope for the quadratic term was the best fit versus a model with a random intercept and fixed slopes for both the linear and quadratic term (X^2 = 28.23, df = 2, p <.001). This was also the case with regards the outcome vector magnitude displacement counts per minute (X^2 = 34.75, df = 2, p <.001). Lastly, regarding the outcome walking speed (km·hr^{-1}), a model with a random intercept and random slopes for the linear and quadratic terms fitted the data best versus a model with a random intercept, a random slope for the linear term, and fixed slope for the quadratic term (X^2 = 15.18, df = 3, p <.01).

Table 11. Log-likelihood ratio tests of linear mixed models of increasing complexity

Outcome (model)	**logLik**	**deviance**	χ^2	**Chi df**	***p***
ActiGraph vertical axis counts·min^{-1}					
Random intercept with fixed slope for linear term model	-1664.9	3329.8	-	-	-
vs. Random intercept with fixed slopes for linear and quadratic terms model	-1631.0	3261.9	67.87	1	<.001
vs. Random intercept with random slope for linear term and fixed slope for quadratic term model	-1616.9	3233.7	28.23	2	<.001
vs. Random intercept and random slopes for linear and quadratic terms model	-1615.3	3230.6	3.11	3	>.05
ActiGraph vector magnitude displacement counts·min^{-1}					
Random intercept with fixed slope for linear term model	-1651.4	3302.7	-	-	-
vs. Random intercept with fixed slopes for linear and quadratic terms model	-1626.5	3253.1	49.69	1	<.001
vs. Random intercept with random slope for linear term and fixed slope for quadratic term model	-1609.2	3218.3	34.75	2	<.001
vs. Random intercept and random slopes for linear and quadratic terms	-1607.7	3215.4	2.87	3	>.05
Walking speed (km·hr^{-1})					
Random intercept with fixed slope for linear term model	-162.5	325.0	-	-	-
vs. Random intercept with fixed slopes for linear and quadratic terms model	-117.5	234.9	90.07	1	<.001
vs. Random intercept with random slope for linear term and fixed slope for quadratic term model	-106.2	212.4	22.55	2	<.001
vs. Random intercept and random slopes for linear and quadratic terms	-98.6	197.2	15.18	3	<.01
vs. Variations in random intercept and random slopes for linear and quadratic terms model	-98.0	196.0	1.25	5	>.05

Notes: p: p-value

Table 12 reports the log-likelihood test results for the base best-fitting models and of the models with included predictors, namely, in order of researcher practicality (i.e., burden in terms of time and/or expense): sex, age, BMI, number of different medications taken per day, IPAQ-measured total physical activity, fat-free mass, and short physical performance battery score. For ActiGraph vertical axis counts per min, the best fitting parsimonious model was the one allowing a random intercept with a random slope for the linear term and a fixed slope for the quadratic term (logLik = -1616.9, deviance = 3233.7), and the fit was further improved by including the predictors number of medications taken per day, IPAQ-assessed total physical activity, and bio-impedance-assessed fat-free mass into the model (logLik = -1385.8, deviance = 2771.5). These predictors also significantly improved the fit of models with the remaining two outcomes, vector magnitude displacement counts per min (random intercept with random slope for linear term and fixed slope for the quadratic term model: logLik = -1372.4, deviance = 2744.8) and walking speed (random intercept and random slopes for linear and quadratic terms model: logLik = -78.1, deviance = 156.1).

Table 12. Log-likelihood ratio tests of best-fitting models including predictors of METs

Outcome (model)	logLik	deviance	X^2	Chi df	*p*
Vertical axis counts·min^{-1}					
Random intercept with random slope for linear term and fixed slope for quadratic term model (base model $^{\#1}$)	-1616.9	3233.7	-	-	-
(base $^{\#1}$) *vs.* (base $^{\#1}$) + Sex	-1616.6	3233.1	0.58	1	>.05
(base $^{\#1}$) *vs.* (base $^{\#1}$) + Age	-1616.8	3233.6	0.12	1	>.05
(base $^{\#1}$) *vs.* (base $^{\#1}$) + BMI	-1616.9	3233.7	0.0008	1	>.05
(base $^{\#1}$) + Medications	-1537.5	3074.9	-	-	-
(base $^{\#1}$) + IPAQ Total PA	-1501.1	3002.1	-	-	-
(base $^{\#1}$) + FFM	-1463.1	2926.2	-	-	-
(base $^{\#1}$) + Short Performance Physical Battery score	-1615.4	3230.9	-	-	-
(base $^{\#1}$) + Medications + IPAQ Total PA	-1461.4	2922.9	-	-	-
(base $^{\#1}$) + Medications + IPAQ Total PA + FFM	-1385.8	2771.5	-	-	-
Vector magnitude displacement counts·min^{-1}					
Random intercept with random slope for linear term and fixed slope for quadratic term model (base model $^{\#2}$)	-1609.2	3218.3	-	-	-
(base $^{\#2}$) *vs.* (base $^{\#2}$) + Sex	-1608.1	3216.2	2.08	1	>.05
(base $^{\#2}$) *vs.* (base $^{\#2}$) + Age	-1609.0	3217.9	0.36	1	>.05
(base $^{\#2}$) *vs.* (base $^{\#2}$) + BMI	-1608.5	3217.1	1.21	1	>.05
(base $^{\#2}$) + Medications	-1526.6	3053.3	-	-	-
(base $^{\#2}$) + IPAQ Total PA	-1491.1	2982.2	-	-	-
(base $^{\#2}$) + FFM	-1453.3	2906.7	-	-	-
(base $^{\#2}$) + Short Performance Physical Battery score	-1608.2	3216.4	-	-	-
(base $^{\#2}$) + Medications + IPAQ Total PA	-1449.1	2898.2	-	-	-
(base $^{\#2}$) + Medications + IPAQ Total PA + FFM	-1372.4	2744.8	-	-	-
Walking speed (km·hr^{-1})					
Random intercept and random slopes for linear and quadratic terms model (base model $^{\#3}$)	-98.6	197.2	-	-	-
(base $^{\#3}$) *vs.* (base $^{\#3}$) + Sex	-97.7	195.31	1.91	1	>.05
(base $^{\#3}$) *vs.* (base $^{\#3}$) + Age	-98.5	197.0	0.17	1	>.05
(base $^{\#3}$) *vs.* (base $^{\#3}$) + BMI	-97.2	194.4	2.86	1	>.05
(base $^{\#3}$) + Medications	-91.1	182.1	-	-	-
(base $^{\#3}$) + IPAQ Total PA	-85.6	171.2	-	-	-
(base $^{\#3}$) + FFM	-85.7	171.5	-	-	-
(base $^{\#3}$) + Short Performance Physical Battery score	-92.5	185.0	-	-	-
(base $^{\#3}$) + Medications + IPAQ Total PA	-82.1	164.2	-	-	-
(base $^{\#3}$) + Medications + IPAQ Total PA + FFM	-78.1	156.1	-	-	-

Notes: vs.: denotes testing statistical difference between models; +: denotes variables that were added to the base model; *p*: *p*-value; MET: metabolic equivalent; BMI = body mass index; IPAQ: International Physical Activity Questionnaire; PA = physical activity; FFM = fat free mass

Table 13 details the 3-MET moderate-intensity physical activity vertical axis and vector magnitude and walking speed cut-points estimated using the best fitting models. Specifically, an ActiGraph vertical axis cut-point of 1184 ± 884 counts·min^{-1}, an ActiGraph vector magnitude displacement cut-point of 2192 ± 830 counts·min^{-1}, and a walking speed cut-point of 2.6 ± 0.9 km·hr^{-1} all represented moderate-intensity physical activity (3 METs). Mostly, there was a marked reduction in intercept SD with the inclusion of significant predictors

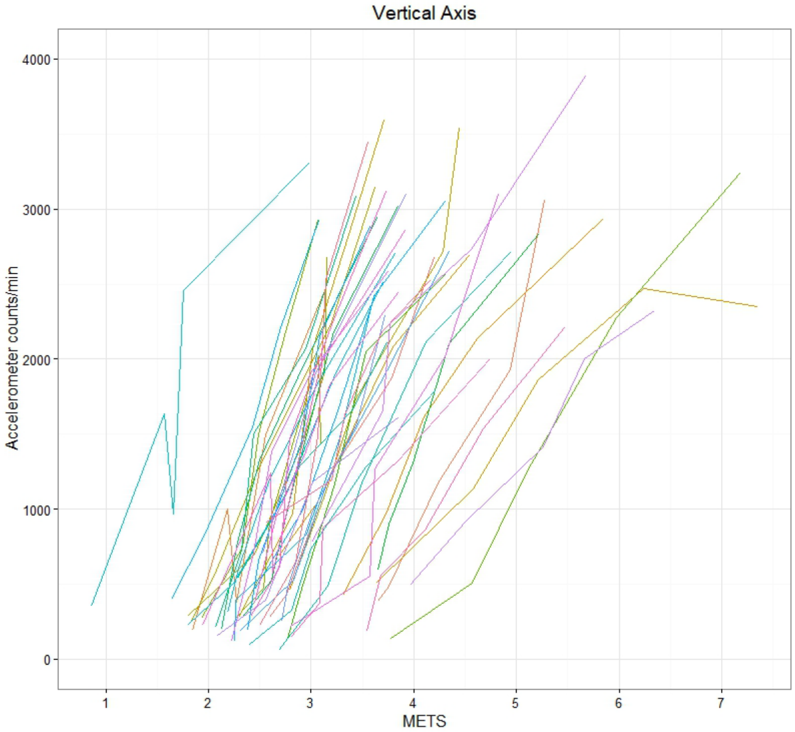

Figure 3. Individual participant's ActiGraph vertical axis counts·min^{-1} as a function of METs

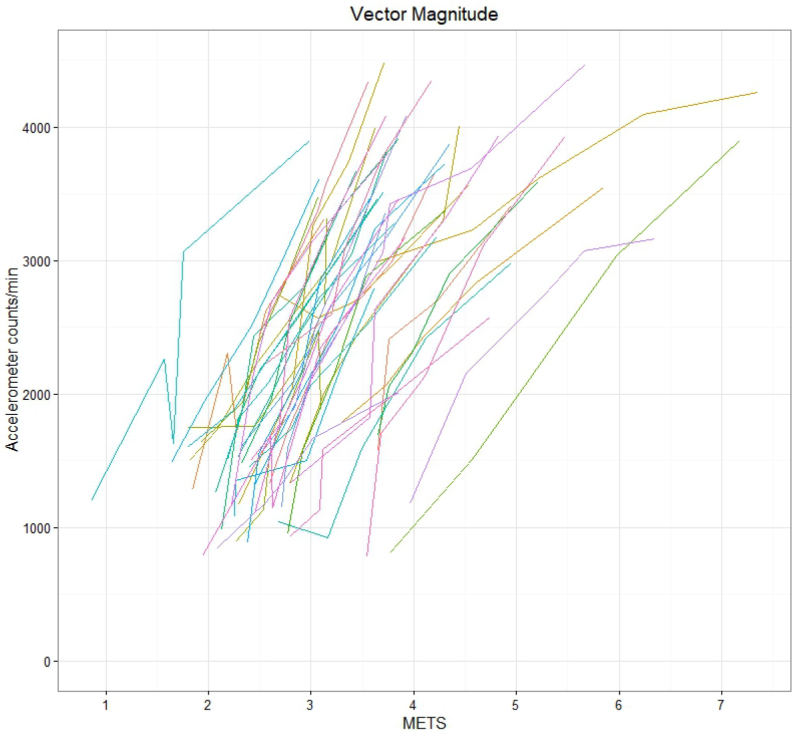

Figure 4. Individual participant's ActiGraph vector magnitude (counts·min^{-1}) as a function of METs

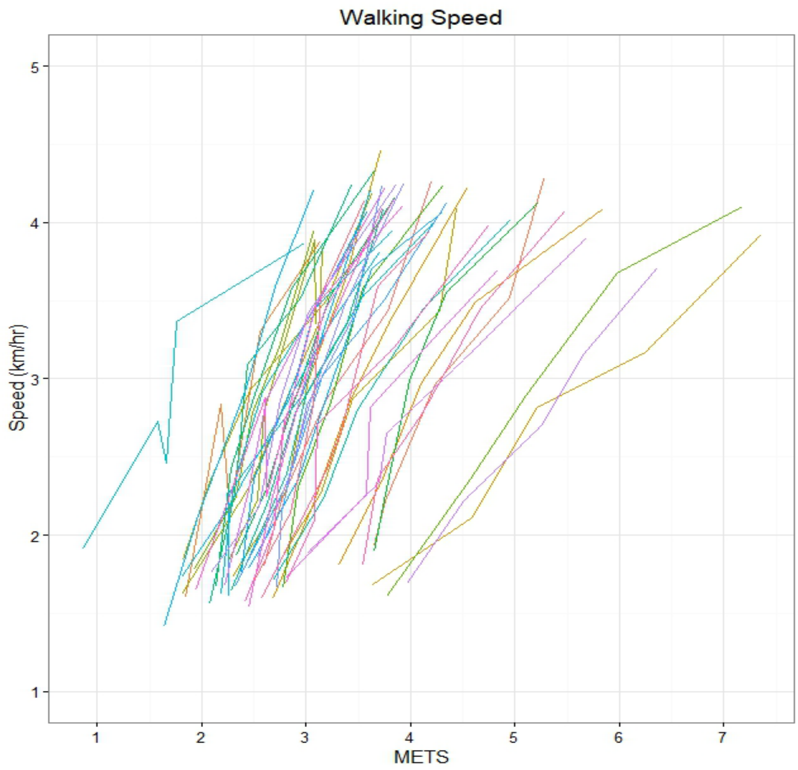

Figure 5. Individual participant's walking speed (km·hr^{-1}) as a function of MET

across models and outcomes. The inclusion of number of medications taken per day, IPAQ-assessed total physical activity and fat-free mass improved the fit of the model while sex, age, BMI, or physical function did not. The inclusion of these three predictors reduced inter-individual variability by 5.2%, 7.8%, and 11.1% for vertical axis counts, vector magnitude displacement counts, and walking speed, respectively.

4.7 Discussion

To date, there has been a multitude of ActiGraph accelerometer cut-points (e.g., [2, 226, 243, 320, 321]) that have been applied in studies to better understand the time spent in specific intensities (e.g., moderate) of physical activity in older adults [118]. It is unclear, however, which moderate-intensity physical activity cut-point is most appropriate for use with Chinese older adults for age- and ethnicity-related reasons [222-224, 279, 280] and whether this cut-point may differ substantially between individuals [225]. Therefore, we first aimed to establish an age- and, perhaps, ethnicity-appropriate cut-point to define moderate-intensity physical activity in Chinese older adults and, second, to assess the inter-individual variability of that cut-point.

Of note, the ActiGraph GT3X+ used in this study is not directly comparable to the pre-GT3X ActiGraph models, for example, that were used to develop the most commonly used

Table 13. Linear mixed model estimates of regression parameters

Outcome (model)	**Moderate-intensity physical activity cut-point = 3 METs (Intercept ± SD)**	**95% CIs of intercept**	**3 METs Linear term (95% CIs)**	**3 METs Quadratic term (95% CIs)**	**Predictor variable/s (95% CIs)**
ActiGraph vertical axis counts·min^{-1}					
Random intercept with random slope for linear term and fixed slope for quadratic term (base model #1)	1184 ± 884	916; 1453	1490 (1357; 1623)	-51.50 (-99; -4)	-
(base #1) + Medications	1210 ± 858	943; 1477	1466 (1337; 1594)	-55.63 (-102; -9)	32.37 (-105; 169)
(base #1) + IPAQ Total PA	1242 ± 819	984; 1500	1503 (1366; 1641)	-60 (-111; -9)	0.07 (-0.23; 0.37)
(base #1) + FFM	1192 ± 870	915; 1469	1499 (1354; 1644)	-61 (-111; -12)	4 (-28; 36)
(base #1) + Medications + IPAQ Total PA	1223 ± 819	962; 1484	1478 (1348; 1609)	-62 (-112; -12)	Medications: 55 (-83; 193) IPAQ Total PA: 0.08 (-0.22; 0.39)
(base #1) + Medications + IPAQ Total PA + FFM	1206 ± 838	932; 1481	1490 (1351; 1628)	-68 (-119; -17)	Medications: 61 (-86; 208) IPAQ Total PA: 0.08 (-0.24; 0.40) FFM: 0.52 (-32; 33)
ActiGraph vector magnitude displacement counts·min^{-1}					
Random intercept with random slope for linear term and fixed slope for quadratic term (base model #2)	2192 ± 830	1940; 2445	1332 (1210; 1455)	-70 (-118; -21)	-
(base #2) + Medications	2208 ± 813	1955; 2461	1300 (1185; 1415)	-71 (-117; -25)	78 (-64; 221)
(base #2) + IPAQ Total PA	2242 ± 775	1997; 2486	1332 (1204; 1460)	-69 (-120; -18)	0.07 (-0.24; 0.37)
(base #2) + FFM	2187 ± 825	1924; 2450	1349 (1220; 1478)	-83 (-132; -34)	22 (-11; 55)
(base #2) + Medications + IPAQ Total PA	2225 ± 754	1985; 2466	1299 (1179; 1420)	-64 (-15; -113)	Medications: 111 (-24; 247) IPAQ Total PA: 0.09 (-0.21; 0.38)
(base #2) + Medications + IPAQ Total PA + FFM	2201 ± 765	1950; 2452	1317 (1193; 1441)	-73 (-122; -24)	Medications: 115 (-28; 258) IPAQ Total PA:

					0.12 (-0.19; 0.43) FFM: 16 (-16; 47)
Walking speed ($km \cdot hr^{-1}$)					
Random intercept and random slopes for linear and quadratic terms model (base model [#3])	2.6 ± 0.9	2.4; 2.9	1.5 (1.4; 1.6)	-0.23 (-0.55; 0.26)	-
(base [#3]) + Medications	2.7 ± 0.9	2.4; 2.9	1.5 (1.4; 1.6)	-0.26 (-0.29; -0.23)	-0.09 (-0.21; 0.03)
(base [#3]) + IPAQ Total PA	2.7 ± 0.8	2.4; 2.9	1.5 (1.4; 1.7)	-0.25 (-0.28; -0.22)	0.0002 (-0.0001; 0.0005)
(base [#3]) + FFM	2.6 ± 0.9	2.3; 2.9	1.5 (1.4; 1.7)	-0.25 (-0.29; -0.22)	0.01 (-0.03; 0.04)
(base [#3]) + Medications + IPAQ Total PA	2.7 ± 0.8	2.4; 2.9	1.5 (1.4; 1.7)	-0.26 (-0.30; -0.23)	Medications: 0.05 (-0.17; 0.17), IPAQ Total PA: 0.0001 (-0.0001; 0.0005)
(base [#3]) + Medications + IPAQ Total PA + FFM	2.7 ± 0.8	2.4; 2.9	1.6 (1.4; 1.7)	-0.29 (-0.33; -0.25)	Medications: -0.06 (-0.18; 0.06) IPAQ Total PA: 0.0002 (-0.0001; 0.0005) FFM: 0.02 (-0.01; 0.05)

Notes: MET: metabolic equivalent; SD: standard deviation; CIs: confidence intervals; IPAQ: International Physical Activity Questionniare; PA: physical activity; FFM: fat free mass moderate-intensity cut-points in older adult physical activity research (e.g., [2, 243, 320, 321]) [118]. Specifically, the older versions of the ActiGraph (e.g., 7164; GT1M) did not have an option to use a low-frequency extension filter during data analysis, as was used in this study. However, in younger adults, GT3X data using the low-frequency filter has produced similar output to that of the ActiGraph 7164, which allows for direct comparisons between those ActiGraph versions as well as the GT1M, given output from the 7164 was not significantly different from three versions of the GT1M during walking [254]. Therefore, in this discussion, comparison will be made with cut-point studies that did not use the low-frequency, and also because only two accelerometer calibration studies exist that applied this filter, one of which was a previous study of ours [225, 322].

Primary study aim: The 3-METs vertical axis moderate-intensity physical activity cut-point ($\geq$1184 counts·min^{-1}) defined in this study on Chinese older adults was 39.3% lower than the most commonly-used cut-point in older adult physical activity research ($\geq$1952 counts·min^{-1} [2]) and 41.4 percent lower than another that has been frequently used ($\geq$2020 counts·min^{-1} [320]) [118]. This suggests that these latter cut-points underestimate time spent in moderate-intensity physical activity. The major reason for the difference between the cut-points appears to be the lower RMR value (1 MET = 2.9 mL O_2·kg^{-1}·min^{-1}) found and adjusted for in this study versus the higher referent RMR value (3.5 mL O_2·kg^{-1}·min^{-1}) otherwise applied – equating to a 17.1% lower energy expenditure at any given MET level for our participants. While this finding is in line with decreasing RMR with ageing, the importance of adjusting for individual RMR – when studying individuals or small groups – was further highlighted when considering our participants' RMR range (1.4-4.4 mL O_2·kg^{-1}·min^{-1}), which was wider than RMR ranges previously reported (1.8-4.4 mL O_2·kg^{-1}·min^{-1}) [225, 226, 258]. In summary, no adjustment for individual RMR may have implications for the valid assessment of energy expenditure. However, the increased accuracy of this approach would have to be taken into consideration in relation to a study's sample size – determining individual cut-points is costly and may not be feasible for large studies.

In consideration of other oft-applied moderate-intensity physical activity cut-points in older adult-based research, our cut-point of 1184 counts·min^{-1} was different by 424 counts·min^{-1} [321] ($\geq$760 counts·min^{-1}; 55.8% higher, p <.05) and 143 counts·min^{-1} [243] ($\geq$1041 counts·min^{-1}; 13.7% higher, p >.05) [118]. It is difficult to compare our cut-point with these studies' findings because, for example, both studies applied arbitrary approaches to define a cut-point: Matthew et al. [321] defined a cut-point from counts·min^{-1} percentiles (data based on participants performing 28 different activities, not just walking) and Copeland et al. [243] decided that walking 3.2 km·hr^{-1} was a "reasonable marker" of moderate-intensity physical activity (finding this speed to equal 3.7 METs, not 3 METs). Our cut-point was also higher than a less-used 824 counts·min^{-1} cut-point [322] (43.7% higher, p <.05) that was established from data that applied the low-frequency extension filter. Again, however, a direct comparison to the current study was difficult, considering the small sample size (n=14), treadmill-based protocol, and statistics used to define the cut-point. Interestingly, however, there was a 171 counts·min^{-1} difference between our new moderate-intensity physical activity cut-point and our previously-defined threshold of ≥1013 counts·min^{-1} [225] (16.9% higher, p >.05), cut-points having been developed using the same methodology bar one difference: participant ethnicity (Chinese and Caucasian). Meaning, from these examples, all but the new cut-point of 1184 counts·min^{-1} would overestimate time spent in moderate-intensity physical activity for our sample of *Chinese* older adults.

That being said, when specifically considering our two studies' findings, the evidence does not support a Chinese-specific cut-point for defining moderate-intensity physical activity in older adults. That is, between our independent cohorts, there was a non-significant difference between moderate-intensity physical activity cut-points, data on RMR (Chinese: 2.9 *vs.* Caucasian: 2.8 mL O_2·kg^{-1}·min^{-1} [225]) and 3-METs walking speed thresholds (Chinese: 2.6 *vs.* Caucasian: 2.5 km·hr^{-1} [225]) were almost identical.

Assuming that the difference between our two cut-points was not due to sampling variation (i.e., to chance), one reason for the higher cut-point value observed in Chinese may relate to the fact that mean height between our Chinese (1.63 m) and Caucasian (1.69 m) [225] cohorts was different. Shorter average height for ethnic Chinese peoples versus those of Caucasian/European descent has been evidenced [323]. Used as a proxy for leg/stride length [324, 325], shorter height may explain the higher production of accelerometer counts for Chinese versus Caucasian older adults between our two samples, because the former would more likely take shorter strides for a given height and therefore more steps over the same distance. Indeed, shorter leg lengths in Chinese versus Caucasian/European peoples has been previously noted [326].

The 3-METs vector magnitude moderate-intensity physical activity cut-point found in this study was 2192 counts·min^{-1}. This finding was higher than the vector magnitude threshold of 1924 counts·min^{-1} from our previous study (13.9% higher) [225] and 1776 counts·min^{-1} from the only other study that could be found reporting this information related to older adults (23.4% higher), albeit females only. [208]

Our data suggest that walking 2.6 $km \cdot hr^{-1}$ is equal to moderate-intensity physical activity at 3-METs and is almost identical to our previous 2.5 $km \cdot hr^{-1}$ finding in the only other study found reporting such information on older adults [225]. With regards to adults, our findings are markedly lower (35% decrease) than the 4.0 $km \cdot hr^{-1}$ at 3 METs reported in the Compendium of Physical Activities (1 MET = 3.5 mL $O_2 \cdot kg^{-1} \cdot min^{-1}$) [256]. Given that exercising at higher intensities than necessary may encourage feelings of displeasure [327] and therefore discourage participation, our findings that moderate-intensity walking can be undertaken at a substantially lower walking speed than previously suggested has important implications for future prescription of walking a speed for health benefits and associated achievement of physical activity guidelines in older adults.

Secondary study aim: The finding of large variability in ActiGraph counts (vertical axis and vector displacement) and walking speed for moderate-intensity physical activity cut-point among older adult participants suggests that, where possible, individual calibration of cut-points would be preferable than applying a pre-defined group-based cut-point from a different cohort. While important for studies with small sample sizes (e.g., clinical) that are concerned with energy expenditure and time spent in moderate- to vigorous-intensity physical activity, it would be impractical and not essential in population-level epidemiological studies. The current study's finding of large inter-individual variability in cut-points is in line with the only other study to investigate this issue, our previous calibration study [225]. Unlike that study, however, including BMI in the prediction equations in this study did not improve model fit. However, we did find that there were some easily measurable variables that improved the fit of the model: number of medications taken per day, IPAQ-measured total physical activity ($mins \cdot week^{-1}$), and fat-free mass (kg).

4.8. Strengths and limitations

Strengths of this study, for reasons aforementioned, include: (1) assessing and adjusting for individual RMR; (2) using an overground walking rather than a treadmill-based protocol; (3) and the application of linear mixed models to estimate moderate-intensity physical activity cut-points and not, for example, arbitrary definitions (e.g., [243, 321]) or linear regression on pooled data (e.g.,

[2]) that cannot account for the violation of independency of observations nor determine inter-individual variability in cut-points. This replication of methodology of our previous study [225] also allowed for direct comparison of findings.

Limitations of the current study also warrant consideration. Our participants' age range was wide (60-85 years old), but mean age was 68.7 years, and inclusion criteria stated that individuals could walk 10 metres unassisted, which may not be representative of all older adults. This may have implications for RMR (older age, lower RMR [263, 264]) and gait [228, 229] and the subsequent number of accelerometer counts produced. Another limitation was that our calibration protocol only involved walking, and no other activities (e.g., vacuuming) as some studies have done (e.g., [315, 328]). That being said, walking is the most common form of physical activity participated in by adults (including older adults) [329-331] and thus changes in, for example, overall physical activity would more likely be influenced by walking than any other physical activity. Lastly, moderate is only one intensity on a spectrum, albeit one that has been shown important for health benefits in relation to numerous markers of health and disease [19], as well as being the prescribed intensity for health benefits [332].

4.9. Conclusion

Our data do not support the need for a Chinese-specific cut-point to define moderate-intensity physical activity in older adults. Our ≥1184 vertical axis counts·min^{-1} threshold was, however, substantially lower than a cut-point developed in a cohort of young adults and the most commonly-used in older adult research, highlighting the need for age-appropriate cut-points. Notably, there was large variability in both vertical axis and vector magnitude displacement count cut-points and RMR, which supports the need to individually-calibrate moderate-intensity physical activity cut-points when feasible. In summary, the findings of this study further highlight the importance of age-specific cut-points for defining moderate-intensity physical activity in older adults and calibrating equations at the individual level for studies with small cohorts

Chapter 5

Perceived built environment and Hong Kong Chinese older adults' accelerometer-assessed physical activity

5.1 Introduction

In *Chapters 1 and 2,* it was established that physical activity, particularly moderate- to –vigorous-intensity physical activity, is beneficial to health and influenced by the built environment [25, 27, 100-102, 333-335]. Moreover, it was noted that the use of inappropriate cut-points for deriving moderate- to vigorous-intensity physical activity in older adults using accelerometer counts (e.g., Freedson et al. cut-point [2]) may have been responsible for the large number of nil associations between built environmental attributes and this behaviour in a recent review [101]. In *Chapter 4,* the fundamental importance of validly assessing Chinese older adults' physical activity was discussed, and a new moderate- to vigorous-intensity physical activity cut-point developed. This chapter will detail a study that applies that new cut-point to measure accelerometer-based moderate- to vigorous-intensity physical activity in Hong Kong Chinese older adults and examine its association with neighbourhood built environmental attributes.

How built environmental attributes are measured also has implications for their association with physical activity. Indeed, findings from a recent systematic review and meta-analysis on the built environment and physical activity revealed that, overall, there were numerous differences in the associations between environmental exposures and physical activity outcomes based on the type of environmental measure used [101] – i.e., whether environmental attributes were perceived or objectively measured [101]. In general, stronger associations were found between physical activity and perceived rather than objectively-measured built environmental attributes [101]. This is consistent with other research [336, 337]. That being said, the strength of the physical activity associations found in the review tended to differ by the domain in which specific built environmental attributes were classified [101]. Specifically, in consideration of Pikora's framework [338], built environmental attributes more aligned with function (e.g., walk-friendly infrastructure) were more likely to be significantly associated with physical activity when objective measures were used [101]. The opposite held true for attributes classified in the safety and aesthetic-related domains (e.g., greenery and aesthetically pleasing scenery), whereby perceived measures were more likely to be significantly associated with physical activity [101]. These results suggest that perceived and objective measures of the environment are not equivalent and are both potentially important determinants of older adults' physical activity behaviour.

Unlike the objective environment, perceptions of the same neighbourhood environment can greatly differ across individuals due to differences in socio-demographics (e.g., age), health status (e.g., physical function), preference, experience, culture, and/or amount of walking in the neighbourhood (e.g., regular walkers may have more accurate perceptions of their local environments) [339]. Assessing perceptions is important because they are more proximal to an individual's intentions and subsequent behaviours than are objective stimuli [340, 341]. Physical activity findings related to perceived exposures may also have further positive implications for urban planners and neighbourhood modifications/design. For example, strong evidence for a positive association between neighbourhood greenery and aesthetically pleasing scenery and older adults' total physical activity was recently reported (perceived exposures only) [101]. Planting trees and flora are micro-scale interventions that would be less costly and more easily implemented than other micro- and macro-level interventions to street design and layout more aligned with objective exposures (e.g., increasing access and availability of neighbourhood shops, commercial destinations, and public transport) [101]. Moreover, perceived measures (e.g., NEWS questionnaire [97, 342]) often define neighbourhood in terms of time to reach a destination (e.g., 10-20 minutes' walk from home [97, 342]), rather than set distances (e.g., objective 400 m home-centred buffers). This is particularly pertinent to older adults, since they differ greatly in mobility [47], walking speed [225], and physical function [319], and for which an objective set distance could not account. Thus, for this demographic, time to destinations is likely to be a more relevant measure of the neighbourhood than the objective distance to a destination. For these reasons, perceived neighbourhood attributes may be more strongly associated with older adults' moderate-to vigorous-intensity physical activity than their objective counterparts.

In Asia, only five articles investigating associations between the perceived built environment and non-domain-specific physical activity have been published, all with total walking as the outcome variable [343-347]. Three of these five articles were from Japan [343, 344, 347] and one article each from Singapore [345] and South Korea [346]. None of the studies used objective assessments of physical activity. The candidate conducted an unpublished meta-analysis using the statistical approach outlined by Cerin et al. [100] on these five articles' findings, and there was sufficient evidence (i.e., ≥5 findings reported from ≥3 articles) to determine a direction of physical activity-related associations for five specific built environmental attributes. Only aesthetically pleasing scenery and neighbourhood greenery was significantly positively related to total physical activity (p <.001) [343-347]. All other associations that were sufficiently studied were nil (p >.05), which included access to shops/commercial destinations [344-347], no physical environmental barriers to walking (e.g., hills) [345, 347], traffic safety [344-347], and crime-related personal safety [344-347]. The lack of significant associations with physical activity for the majority of environmental exposures may be due to three out of the five studies [343, 345, 347] being of low quality [101] (Appendix 6) in terms of failing to stratify for recruitment sites in relation to environmental attributes [343, 345, 347]. To date, no study has been conducted in Hong Kong or other parts of China that has examined perceived built environmental attributes and accelerometer-assessed non-domain-specific physical activity (i.e., moderate- to vigorous-intensity physical activity).

Understanding individual-level moderators of associations between built environmental attributes and physical activity is important because different environmental attributes may affect the behaviour of specific subgroups of the population in different ways. For example, those with low physical function versus those with the high function may have a different relationship with the built environment. Indeed, a recent study of Hong Kong older adults found that those diagnosed with musculoskeletal disease (e.g., arthritis, osteoporosis etc.) had stronger associations with specific built environmental attributes access to a diversity of destination (land-use mix), proximity to recreational facilities, and easy access to residence than those not diagnosed with the condition [348]. However, individual-level moderators of environment-physical activity associations have been under-researched, particularly in Asia [101].

Regarding perceived built environmental attribute associations with non-domain-specific physical activity (total walking), only three of the five studies [343, 344, 346] have investigated potential moderators [101]: age [343], sex [343, 344], employment status [343], and residential density/urbanisation [346]. No study has been conducted in Hong Kong that has examined moderating effects on associations between perceived built environmental attributes and accelerometer-assessed moderate- to vigorous-intensity physical activity.

For these reasons, this chapter details a Hong Kong-based study that investigated the association between perceived built environmental attributes and older adults' accelerometer-assessed moderate- to vigorous-intensity physical activity and potential moderators of these associations. Such information may help to inform future built environment and physical activity research, policy, or practice.

5.2 Aims

The specific objectives of this chapter are:

1. Investigate the associations between perceived built environmental attributes and accelerometer-assessed moderate- to vigorous-intensity physical activity in Chinese older adults; and
2. Investigate the moderating effects of age, sex, education, and the number of diagnosed medical conditions on the above associations.

5.3 Methods

A general overview of the methodology used in this study was provided in *Chapter 3*. The proceeding information is relevant to only this chapter.

5.3.1 Data

5.3.1.1 Accelerometer data reduction

Cut-point thresholds were used to determine the proportion of time spent in different intensities. Specifically, for moderate- to vigorous-intensity physical activity, two cut-points were applied: $\geq$1184 counts·min^{-1} *(Chapter 4)* and $\geq$1952 counts·min^{-1} [2]. For light intensity physical activity, the two cut-point ranges 25-1183 counts·min^{-1} (new cut-points) and 100-1951 counts·min^{-1} [2] were used. Average ActiGraph accelerometer wear time was also calculated after exporting .csv files using Actilife software into a Microsoft Excel® spreadsheet.

5.3.1.2 Outcome variable: Accelerometer-assessed moderate- to vigorous-intensity physical activity

Average daily minutes of ActiGraph-assessed moderate- to vigorous-intensity physical activity was the outcome variable in analyses. Light intensity physical activity was also calculated as a descriptor rather than outcome variable.

5.3.1.3 Covariates and moderators: socio-demographic and health-related variable/s

Interviewer-administered questionnaires provided data on age (in years), sex (‘female’ or ‘male’), educational attainment (‘no formal education;’ ‘primary school;’ ‘secondary school;’ ‘post-secondary education’ – recoded as ‘≤primary schooling’ and ‘≥secondary schooling’), marital status (‘never married;’ ‘married or cohabiting;’ ‘divorced or separated;’ ‘widowed;’ and ‘other’ – recoded as ‘married or cohabiting;’ ‘widowed;’ and ‘other’), living arrangements (‘living alone’ or ‘living with others’), housing (‘private;’ ‘public and aided;’ and ‘renting’), and household car availability (‘yes’ or ‘no’). For participants recruited at Elderly Health Centres, Elderly Health Centre medical staff provided data on the number of diagnosed medical conditions and, for those recruited from community centres, data were collected by researchers using the same clinical health-problems checklist. This checklist included naming chronic conditions, namely: hypertension, heart disease, cerebrovascular disease, asthma, tuberculosis of lung, chronic obstructive airways disease, dementia, depression, Parkinson’s disease, disorder of thyroid, gout, diabetes mellitus, hypercholesterolaemia, peptic ulcer, urinary incontinence, disorder of prostate, polyarthritis, osteoporosis, adhesive shoulder capsulitis, hearing loss, cataract, glaucoma, and cancer. This information was used to calculate the total number of diagnosed medical conditions for each participant. Age, sex, education, and the number of diagnosed medical conditions were treated as covariates in the main effects models and moderators in the interaction effects models of built environmental attributes and moderate- to vigorous-intensity physical activity. Household car availability, marital status and living arrangements were entered as covariates in all regression models.

5.3.1.4 Covariate: accelerometer wear time

Average daily minutes of ActiGraph accelerometer wear time was treated as a covariate in all regression models.

5.3.2 Data analyses

Descriptive statistics were computed for all measured variables. To address aims 1 and 2, generalised linear models (GLMs) rather than generalised additive models with robust standard errors were used as there was insufficient evidence of curvilinearity in effects (based on scatter plots). Generalised linear models with robust standard errors can accommodate positively-skewed outcomes when data are correlated (i.e., ‘clustered;’ collected from individuals living in selected tertiary planning units). In this study, GLMs with Gamma variance and logarithmic link functions were used to model the moderate- to vigorous-intensity physical activity outcome. The reported antilogarithms of the regression coefficients of moderate- to vigorous-intensity physical activity represent the proportional difference in daily minutes of moderate- to vigorous-intensity physical activity associated with a 1-unit increase in the predictor (i.e., each built environmental attribute on the NEWS questionnaire [97, 342]).

First, a set of main-effect GLMs estimated the dose-response association for each single environmental attribute with the outcome, adjusting for age, sex, education, car in the household, number of diagnosed medical conditions, average daily ActiGraph accelerometer wear time, and type of recruitment centre (Elderly Health Centre *vs.* community centre).

Second, a separate set of single-environment-variable GLMs were computed to investigate potential moderating effects of age, sex, education, household car availability, and the number of diagnosed medical conditions by adding a single two-way interaction term to the main-effect GLMs. Significant interaction effects were defined as a 10-unit difference in quasi-Akaike Information Criterion when comparing models with and without a specific interaction term (i.e., smaller quasi-Akaike Information Criterion value for models with interaction terms). Significant interaction effects were probed by estimating associations for specific values of the moderator (e.g., ≤primary schooling vs. ≥secondary schooling) using linear combinations of regression coefficients. For continuous moderators (i.e., age and health-related variables such as the number of diagnosed medical conditions), associations were estimated at average and mean ±1 SD values of the moderator. Lastly, the final multivariate models included only significant main and interaction effects. All analyses were conducted in Stata 14.

5.4 Results

A similar percentage of older adults were recruited from different neighbourhood strata, specifically: low walkable and low socio-economic status residents (25.9%), low walkable and high- socio-economic status residents (23.6%), high walkable and low socio-economic status residents (24.9%), and high walkable and high socio-economic status (25.6%). High mean levels of perceived residential density, street connectivity, access to land-use mix—diversity of destinations and overall destinations and services, infrastructure for walking, easy access to residential entrance, fence/barrier separating sidewalk/pavement and traffic, and presence of people and low mean levels of physical environmental barriers to walking and crime were reported.

Participant (n=402) and physical activity characteristics are presented in Table 14. Overall, applying two different cut-points to classify moderate- to vigorous-intensity physical activity, Chinese older adults accrued on average 65 min·day^{-1} (≥1184 counts·min^{-1} cut-point) and 26 min·day^{-1} (Freedson et al.'s ≥1952 counts·min^{-1} cut-point [2]) equivalent to 455 min·week^{-1} and 182 min·week^{-1} [2], respectively. Regarding light intensity physical activity, participants accumulated on average 342 min·day^{-1} (25-1183 counts·min^{-1} cut-point) and 273 min·day^{-1} (Freedson et al.'s 100-1951 counts·min^{-1} cut-point [2]) equivalent to 2394 min·week^{-1} and 1911 min·week^{-1} [2], respectively. Average daily ActiGraph wear time was 811 min·day^{-1}.

Table 14. Participant socio-demographic, health-related, physical activity, and environmental characteristics

Variable	Mean ± SD or %
Socio-demographic	
Age (years)	75.5 ± 6.2
Sex (female)	68.9%
Educational attainment	
≤Primary schooling	53.2%
≥Secondary schooling	46.8%
Marital status	
Married or cohabiting	62.9%
Widowed	28.4%
Other	8.7%
Household with car	28.9%
Housing	
Public and aided	50.8%
Private, purchased	44.0%
Renting	5.2%

Living alone	23.9%
Neighbourhood type	
Low walkable, low SES	25.9%
Low walkable, high SES	23.6%
High walkable, low SES	24.9%
High walkable, high SES	25.6%
Health-related	
Number of diagnosed medical conditions	3.1 ± 2.0
Accelerometry-related	
Wear time (min·day^{-1})	810.6 ± 91.7
Moderate- to vigorous-intensity physical activity	
≥1184 counts·min^{-1} cut-point (min·day^{-1})	64.7 ± 36.3
≥1952 counts·min^{-1} cut-point (min·day^{-1})	25.7 ± 23.3
Light intensity physical activity	
25-1183 counts·min^{-1} cut-point (min·day^{-1})	342.1 ± 88.7
100-1951 counts·min^{-1} cut-point (min·day^{-1})	272.7 ± 81.9
Built environmental attributes – NEWS questionnaire	
Residential density	652.1 ± 149.8
Street connectivity	3.6 ± 0.6
Land-use mix—destination diversity	3.4 ± 0.8
Access to destinations and services	3.8 ± 0.5
Physical environmental barriers to walking	1.6 ± 0.6
Infrastructure for walking	3.6 ± 0.5
Bridge/overpass connection to services	1.9 ± 1.1
Indoor places for walking	2.5 ± 1.0
Benches/sitting facilities	2.5 ± 1.2
Easy access to entrance of residence	3.7 ± 0.7
Aesthetics	2.8 ± 0.8
Social disorder and littering	1.9 ± 0.7
Traffic and road hazards	1.7 ± 0.5
Fence separating sidewalk and traffic	3.0 ± 1.2
Traffic speed	2.7 ± 0.6
Crime	1.3 ± 0.5
Presence of people in the streets	3.5 ± 0.6
Crowdedness	1.7 ± 0.8

Notes: SD: standard deviation; SES: socio-economic status; NEWS: Neighborhood Environment Walkability Scale questionnaire

In single environmental attribute main-effect models (Table 15), access to a bridge or overpass connection (new cut-point: p = .024; Freedson et al. cut-point [2]: p = .022), social disorder and littering (new cut-point: p = .003; Freedson et al. cut-point [2]: p = .011) and access to land-use mix—diversity of destinations were signifcantly (new cutpoint: p = .017) were positively associated with older adults' moderate- to vigorous-intensity physical activity minutes per day.

Table 15. Associations between built environmental attributes and accelerometer-assessed moderate- to vigorous-intensity physical activity by cut-point – main effects, single environmental variable models

Environmental attribute	Moderate- to vigorous-intensity physical activity ($min{\cdot}day^{-1}$)			
	≥1184 $counts{\cdot}min^{-1}$ cut-point		≥1952 $counts{\cdot}min^{-1}$ cut-point [2]	
	e^b (95% CIs)	*p*	e^b (95% CIs)	*p*
Residential density	0.9996 (0.9992; 1.000)	.090	0.9996 (0.9990; 1.000)	.125
Land-use mix—destination diversity	1.083 (1.014; 1.156)*	.017	1.050 (0.941; 1.171)	.386
Access to destinations and services	1.066 (0.967; 1.174)	.199	1.014 (0.864; 1.191)	.861
Physical barriers to walking (e.g., hills)	0.916 (0.834; 1.004)	.061	0.903 (0.768; 1.061)	.215
Street connectivity	1.027 (0.937; 1.126)	.566	1.044 (0.916; 1.189)	.517
Infrastructure for walking	1.063 (0.958; 1.178)	.250	1.012 (0.848; 1.208)	.893
Indoor places for walking	0.999 (0.958; 1.042)	.966	0.991 (0.923; 1.064)	.798
Aesthetics	1.007 (0.944; 1.074)	.829	1.040 (0.923; 1.173)	.520
Presence of people in the streets	0.955 (0.868; 1.051)	.351	0.979 (0.856; 1.122)	.766
Crowdedness	1.032 (0.973; 1.095)	.296	1.031 (0.932; 1.140)	.553
Traffic and road hazards	0.976 (0.901; 1.057)	.543	1.025 (0.880; 1.194)	.748
Traffic speed	1.009 (0.919; 1.107)	.856	1.068 (0.948; 1.202)	.278
Social disorder and littering	1.106 (1.031; 1.187)**	.005	1.189 (1.038; 1.362)*	.012
Crime	1.035 (0.962; 1.112)	.356	1.092 (0.928; 1.286)	.290
Bridge/overpass connection	1.063 (1.010; 1.119)*	.019	1.098 (1.015; 1.187)*	.019
Easy access to residence	0.996 (0.930; 1.066)	.900	1.058 (0.939; 1.191)	.355
Fence separating sidewalk and traffic	0.999 (0.953; 1.047)	.980	1.012 (0.946; 1.083)	.730
Sitting facilities	1.005 (0.959; 1.054)	.822	1.019 (0.947; 1.097)	.617

Notes: e^b: antilogarithm of the regression coefficient; CIs = confidence intervals. Each model per applied cut-point was adjusted for age, sex, education, household car availability, living arrangements, marital status, the number of diagnosed medical conditions, and type of recruitment centre. **p* <.05; ***p* <.01; ****p* <.001

In multivariate main-effect models (Table 16), residential density was signifcantly (new cutpoint: *p* =.006; Freedson et al. cut-point [2]: *p* =.015) negatively associated (i.e., less time spent in) with older adults' moderate- to vigorous-intensity physical activity minutes per day, and access to a bridge or overpass connection (new cut-point: *p* =.024; Freedson et al. cut-point [2]: *p* =.022) and increased social disorder and littering (new cut-point: *p* =.003; Freedson et al. cut-point [2]: *p* =.011) were significantly positively associated with moderate- to vigorous-intensity physical activity minutes per day. Land-use mix—destination diversity was significantly positively associated with moderate- to vigorous-intensity physical activity minutes per day classified by the new cut-point (*p* =.002) and approached significance (*p* =.05) when classified using the Freedson et al. cut-point [2], respectively.

The results of the multiple-environmental-variable models presented in Table 16 translate to the following differences in moderate- to vigorous-intensity physical activity $min{\cdot}day^{-1}$ (specified cut-point in brackets) associated with a 1-point increase on each relevant NEWS subscale: *residential density:* a 0.1% decrease (<1 $min{\cdot}day^{-1}$; ≥1184 $counts{\cdot}min^{-1}$ and Freedson et al. cut-point [2]), *land-use mix—destination diversity:* a 12% (≈7.8 min·day^{-1}; ≥1184 counts·min^{-1} cut-point) and 11% increase (≈7.8 min·day^{-1}; Freedson et al. cut-point [2]); *bridge/overpass connection:* a 6% (≈3.9 min·day^{-1}; ≥1184 counts·min^{-1} cut-point) and 10% increase (≈2.6 min·day^{-1}; Freedson et al. cut-point [2]); and *social disorder/littering:* a 12% (≈7.8 min·day^{-1}; ≥1184 counts·min^{-1} cut-point) and 20% increase (≈5.1 min·day^{-1}) (Freedson et al. cut-point [2]).

Table 16. Associations between built environmental attributes and accelerometer-assessed moderate- to vigorous-intensity physical activity by cut-point – main effects, multiple-environmental variable models

Environmental attribute	Moderate- to vigorous-intensity physical activity (min·day^{-1})			
	≥1184 counts·min^{-1} cut-point		≥1952 counts·min^{-1} cut-point [2]	
	e^b (95% CIs)	*p*	e^b (95% CIs)	*p*
Residential density	0.9994 (0.9990; 0.9998)**	.006	.9993 (.9990; .9999)*	.015
Land-use mix—destination diversity	1.119 (1.042; 1.201)**	.002	1.110 (1.000; 1.232)	.050
Bridge/overpass connection	1.063 (1.008; 1.121)*	.024	1.098 (1.013; 1.189)*	.022
Social disorder and littering	1.117 (1.040; 1.201)**	.003	1.203 (1.044; 1.387)*	.011

Notes: e^b: antilogarithm of the regression coefficient; CIs: confidence intervals. Each model per applied cut-point was adjusted for age, sex, education, household car availability, living arrangements, marital status, the number of diagnosed medical conditions, and type of recruitment centre. **p* <.05; ***p* <.01; ****p* <.001

Table 17 presents the first-order moderating effects of specific participant characteristics on a given built environmental attribute and moderate- to vigorous-intensity physical activity association. Specifically, age moderated the associations of land-use mix—diversity of destinations and moderate- to vigorous-intensity physical activity (new cut-point only), whereby a stronger positive association was found in older participants. Age also moderated the association of social disorder/littering of destinations and moderate- to vigorous-intensity physical activity (Freedson et al. cut-point [2] only), a stronger positive association again being found in older individuals. The next investigated moderator to produce a significant finding on physical activity associations was sex (both findings related to the Freedson et al. cut-point [2] only). Sex moderated the association between access to overall destinations and services and moderate- to vigorous-intensity physical activity – men showing a positive association that was not found in women. Sex also moderated the association between traffic speed and moderate- to vigorous-intensity physical activity, a positive association being found in women only. The last moderator to significantly interact with perceived environmental attributes on physical activity was the number of diagnosed medical conditions (Freedson et al. cut-point [2] only). A positive association between neighbourhood aesthetics and moderate- to vigorous-intensity physical activity was found for individuals with a lower number of diagnosed medical conditions.

Table 17. Interaction effects on associations between built environmental attributes and accelerometer-assessed moderate- to vigorous-intensity physical activity by cut-point

Interaction	Moderate- to vigorous-intensity physical activity (min·day^{-1})			
	≥1184 counts·min^{-1} cut-point		≥1952 counts·min^{-1} cut-point [2]	
	e^{b} (95% CIs)	*p*	e^{b} (95% CIs)	*p*
Age*Land-use mix—destination diversity				
81.7 years (+1 SD)	1.227 (1.106; 1.360)***	<.001	-	-
75.5 years (average)	1.115 (1.044; 1.191)**	.001	-	-
69.4 years (-1 SD)	1.014 (0.922; 1.116)	.768	-	-
Age*Social disorder and littering				
81.7 years (+1 SD)	-	-	1.351 (1.137; 1.604)**	.001
75.5 years (average)	-	-	1.183 (1.033; 1.354)*	.015
69.4 years (-1 SD)	-	-	1.036 (0.867; 1.237)	.698
Sex*Access to destinations and services				
Women	-	-	0.906 (0.761; 1.079)	.269
Men	-	-	1.423 (1.028; 1.971)*	.034
Sex*Traffic speed				
Women	-	-	1.177 (1.017; 1.326)*	.028
Men	-	-	0.901 (0.769; 1.054)	.193
Number of medical conditions*Aesthetics				
5.10 conditions (+1 SD)	0.925 (0.843; 1.015)	.099	0.890 (0.789; 1.004)	.058
3.07 conditions (average)	1.003 (0.937; 1.073)	.931	1.031 (0.920; 1.155)	.604
1.05 conditions (-1 SD)	1.088 (0.996; 1.188)	.062	1.193 (1.023; 1.392)*	.024

Notes: e^{b}: antilogarithm of regression coefficient; CIs: confidence intervals; *p*: *p*-value. $*p < .05$; $**p < .01$; $***p < .001$

5.5 Discussion

This is the first study to investigate the association between perceived built environmental attributes and accelerometer-assessed moderate- to vigorous-intensity physical activity in a community sample of Hong Kong Chinese older adults. Two accelerometer cut-points were used to classify moderate- to vigorous-intensity physical activity behaviour to compare any differences in associations with the built environment. Secondary aims of this study were to examine the interaction between built environmental attributes and participant characteristics on daily minutes of moderate- to vigorous-intensity physical activity.

5.5.1 Daily moderate- to vigorous-intensity physical activity

Findings related to moderate- to vigorous-intensity physical activity participation lend support to the fact that Hong Kong Chinese older adults are more physically active than adults of the same age from other countries. On average, using our newly-developed cut-point, older adults accumulated 453 min·week^{-1} of moderate- to vigorous-intensity physical activity, which is 202% above current recommendations of 150 min·week^{-1} [23, 27]. Using the most widely-used moderate- to vigorous-intensity physical activity cut-point (i.e., Freedson et al. [2]), our participants still exceeded recommendations but to a much lesser extent when compared to our newly-developed cut-point, accruing 180 min·week^{-1}. By comparison, British [86] and Australian older adults [266] have been reported to participate in 139 and 110 weekly minutes of moderate- to vigorous-intensity physical activity, respectively, when this behaviour was classified using the Freedson et al. cut-point [2]. In our results, the stark difference in daily minutes of moderate- to vigorous-intensity physical activity (273 min·week^{-1}) as classified by the two discrete cut-points, can be partly explained by what we learned in *Chapter 4* about the inappropriateness of applying cut-points developed in young Caucasian adults (i.e., Freedson et al. cut-point [2]) to older adults and the Freedson et al.'s cut-point not accounting for individual differences in RMR and gait [225].

5.5.2 Main effects of perceived neighbourhood attributes

These high levels of moderate- to vigorous-intensity physical activity in Hong Kong Chinese older adults have previously been attributed to cultural and environmental factors [247, 334, 349]. Indeed, in this study, three specific built environmental attributes were significantly associated with participants' moderate- to vigorous-intensity physical activity for both applied cut-points and one further attribute significantly related to this outcome operationalised using the new cut-point only. Specifically, in order of strongest positive associations, access to land-use mixes—diversity of destinations, presence of social disorder and/or littering, access to a bridge or overpass connection were associated with older adults' moderate- to vigorous-intensity physical activity. Residential density was negatively associated with older adults' moderate- to vigorous-intensity physical activity.

We found that increased access to land-use mix—diversity of destinations was significantly positively associated with moderate- to vigorous-intensity physical activity as classified by the new-cut-point and approached significance in relation to the Freedson et al. cut-point [2]. This is in line with the finding of a recent meta-analysis which reported a positive association of this particular environmental attribute with older adults' objectively assessed total physical activity [101]. Neighbourhoods rich in a diversity of destinations promote walking (and, hence, physical activity) among older adults because shopping has been highlighted as the most prevalent reason for this demographic to venture out of home [115], and thus important for their daily living.

With regards to social disorder and/or littering, again, while not directly comparable, our finding is somewhat at odds with recent evidence from a published meta-analysis reporting that aesthetically pleasing neighbourhoods were not associated with total objectively-assessed physical activity in older adults [101] and from an unpublished meta-analysis of Asian studies reporting a positive association using self-report measure of aesthetics and objectives measures of physical activity (aforementioned) [343-347]. Our finding may be idiosyncratic of Hong Kong. Also, more physically active older adults may be more aware of social disorder and litter near their homes [350]. Alternatively, destination-rich busy neighbourhood areas may attract more social disorder and littering [351].

Regarding overpass connections, while not directly comparable, the finding is in agreement with recent evidence from a meta-analysis suggesting that perceived walk-friendly infrastructure was positively associated with total objectively-assessed physical activity in older adults [101]. In Asia, there has not been sufficient research with regards walk-friendly infrastructure and its effects on older adults' physical activity [344, 345, 347]. That being said, footbridges and overpass connections are typical of Hong Kong and likely assists older adults overcome issues when walking on steep terrain and in areas with high traffic volume. Indeed, a positive association with weekly minutes of neighbourhood recreational walking [75] has previously been reported in this population, but not transport-related walking [251].

Our result of a negative association between moderate to vigorous-intensity physical activity and residential density did not agree with the nil association reported in a recent meta-analysis in relation to older adults' objectively measured total physical activity [101]. While residential density is usually a proxy for high levels of access to destinations and services and diverse land uses [352], it may be that this finding may be specific to Hong Kong given its extreme residential density versus other cities [334] – for example, older adults cannot walk at a moderately-intense pace due to high levels of crowdedness. This claim is supported by our finding that moderate- to vigorous-intensity physical activity was only significantly negatively associated with residential density after controlling for land use mix—diversity of destinations, that is, once the mutual 'confounding' effects of density and land-use mix were accounted for. This implies that increasing neighbourhood residential density alone and excessively does not facilitate participation in moderate- to vigorous-intensity physical activity and, thus, planners should ensure neighbourhoods are not overly dense therein and include destinations that encourage older adults to leave their home (e.g., shops).

The majority of our findings on the associations between built environmental attributes and moderate- to vigorous-intensity physical activity were nil. This could be due to accelerometers not being able to distinguish between physical activity domains (e.g., transportation versus household activities) and differentiate ambulatory movement (i.e., walking) from other types of physical activity [192]. Different types/domains of physical activity (e.g., recreational) have been shown to have a different relationship with built environmental attributes [100, 102] compared to non-domain-specific total physical activity [101]. Similarly, context-specific physical activity (e.g., walking within the neighbourhood) has been highlighted as having a different association with the neighbourhood built environment than non-context-specific total walking [251]. The use of domain/context-specific measures in addition to accelerometry would provide a more comprehensive picture of the relationship between older adults' physical activity behaviour and the neighbourhood built environment.

5.5.3 Moderators of perceived environment–physical activity associations

Understanding moderators of physical activity-built environment associations is important because it may identify groups whose moderate- to vigorous-intensity physical activity is more affected by built environmental attributes than others. In the present study, age moderated the effect of land-use mix—diversity of destinations on physical activity, whereby increased access to a diversity of destinations appeared to be more important for moderate- to vigorous-intensity physical activity participation in older Hong Kong Chinese older adults (>75 years old). This stronger association in older-aged adults is at odds with a USA-based study reporting a stronger moderating effect for younger adults (65-79 years old) than those older (≥80 years old) between land use-mix—destination diversity and total physical activity [353] – the only other study to investigate these effects. It may be that these findings are culture and/or city-specific. It may also be related to the fact that the USA-based study recruited participants from retirement homes and communities (including assisted living) [353]. Assisted living for older residents, who likely have lower physical function, includes preparing and providing meals to residents [353]. This means there would be less need for older participants to venture into the local neighbourhood to undertake, for example, shopping-related trips (including grocery shopping), shown to be an important reason for engagement in transport-related physical activity [115]. Convenience sampling may also have compounded this issue if indeed this was the case in the Chad et al. study [353] because it would more likely mean that older residents were recruited from the same assisted living facility. Hence, in the USA-based study, moderate- to vigorous-intensity in 'younger' older adults would have been more influenced by differing levels of access to a variety of neighbourhood destinations because these individuals might have been recruited from living arrangements encouraging more independence. In our Hong Kong sample, participants were living independently in the community and, therefore, a variety of local neighbourhood destinations remained more important for older-aged individuals' accumulation of moderate- to vigorous-intensity physical activity, whose physical function would likely have been lower than those who were younger.

No other moderating effects were found in relation to other significant built environment correlates, which is promising because it implies that manipulation of the physical environment would equally affect moderate- to vigorous-intensity physical activity across demographic sub-groups of the older population. The lack of interactions in this study may be due to the ultra-dense nature of Hong Kong neighbourhoods and the associated high level of accessibilities to destinations.

A higher number of interaction effects were reported in relation to the Freedson et al. cut-point [2]. Age moderated the association between moderate- to vigorous-intensity physical activity and social disorder/littering (stronger association for adults >75 years old), sex moderated the association between moderate- to vigorous-intensity physical activity and access to services (stronger association for men) and traffic speed (stronger association for women), and number of diagnosed conditions moderated the association between moderate- to vigorous-intensity physical activity and aesthetics (stronger association for those diagnosed with the least number of medical conditions). Ostensibly, age-related findings add to a dearth of evidence on these differential effects [101], sex-related findings with regards access to services disagree with previously reported nil effects [343, 354-356] and partly agree with another study reporting mixed results [357], sex-related findings regarding traffic speed disagree with previously reported nil findings [274, 344, 356], and number of medical conditions-related findings with regards neighbourhood aesthetics disagree with the nil findings of other studies investigating health status-related moderating effects [358, 359]. This lack of agreement with previous research and, indeed, findings related to our newly-developed cut-point – a more valid measure of Chinese older adults' moderate- to vigorous-intensity physical activity – leads us to consider the legitimacy of interactions effects related to moderate- to vigorous-intensity physical activity determined using the Freedson et al. cut-point [2].

Age, sex, and health status would likely impact on individual cut-point calibration, whereby age [263] and sex [360]*(Chapter 4)* influence RMR and age [264] and a number of diagnosed conditions may impact gait and walk. These factors were not taken into account in the Freedson et al. calibration study [2] because their participants were healthy young adults with high physical function. Thus, interaction effects may be an artefact of measurement issues rather than representing real effects due to the inability of the Freedson et al. cut-point [2] to validly assess moderate- to vigorous-intensity physical activity in this demographic. Indeed, *Chapter 4* highlighted the large variability in cut-points across individuals and, based on a normal distribution, only 19.5% of our methodology study's cohort would be expected to have a moderate- to vigorous-intensity physical activity cut-point the same as Freedson et al. (≥1952 counts·min^{-1} [2]) or higher (Appendix 17).

5.6 Conclusion

In summary, neighbourhoods with higher access to a diversity of destinations, social disorder and/or littering and access to a bridge or overpass connection were positively associated with Hong Kong Chinese older adults' moderate- to vigorous-intensity physical activity as classified by our new accelerometer cut-point. Higher residential density was negatively associated with older adults' moderate- to vigorous-intensity physical activity. The same associations classified using the most commonly-used cut-point (i.e., [2]) in older adult-based physical activity research were in the same direction but not as strong. This was likely due to numerous methodological issues associated with the development of this cut-point [2]. These study/cut-point [2] limitations also likely explained the increased amount of moderating effects for physical activity-built environment associations versus our newly-developed cut-point, which assesses Chinese older adults' moderate- to vigorous-intensity physical activity more validly. Access to a wide range of neighbourhood destinations was an important correlate of Hong Kong Chinese older adults' participation in moderate- to vigorous-intensity physical activity. Higher [extreme] residential density in itself was found to negatively impact this behaviour. Therefore, neighbourhoods need to be created/redesigned so that they provide good access to a variety of destinations but are not overly dense in terms of residences alone. Footbridge overpasses were found to be positively associated with moderate- to vigorous-intensity physical activity. While this finding may be idiosyncratic of Hong Kong – helping older adults navigate particularly steep terrain and areas with high traffic volume – it highlights the importance of prioritising the inclusion of this built environmental attribute in neighbourhoods.

Chapter 6
Perceived built environment and Hong Kong Chinese older adults' accelerometer-assessed sedentary time

6.1 Introduction

Sedentary behaviour is a risk factor for non-communicable diseases. Increased sitting, lying down, watching television, and computer use has been associated with increased mortality [59, 78, 361-363] and metabolic and cardiovascular risk [364-369]. Prevalence of these behaviours increases with age and evidence suggests that older adults can spend up to 80% of waking time being sedentary [80, 370-372]. Thus, identifying and understanding the correlates of sedentary time is important for devising interventions to reduce older adults' sedentary behaviour and improve their health.

According to socio-economic models of behaviour, there are various layers of influences on any given behaviour, including sedentary behaviour [85]. In order to develop the most effective public health interventions, such influences, including the built environment, need to be understood. If it is found that the built environment – such as physical neighbourhood attributes – reduces levels of sedentary behaviour, this may be particularly promising since older adults spend most of their time in their neighbourhood, including at home [373]. Because of this, even small effect sizes may contribute to substantial public health benefit for older adults, versus, for example, individual-level interventions that may have larger effect sizes but effects are not as prolonged and do not reach as many people. Positive influences of specific characteristics of the built environment (e.g., good access to destinations and services and a mix of land-uses) on physical activity have already been evidenced [100-102]. However, whether the effects of the built environment extend to sedentary behaviour remains unclear due to the lack of research on this issue. The general hypotheses would follow the findings of our three recently published meta-analyses [100-102]:

neighbourhoods that are safe, aesthetically-pleasing, with good access to destinations and services and a mix of land-uses would encourage older adults to leave their home and subsequently be less sedentary.

Unlike physical activity research [101], there is a scarce amount of literature available investigating the association between built environmental attributes and older adults' objectively-measured sedentary time. A scoping review found only four published articles on this topic, with no consistent findings being reported [240-242, 374]. Cerin et al. [242] found that objectively measured net residential density (400 m buffer) and public transit density (1 km buffer) were negatively associated with Hong Kong Chinese older adults' sedentary time. In contrast, Van der Berg et al. [374] found that increased residential density – living in an apartment or duplex versus a villa – was related to increased accelerometer-assessed sedentary time in older adults living in Iceland. Shaw et al. [240] found that greater perceived crime was associated with greater inclinometer-assessed sedentary time in one cohort of Scottish-British older adults out of three. Finally, Fleig et al. [241] found no association between any perceived built environmental attributes (e.g., access to services) and accelerometer-assessed sedentary time in older adults living in Canada.

A lack of consistent findings has also been observed in studies of older adults self-reporting their sedentary behaviour in relation to the built environment (n=3 articles) [237-239]. Urbanisation, feeling of unsafety, and the absence of noise were shown to be associated with significantly higher amounts of television viewing in Belgian older adults [239]. In contrast, in the same study, shorter distances to facilities and presence of cultural facilities, street lighting and neighbourhood greenery were significantly associated with lower amounts of television viewing [239]. In a study from Taiwan, low levels of traffic safety were associated with significantly higher odds of older adults watching television for two hours or more per day [237]. In line with this result, Australian older adults who did not perceive local traffic as a deterrent to walking reported significantly lower television viewing time [238]. However, when using objective measures of sedentary time, Fleig et al. did not find significant associations with traffic safety [241].

When considering the findings of studies using perceived and objective measures of sedentary behaviour (n=7 articles), it is difficult to make direct comparisons due to the low number of studies published and various methods and methodologies used therein (Appendix 18). However, it seems that low levels of safety – personal [239, 240] and traffic [237, 238] – may be associated with more sedentary time in older adults. In contrast, findings related to access to destinations and services and other physical aspects of the environment appear to produce diverse results [239, 241, 242, 374].

Mixed findings may be due to a variety of reasons, including differences in Western and Eastern culture and/or geographical contexts. For example, Western cities like those in Iceland (Reykjavik) [374] are more homogenously lower density with generally poorer access to destinations and facilities than Eastern cities like Hong Kong (China) [242, 334, 375]. The difference between findings in Hong Kong and Reykjavik might be due to differences in the associations between density and socio-economic status. Density is unrelated to income in Hong Kong [376], while it might be negatively related to income in Iceland (those living in villas being of higher socio-economic than those living in apartments). Further, socio-economic status may be associated with a higher tendency for replacing some sedentary time with leisure-time physical activity [377, 378].

With regards to crime-related safety, Western cities/regions such as Scotland [240] (98 crimes/offences·1,000 people^{-1} [379]) and Belgium [239] (79 crimes/offences per 1,000 people [380]) have higher rates of crime than Eastern cities/regions like Hong Kong [242] (8 crimes/offences·1,000 people^{-1} [381]) and Taiwan [237] (Taiwan has been noted as having a higher rating of personal safety than, for example, Belgium and the United Kingdom [382]). Thus, older adults living in Western cities/region may be less inclined to leave their home. Regarding traffic safety-related findings, Australia is a notoriously car-dependent society (i.e., at least 89% of households own a car – 20% of which own three or more cars [383]), and with car ownership being 559 cars per 1,000 people [384], it may follow, then, that safety around traffic is more of an issue in Australia [238] than in Canada [241] (420 cars·1,000 people^{-1}[385]) where car ownership proportional to the population is markedly lower. That being said, this logic does not apply to the Taiwan-based study [237] where car ownership is 333 cars per 1,000 people [386]. However, unlike Australia (5.4 road deaths·1,000 people^{-1}) and Canada (6.0 road deaths·1,000 people^{-1}), Taiwan has a much higher fatality rate (13.6 road deaths·1,000 people^{-1}) [387] and therefore traffic-related safety is more of an issue. Or it may be that Hsueh et al.'s stratification of recruitment sites by urbanisation (highly urbanised Taipei City [likely high traffic] and rural Chiayi County [likely low traffic]) allowed for adequate variability in the data to detect a significant association [237], which the Canada-based study examining traffic-related safety and sedentary behaviour did not do and found a nil association [241].

Considering study quality may be important when interpreting the results above, given the small number of articles published in this area [237-242, 374]. Following the criteria of our quality assessment scale [100-102] only one study was deemed of high quality [242], five of moderate quality [237-239, 241, 374], and the remaining study being low in quality [240] (Appendix 18). [Incidentally, the data used for the current thesis is from the same dataset as that of the Cerin et al. study [242].] The lack of high-quality research may partly explain why 81% of individual investigations (77/95 individual associations) of built environmental attributes and sedentary behaviour were non-significant (p >.05) [237-242, 374] (Appendix 18).

Examining moderating effects on associations between the built environment and sedentary behaviour may also provide us with a better overall understanding of the relationship between exposures and outcomes by helping to identify sub-groups of the older adult population most in need of/most sensitive to specific characteristics of the built environment. However, to date, only three studies have investigated any moderating effects on built environment-sedentary behaviour associations by sample characteristics (e.g., sex) [238, 242, 374]. In Australia, no significant interactions (p >.05) for age, sex, change in mobility, or working status were found [238]. Likewise, no moderating effects for sex were found in older adults living in Iceland (p >.05) [374]. In the Hong Kong-based study [242], however, three significant (p's <.05) moderators were found of which sex had the highest number of interactions (n=4) – contrary to the findings of the other two 'Western' studies [238, 374] – followed by household car ownership (n=2), and education (n=1) [242]. Specifically, significant negative associations were found in women only for retail density, food outlet density and public transit density. However, a negative association between entertainment density and accelerometry-assessed sedentary time was found only for men. Further, public transit density was negatively related to sedentary time in those with secondary or higher education only and in those with no car in the household [242]. In addition, distance to the nearest trail and accelerometer-assessed sedentary time were positively associated in Hong Kong older adults with no car in the household [242].

Sex and level of education, for example, may affect the choice of preferred physical activities that may replace/displace sedentary time. Older women in Hong Kong are more likely to follow traditional gender roles such as taking control of daily household-related duties including grocery shopping [344, 388], which may be helped with access to public transport. Conversely, men are more likely to venture out of the home for non-household-related purposes [389], socialising with other men to gamble [390] and/or play board games [391]. Older adults with higher education levels have reported walking more for recreation versus less educated individuals [75], who may prefer to participate in other forms of recreation such as group-based classes at recreational facilities (e.g., tai-chi). Discretionary income may also play a role, since those with higher education levels are more likely to have more money, to more often use public transport and purchase goods and services in their neighbourhoods. These findings highlight that sub-groups of Hong Kong Chinese older adults (e.g., women) have a different relationship with specific built environmental attributes and time spent sedentary [242], which may differ again when compared to other countries such as Australia [238] and Iceland [374].

In Hong Kong, while knowing the relationship between the objective built environment and accelerometer-assessed sedentary time in older adults (and associated moderating effects) [242], it is still meaningful to extend the investigation in the current PhD thesis to the perceived environment. Stronger associations with the built environment have been evidenced for matched perceived than objective environmental characteristics, albeit in relation to physical activity outcomes [101, 336]. Different relationships by environment measurement methods between the perceived and objective environment and physical activity outcomes were also found [101]. Therefore, it may be that the perceived environment is more closely aligned with the individual, their definition of 'neighbourhood' and associated physical activity. It is unknown whether a similar relationship holds for sedentary behaviour.

Sedentary time classification may also play a role in defining associations between the perceived built environment and sedentary time. As we learned from *Chapter 4*, even valid measures of physical activity behaviour (i.e., accelerometry) could be improved with the application of a more appropriate accelerometer count cut-point to classify older adults' moderate- to vigorous-intensity physical activity. The previous use of a less appropriate cut-point [2] and subsequent misclassification of moderate- to vigorous-intensity physical activity was identified as a potential reason for the high number of nil associations within the built environment-physical activity research base [101]. Indeed, in *Chapter 5*, we saw that, generally, our [more appropriate] cut-point had stronger associations with built environmental attributes versus a [less appropriate] cut-point [2] most commonly-used in older adult physical activity research [118]. While the majority of sedentary behaviour-based studies (4/7 articles), including the Cerin et al. study [242], used valid objective measures of sedentary behaviour (i.e., ActiGraph [241, 242, 374] and *activ*PAL™ [240]), the ActiGraph-based studies classified sedentary time as <100 accelerometer counts·min^{-1}. This cut-point has been evidenced as being too high for older adults (<25 accelerometer counts·min^{-1}

being more appropriate) [205] and therefore activity counts recorded between the 25-99 accelerometer counts·min^{-1} threshold would have been categorised as sedentary behaviour when it was light intensity physical activity. This may not be a trivial consideration given some researchers purport that sedentary behaviour [363] and light intensity physical activity [69] are behaviours independent of moderate- to vigorous-intensity physical activity.

Despite such contention, no study to date has investigated whether older adults' moderate- to vigorous-intensity physical activity mediates the association between sedentary behaviour and the built environment. The author has identified only one study that had conducted mediation analysis in relation to sedentary behaviour but was focused on psychosocial mediators (i.e., attitude towards walking and behavioural control for walking) [241]. Examining the extent to which the potential impact of aspects of the neighbourhood environment on sedentary time is due to these aspects promoting engagement in moderate- to vigorous-intensity physical activity is important. This is because it can quantify the potential reduction in sedentary time from living in favourable neighbourhood attributes that is due to increases in moderate- to vigorous-intensity physical activity versus light intensity physical activity. From a health perspective, neighbourhood characteristics that help substitute sedentary time with moderate- to vigorous-intensity physical activity rather than light intensity physical activity are preferred. In summary, more research is needed for a better understanding of how the built environment affects older adults' accelerometer-assessed sedentary time and the role that moderators and moderate- to vigorous-intensity physical activity – as a mediator – may play on that association.

6.2 Aims

The specific objectives of this chapter are:

1. Investigate the associations between perceived built environmental attributes and accelerometer-assessed sedentary time in Hong Kong Chinese older adults; and
2. Investigate the moderating effects of age, sex, education, and the number of diagnosed medical conditions on the above associations.
3. Investigate whether moderate- to vigorous-intensity physical activity explains (mediates) any identified significant associations between perceived built environmental attributes and accelerometer-assessed sedentary time.

6.3 Methods

A general overview of the methodology used in this study was provided in *Chapter 3*. The proceeding information is relevant only to this chapter.

6.3.1 Data

6.3.1.1 Accelerometer data reduction

A range of 0-24 counts·min^{-1} [205] was used to determine the average number of daily minutes spent sedentary. Average ActiGraph accelerometer wear time was also calculated after exporting .csv files using Actilife software into a Microsoft Excel® spreadsheet.

6.3.1.2 Outcome variable: accelerometer-assessed sedentary time

Average daily minutes of ActiGraph-assessed sedentary time was the outcome variable in the analyses.

6.3.1.3 Covariates and moderators: socio-demographic, health-related variable/s, and accelerometer-assessed moderate- to vigorous-intensity physical activity

Covariates and moderators were the same as described in *Chapter 5's* section 5.3.1.3. Age, sex, education, and the number of diagnosed medical conditions were treated as covariates in the main effects models and moderators in the interaction effects models of built environmental attributes and sedentary time. Household car availability, marital status, living arrangements, and type of recruitment centre were entered as covariates in all regression models.

6.3.1.4 Covariate: accelerometer wear time

Average daily minutes of ActiGraph accelerometer wear time was treated as a covariate in all regression models.

6.3.1.5 Mediator: accelerometer-assessed moderate- to vigorous-intensity physical activity

Daily minutes of moderate- to vigorous-intensity physical activity was examined as a potential mediator of the identified significant associations between built environmental attributes and sedentary time.

6.3.2 Data analyses

Descriptive statistics were computed for all measured variables. To address the three study aims, GLMs with robust standard errors rather than generalised additive models were used as there was insufficient evidence of curvilinearity in effects (based on scatter plots). GLMs with robust standard errors can accommodate normally and non-normally distributed data that are correlated (i.e., 'clustered;' collected from individuals living in selected tertiary planning units). In the current study, GLMs with Gaussian variance and identity link functions were used to model the sedentary time outcome because the outcome was approximately normally distributed. The reported regression coefficients of sedentary time represent the difference in daily minutes of sedentary time associated with a 1-unit increase in the predictor (i.e., each built environmental attribute on the relevant NEWS subscale [97, 342]).

The progression of complexity of the models from univariate to multivariate, and not including to including interaction terms, followed exactly the process outlined in *Chapter 5's* section 5.3.2. However, additional analyses were undertaken to examine whether accelerometer-assessed moderate- to vigorous-intensity physical activity mediated the observed associations between perceived characteristics of the neighbourhood environment and sedentary time. To investigate if moderate- to vigorous-intensity physical activity mediated the associations between built environmental attributes and sedentary time, and the moderating effects of given moderators (e.g., sex) on these associations, the joint-significance test was used [392]. Mediation analyses were undertaken only for built environmental attributes that showed significant (p <.05) main or interaction effects (with given moderators) on sedentary time (θ path in Figure 6).

Mediation analyses involved two discrete stages. The first stage involved establishing whether an environmental attribute main effect and/or environmental attribute by moderator (e.g., number of diagnosed medical conditions) interaction effect related to sedentary time was also significantly related to moderate- to vigorous-intensity physical activity (the mediator). This was done by estimating the relevant covariate-adjusted main effects and/or interaction effects in relation to moderate- to vigorous-intensity physical activity using GLMs with Gamma variance and logarithmic link functions (*Chapter 5,* section 5.3.2) (α regression coefficients in Figure 6). α path coefficients were estimated for single- and multiple-environmental attribute models. In *Chapter 5,* in relation to findings using our ≥1184 counts·min^{-1} cut-point for moderate- to vigorous-intensity physical activity, four significant built environmental attribute (residential density, land-use mix—destination diversity, bridge/overpass connection, and social disorder and littering) main effects and two interaction effects (age by land use mix - destination diversity and number of diagnosed medical conditions by aesthetics) were reported. Multiple-environmental-attribute models of moderate- to vigorous physical activity included all built environmental attributes and interaction terms with *p*-values <.05 in the final multiple-environmental-attribute models of sedentary time (reason explained below).

The second stage required estimating the associations of moderate- to vigorous-intensity physical activity (mediator) with sedentary time (outcome) controlled for built environmental attribute(s) main effects and, when applicable, interactions between built environmental attributes and each moderator (β path coefficients in Figure 6). This was done using GLMs with Gaussian variance and identity link functions given that sedentary time was, as noted earlier, approximately normally distributed. This analysis also allowed the estimation of the direct (i.e., non-mediated by moderate- to vigorous-intensity physical activity) main and/or interaction effects of built environmental attributes on sedentary time (θ' path coefficients in Figure 6) [393]. For single built environment models, mediation analyses were conducted only for built environmental attributes or their interaction with moderators that were significantly associated with moderate- to vigorous-intensity physical activity (and sedentary time), given that, according to the joint-significant test, moderate- to vigorous-intensity physical activity can be considered a mediator of a built environmental attribute main or interaction effect on sedentary time if both relevant α and β path coefficients are statistically significant (*p* <.05). This logic was not followed for multiple-environmental variables and, instead, all environmental attributes with significant main and interaction effects on sedentary time were included because the author wanted to estimate the effects of all built environment attributes on sedentary time that were mediated as well as those that were not mediated by moderate- to vigorous-intensity physical activity. All analyses were conducted in Stata 14.

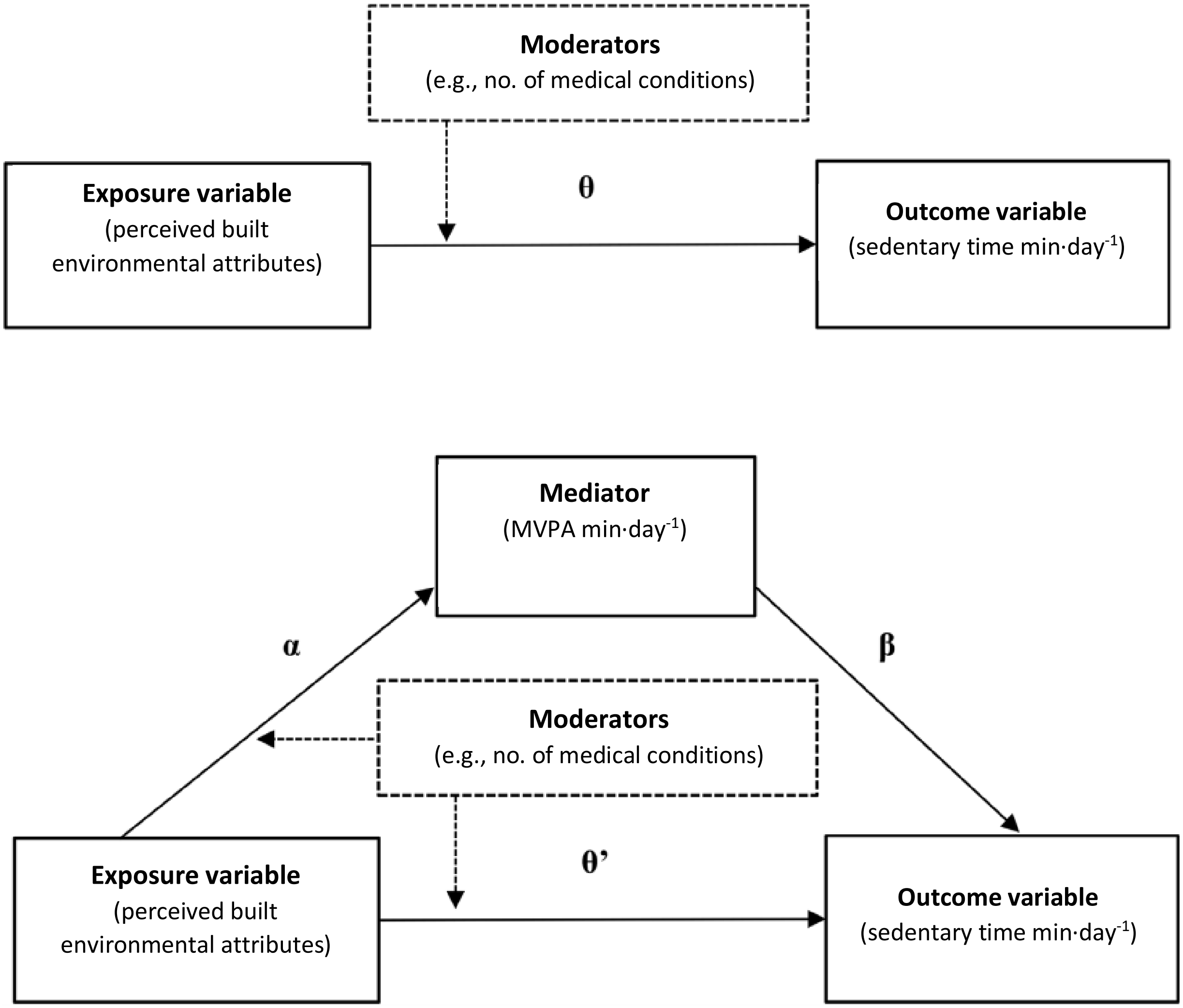

Figure 6. Diagram for the analysis of the main and moderated effects of built environmental attributes on sedentary time mediated by moderate- to vigorous-intensity physical activity

6.4 Results

Hong Kong older adults (n=402) recorded 404.9 ± 98.1 min·day^{-1} of sedentary time. All other relevant descriptive statistics are reported in Table 14 of *Chapter 5*.

In single environmental attribute main-effect models (Table 18), street connectivity (p =.023), social disorder/littering (p =.011), and access to a bridge or overpass connection (p =.037) were significantly negatively associated with older adults' sedentary time. Moreover, presence of people in the streets (p =.001) was significantly positively associated with sedentary time.

Table 18. Associations between perceived built environmental attributes and accelerometer-assessed sedentary time – single environmental variable models (θ path coefficients)

Environmental attribute	Sedentary time (min·day^{-1}) 0-24 counts·min^{-1} cut-point [205]	
	b (95% CIs)	*p*
Residential density	0.012 (-0.042; 0.067)	.662
Land-use mix—destination diversity	-6.973 (-15.887; 1.940)	.125
Access to destinations and services	-5.426 (-17.886; 7.034)	.393
Physical barriers to walking (e.g., hills)	9.559 (-2.614; 21.731)	.124
Street connectivity	-14.232 (-26.497; -1.967)*	.023
Infrastructure for walking	9.927 (-6.903; 26.758)	.248
Indoor places for walking	1.996 (-5.403; 9.395)	.597
Aesthetics	-3.367 (-12.553; 5.819)	.473
Presence of people in the streets	20.158 (8.564; 31.751)**	.001
Crowdedness	-6.735 (-17.537; 4.067)	.222
Traffic and road hazards	-5.779 (-19.450; 7.891)	.407
Traffic speed	4.231 (-15.145; 23.606)	.669
Social disorder and littering	-19.201 (-34.065; -4.337)*	.011
Crime	-8.443 (-30.507; 13.621)	.453
Bridge/overpass connection	-7.328 (-14.216; -0.440)*	.037
Easy access to residence	-2.457 (-16.948; 12.035)	.740
Fence separating footpath and traffic	-0.386 (-7.570; 6.798)	.916
Sitting facilities	0.046 (-7.458; 7.550)	.990

Notes: b: regression coefficient; CIs: confidence intervals. Each model was adjusted for age, sex, education, household car availability, living arrangements, marital status, the number of diagnosed medical conditions, and type of recruitment centre. **p* <.05; ***p* <.01; ****p* <.001

In the multiple-environmental attribute main-effect model, which included only the attributes significant in the single variable models, steet connectivity (*p* =.004), social disorder and littering (*p* =.013), and access to a bridge or overpass connection (*p* =.038) remained significantly negatively associated with older adults' sedentary time (Table 19). Moreover, presence of people in the streets (*p* <.001) was still significantly positively associated with sedentary time.

Table 19. Significant associations between perceived built environmental attributes and accelerometer-assessed sedentary time – multiple-environmental variable model, not including interaction terms (θ path coefficients)

Environmental attribute	Sedentary time (min·day^{-1}) 0-24 counts·min^{-1} cut-point [205]	
	b (95% CIs)	*p*
Street connectivity	-17.50 (-29.56; -5.47)**	.004
Presence of people in the streets	20.73 (9.31; 32.14)***	<.001
Social disorder and littering	-18.83 (-33.68; -3.98)*	.013
Bridge/overpass connection	-7.22 (-14.06; -0.38)*	.038

Notes: b: regression coefficient; CIs: confidence intervals. The model was adjusted for age, sex, education, household car availability, living arrangements, marital status, the number of diagnosed medical conditions, type of recruitment centre and the four environmental attributes listed above. **p* <.05; ***p* <.01; ****p* <.001

With regards to interaction effects, single interaction models (Table 20) showed that the number of diagnosed medical conditions of older adults significantly moderated four environmental attributes' associations with sedentary time. The environmental attributes were: access to indoor places for walking, the presence of people on the streets, crowdedness, and a fence/physical barrier separating the footpath from traffic. Further investigation of the significant interaction effects indicated that indoor places for walking tended to be associated with higher levels of sedentary time in people with a higher number of diagnosed medical conditions. For example, people with a number of conditions 1 SD higher than the sample mean (5.10 conditions) tended to accumulate 10.02 more minutes of sedentary time per day with a 1 unit increase on the scale of perceived indoor places for walking. Although this association was very weak and not

Table 20. Significant interaction effects of perceived built environmental attributes with number of diagnosed medical conditions on accelerometer-assessed sedentary time – single interaction models (θ path coefficients)

Environmental attributes with interaction effects on sedentary time	Sedentary time ($min \cdot day^{-1}$) 0-24 $counts \cdot min^{-1}$ cut-point [205]		
	Statistics	***b* (95% CIs)**	***p***
Indoor places for walking	Interaction term	4.13 (0.34; 7.93)*	.033
	Association at mean -1 SD of moderator: 1.05 medical conditions	-6.76 (-1.07; 21.11)	.211
	Association at mean value of moderator: 3.07 medical conditions	1.63 (-6.00; 9.26)	.676
	Association at mean +1 SD of moderator: 5.10 medical conditions	10.02 (-1.07; 21.11)	.077
Presence of people in the streets	Interaction term	7.21 (1.96; 12.45)**	.007
	Association at mean -1 SD of moderator: 1.05 medical conditions	3.60 (-9.64; 16.83)	.594
	Association at mean value of moderator: 3.07 medical conditions	18.22 (7.56; 28.89)**	.001
	Association at mean +1 SD of moderator: 5.10 medical conditions	32.85 (16.15; 49.55)***	<.001
Crowdedness	Interaction term	5.34 (0.44; 10.23)*	.033
	Association at mean -1 SD of moderator: 1.05 medical conditions	-17.69 (-29.94; -5.44)**	.005
	Association at mean value of moderator: 3.07 medical conditions	5.23 (-17.10; 3.39)	.190
	Association at mean +1 SD of moderator: 5.10 medical conditions	3.98 (-12.06; 20.03)	.626
Fence separating footpath and traffic	Interaction term	4.49 (1.25; 7.74)**	.007
	Association at mean -1 SD of moderator: 1.05 medical conditions	-10.22 (-20.65; 0.20)	.055
	Association at mean value of moderator: 3.07 medical conditions	-1.10 (-7.92; 5.71)	.751
	Association at mean +1 SD of moderator: 5.10 medical conditions	8.02 (-0.41; 16.45)	.062

Notes: b: regression coefficient; CIs: confidence intervals. The model was adjusted for age, sex, education, household car availability, living arrangements, marital status, the number of diagnosed medical conditions, and type of recruitment centre. *p <.05; **p <.01; ***p <.001

statistically significant (p =.077), it was significantly different (higher) than that observed in participants with an average number of medical conditions (3.07) and those with a 1 SD below the mean number of conditions (1.05 conditions) (Table 20). A positive association was found between presence of people in the streets and sedentary time only in older adults diagnosed with an average or above average number of medical conditions (3.07 conditions, p =.001; 5.10 conditions, p <.001). Conversely, a negative association between crowdedness and sedentary time was only found in older adults with a below average number of diagnosed conditions (1.05 conditions; p =.005). Finally, while the presence of fences/physical barriers separating footpaths from traffic tended to be negatively related to sedentary time in those with 1 or fewer medical conditions, the opposite was observed for older adults with a 1 SD above average number of conditions (Table 20). Sex, age and educational attainment did not moderate the associations between perceived environmental attributes and sedentary time (see Appendix 19).

Table 21 presents the significant main and interaction effects of the multiple-environmental variable model of sedentary time. Street connectivity (p =.010), social disorder and littering (p =.010), and access to a bridge or overpass connection (p =.045) were significantly negatively associated with older adults' sedentary time. In addition, the number of diagnosed medical conditions was found to moderate the associations of sedentary time with crowdedness and the presence of a fence/physical barrier separating the footpath and traffic. Specifically, a significant negative association was found between crowdedness and sedentary time in older adults diagnosed with ≈1 medical condition (1 SD below average number of conditions) (Table 21). The last remaining significant interaction revealed a positive association between the presence of a fence/physical barrier separating the footpath and traffic and sedentary time in older adults diagnosed with >5 medical conditions (1 SD above average number of conditions) (Table 21).

Table 22 presents the results of single environmental variable mediation models, encompassing α (outcome/mediator: moderate- and vigorous-intensity physical activity min·day^{-1}) and β/θ' (outcome: sedentary time min·day^{-1}) models including moderating effects (where appropriate). Evidence was found that moderate- to vigorous-intensity physical activity fully mediated the association between access to a bridge/overpass connection and sedentary time because the mediator-adjusted association between this neighbourhood attribute and sedentary time was not significant (θ' path coefficient in Table 22). Further, moderate- to vigorous-intensity physical activity partially mediated the associations between social disorder and littering with sedentary time. This is because this environmental attribute was positively related to the mediator (α path

Table 21. Significant associations between perceived built environmental attributes and accelerometer-assessed sedentary time – multiple-environmental variable model, including significant interaction terms (θ path coefficients)

Explanatory variables		Sedentary time ($min \cdot day^{-1}$) 0-24 $counts \cdot min^{-1}$ cut-point [205]	
		***b* (95% CIs)**	***p***
Environmental attributes with main effects on sedentary time			
Street connectivity		-16.20 (-28.57; -3.84)*	.010
Social disorder and littering		-19.59 (-34.40; -4.78)*	.010
Bridge/overpass connection		-7.70 (-15.24; -0.16)*	.045
Environmental attributes with interaction effects of number of diagnosed medical conditions on sedentary time			
	Statistics		
Crowdedness	Interaction term	5.87 (0.82; 10.92)*	.023
	Association at mean -1 SD of moderator: 1.05 medical conditions	-15.21 (-28.37; -2.06)*	.023
	Association at mean value of moderator: 3.07 medical conditions	-3.30 (-13.95; 7.34)	.543
	Association at mean +1 SD of moderator: 5.10 medical conditions	8.61 (-7.63; 24.85)	.299
Fence separating footpath and traffic	Interaction term	5.20 (1.93; 8.47)**	.002
	Association at mean -1 SD of moderator: 1.05 medical conditions	-10.08 (-20.96; 0.81)	.070
	Association at mean value of moderator: 3.07 medical conditions	0.47 (-6.81; 7.76)	.898
	Association at mean +1 SD of moderator: 5.10 medical conditions	11.02 (2.31; 19.73)*	.013

Notes: b: regression coefficient; CIs: confidence intervals. The model was adjusted for age, sex, education, household car availability, living arrangements, marital status, the number of diagnosed medical conditions, type of recruitment centre and all environmental attributes and interaction terms listed in the table. **p* <.05; ***p* <.01; ****p* <.001

coefficient), moderate- to vigorous-intensity physical activity was negatively related to sedentary time after adjustment for the environmental attribute (β path coefficient), and the mediator-adjusted association between the environmental attribute and sedentary time was still statistically significant but attenuated (θ' path coefficient). In contrast, moderate- to vigorous-intensity physical activity did not mediate the associations of street connectivity and presence of people in the street with sedentary time because these environmental attributes were not significantly related to moderate- to vigorous-intensity physical activity (α path coefficients in Table 22). Moderate- to vigorous-intensity physical activity did not mediate any of the interaction effects of environmental variables with diagnosed medical conditions on sedentary time because none of these interaction effects were significant with respect to moderate- to vigorous-intensity physical activity (see IT α path coefficients in Table 22).

In the multiple environmental variable mediation model (section 6.3.2) (Table 23), findings indicated that moderate- to vigorous-intensity physical activity fully mediated the associations of sedentary time with social disorder and littering and access to a bridge/overpass connection.

Moderate- to vigorous-intensity physical activity also partially mediated the moderating effects of the number of diagnosed medical conditions on the association between a fence/physical barrier separating a footpath from traffic and sedentary time because a significant interaction effect was also observed with respect to the mediator (IT α path in Table 23) and the same interaction effect with respect to sedentary time was attenuated after adjustment for the mediator (the θ' path coefficient in Table 23 was 3.67, p =.021 while the θ path coefficient in Table 21 was 5.20, p =.002). The presence of a fence separating footpaths from traffic tended to be negatively associated with moderate- to vigorous-intensity physical activity only in older adults who were diagnosed with >5 medical conditions (1 SD above average number of conditions) (p =.064). However, moderate- to vigorous-intensity physical did not mediate the association of street connectivity with, and the moderating effect of crowdedness by number of medical conditions on, sedentary time (relevant α and IT α paths not significant in Table 23). Given the above and the fact that moderate- to vigorous-intensity physical activity was significantly associated with sedentary time after adjusting for all environmental variables and interaction effects related to sedentary time (β path coefficient in Table 23), it can be concluded that older adults with an above average number of medical conditions and reporting a higher prevalence of fences separating footpaths from traffic tended to accumulate more sedentary time because they engaged in fewer minutes of moderate- to vigorous-intensity physical activity than those with the same number of medical conditions but lower prevalence of fences separating footpaths from traffic in the neighbourhood.

6.5 Discussion

This is the first study to investigate the associations between perceived built environmental attributes and accelerometer-assessed sedentary time in a community sample of Hong Kong Chinese older adults. Secondary aims of this study were to investigate the interaction between built environmental attributes and participant characteristics on daily minutes of sedentary time. The final aim examined whether accelerometer-assessed moderate- to vigorous-intensity physical activity mediated any of the significant associations between built environmental attributes and accelerometer-assessed sedentary time or environmental attributes by socio-demographic/health interaction effects on sedentary time.

Table 22. Single environmental variable mediation models of sedentary time with moderate- to vigorous-intensity physical activity as the mediator

Models	Explanatory variables	Sedentary time (min·day^{-1}) 0-24 counts·min^{-1} cut-point [205] Path	b (95% CIs)	p	MVPA (min·day^{-1}) ≥1184 counts·min^{-1} cut-point Path	e^b (95% CIs)	p
Environmental attributes with main effects on sedentary time							
Street connectivity	MVPA(min·day^{-1})	**β**	-1.30 (-1.49; -1.10)***	<.001	**α**	1.03 (0.94; 1.13)	.566
	Street connectivity	**θ'**	-13.07 (-24.41; -1.73)*	.024	-	-	-
Presence of people in the streets	MVPA(min·day^{-1})	**β**	-1.29 (-1.49; -1.09)***	<.001	**α**	0.96 (0.87; 1.05)	.351
	Presence of people in the streets	**θ'**	16.68 (6.55; 26.81)**	.001	-	-	-
Social disorder and littering	MVPA(min·day^{-1})	**β**	-1.27 (-1.46; -1.09)***	<.001	**α**	1.11 (1.03; 1.19)**	.005
	Social disorder and littering	**θ'**	-10.63 (-23.43; 2.18)*	.011	-	-	-
Bridge/overpass connection	MVPA(min·day^{-1})	**β**	-1.29 (-1.50; -1.09)***	<.001	**α**	1.06 (1.01; 1.12)*	.019
	Bridge/overpass connection	**θ'**	-2.13 (-7.91; 3.64)	.469	-	-	-
Environmental attribute with interaction effects of number of diagnosed medical conditions (DMC) on sedentary time							
Indoor places for walking	MVPA(min·day^{-1})	**β**	-1.29 (-1.49; -1.09)***	<.001	**IT α**	0.99 (0.96; 1.01)	.272
	Indoor places for walking by DMC interaction term	**θ'**	2.85 (-0.40; 6.11)	.086	-	-	-
Presence of people in the streets	MVPA(min·day^{-1})	**β**	-1.27 (-1.48; -1.07)***	<.001	**IT α**	0.96 (0.93; 1.00)	.062
	Presence of people in the streets by DMC interaction term	**θ'**	4.28 (-0.83; 9.39)	.101	-	-	-
Crowdedness	MVPA(min·day^{-1})	**β**	-1.29 (-1.48; -1.09)***	<.001	**IT α**	0.98 (0.95; 1.01)	.257
	Crowdedness by DMC interaction term	**θ'**	3.58 (-0.93; 8.10)	.120	-	-	-
Fence separating footpath and traffic	MVPA(min·day^{-1})	**β**	-1.28 (-1.48; -1.08)***	<.001	**IT α**	0.98 (0.94; 1.02)	.321
	Fence separating footpath and traffic by DMC interaction term	**θ'**	3.14 (0.10; 6.18)*	.043	-	-	-
	Association at mean -1 SD of moderator: 1.05 medical conditions	-	-7.46 (-16.77; 1.86)	.117	-	-	-
	Association at mean value of moderator: 3.07 medical conditions	-	-1.08 (-7.03; 4.87)	.722	-	-	-
	Association at mean +1 SD of moderator: 5.10 medical conditions	-	5.29 (-2.46; 13.05)	.181	-	-	-

Notes: MVPA: moderate- to vigorous-intensity physical activity; *b*: regression coefficient; e^b: antilogarithm of regression coefficient; CIs: confidence intervals; *p: p*-value; α path coefficient:represents the association between the single environmental attribute and moderate- to vigorous-intensity physical activity (the outcome/mediator); β path coefficient: represents the association between moderate- to vigorous-intensity physical activity and sedentary time (outcome) afteradjustment for the single environmental attribute; θ' path coefficient: represents the mediator-adjusted (i.e., moderate- to vigorous-intensity physical activity-adjusted) association between the single environmental attribute and sedentary time (outcome); IT: interaction term; SD: standard deviation. Each model was adjusted for age, sex, education, household car availability, living arrangements, marital status, the number of diagnosed medical conditions, and type of recruitment centre. *p <.05; **p <.01; ***p <.001

Table 23. Multiple environmental variable mediation models of sedentary time with moderate- to vigorous-intensity physical activity as the mediator

Explanatory variables			**Sedentary time (min·day^{-1}) 0-24 counts·min^{-1} cut-point [205]**			**MVPA (min·day^{-1}) ≥1184 counts·min^{-1} cut-point**	
		Path	***b* (95% CIs)**	***p***	**Path**	**e^b (95% CIs)**	***p***
MVPA (min·day^{-1})		**β**	-1.22 (-1.42; -1.02)***	<.001	-	-	-
Environmental attributes with main effects on sedentary time							
Street connectivity		**θ’**	-14.55 (-26.43; -2.68)*	.016	**α**	1.04 (0.95; 1.13)	.416
Social disorder and littering		**θ’**	-11.67 (-25.34; 2.00)	.094	**α**	1.11 (1.04; 1.18)**	.002
Bridge/overpass connection		**θ’**	-2.54 (-8.64; 3.56)	.415	**α**	1.07 (1.01; 1.13)*	.019
Environmental attribute with interaction effects of number of diagnosed medical conditions (DMC) on sedentary time							
Crowdedness	Crowdedness by DMC interaction term	**θ’**	4.16 (-0.597; 8.91)	.086	**IT α**	0.98 (0.95; 1.01)	.139
Fence separating footpath and traffic	Fence separating footpath and traffic by DMC interaction term	**θ’**	3.67 (0.54; 6.79)*	.021	**IT α**	0.98 (0.96; 0.997)*	.023
	Association at mean -1 SD of moderator: 1.05 medical conditions	-	-7.68 (-17.42; 2.06)	.122	-	1.04 (0.98; 1.11)	.178
	Association at mean value of moderator: 3.07 medical conditions	-	-0.23 (-6.79; 6.32)	.944	-	0.99 (0.95; 1.04)	.765
	Association at mean +1 SD of moderator: 5.10 medical conditions	-	7.21 (-1.24; 15.66)	.095	-	0.95 (0.89; 1.003)	.064

Notes: MVPA: moderate- to vigorous-intensity physical activity; *b*: regression coefficient; e^b: antilogarithm of regression coefficient; CIs: confidence intervals; *p: p*-value; α path coefficient: represents the association between the environmental attribute and moderate- to vigorous-intensity physical activity (the outcome/mediator) after adjustment for the environmental attibutes and interaction effects found to be significantly related to sedentary time in Table 4; β path coefficient: represents the association between moderate- to vigorous-intensity physical activity and sedentary time (outcome) afteradjustment for all environmental attributes and interaction effects found to be significantly related to sedentary time in Table 4; θ’ path coefficient: represents the mediator-adjusted (i.e., moderate- to vigorous-intensity physical activity-adjusted) association between the environmental attribute and sedentary time (outcome) afteradjustment for all environmental attributes and interaction effects found to be significantly related to sedentary time in Table 4; IT: interaction term; SD: standard deviation. Each model per applied cut-point was adjusted for age, sex, education, household car availability, living arrangements, marital status, the number of diagnosed medical conditions, and type of recruitment centre. *p <.05; **p <.01; ***p <.001

6.5.1 Average daily sedentary time

Findings related to time spent sedentary suggest that Hong Kong Chinese older adults are less sedentary than adults of the same age in other countries. On average, older adults in this study accrued 404 ± 98 min·day^{-1} (49.9% of daily wear time) of sedentary time, which was substantially lower than findings reported from populations in Canada (526 ± 65 min·day^{-1}; 67.3% of daily wear time) [241], Iceland (618 ± 90 min·day^{-1}; 75.3% of daily wear time) [374], and the United Kingdom (58.3-68.2% of daily wear time) [240]. Estimates were also lower than in a study using the same participants but different methods to classify sedentary time (512.2 min·day^{-1}; 63.2% of daily wear time) [242]. The difference in sedentary time estimates between this study and the previous Hong Kong-based study can be explained by the sedentary time accelerometer cut-point used in the previous study [242] being 75 counts·min^{-1} higher than in the current one (<100 [372] *vs.* <25 counts·min^{-1} [205]) and, thus, more sedentary time was reported in the published study. The employment of different sedentary-time cut-points may also explain some of the difference in sedentary time estimates between the current study and that of the other two studies using ActiGraph accelerometers [241, 374]. Incidentally, the finding of Aguilar-Farias et al. [205] that the <100 counts·min^{-1} sedentary time cut-point was less appropriate for use in older adults than the <25 counts·min^{-1} cut-point was unsurprising, given that the former cut-point was developed in a calibration study of adolescent girls [394] and what we learned in *Chapter 4* about age-related effects on aerobic capacity [263, 264]. Regarding built environment studies reporting associations with older adults' self-reported sedentary behaviour, it is not surprising that our 404 ± 98 min·day^{-1} finding was higher than mean television viewing time reported in Belgium (255 ± 94 min·day^{-1}) [239] and Australia (127.5-137.5 min·day^{-1}) [238] [Hsueh et al. [237] did not report their mean findings]. Television viewing does not assess all behaviours which may affect sitting time estimates (e.g., sitting for meals) [164] and, indeed, all leisure-based screen time in older adults – which would be a higher amount than television viewing alone – has been reported to represent about 64.7% of total sitting time [395]. It should also be taken into consideration that the two built environment studies reporting older adults' television viewing time either used a non-validated questionnaire to assess television viewing [239] or a validated [unnamed] questionnaire shown to produce a validity estimate on the lower end of moderate (.30) [238, 396]. The difficulty in assessing sedentary time has been further reflected in validation studies with accelerometry as the criterion (all validity estimates ≤.39) of more commonly-used questionnaires such as such as the Community Health Activities Model Program for Seniors questionnaire (CHAMPS) [156], International Physical Activity Questionnaire – Short version modified for the Elderly

(IPAQ-E) [154], International Physical Activity Questionnaire – Long version in Chinese (IPAQ-LC) [151], and IPAQ-S [155]. These moderate validity estimates are likely due to issues such as applying inappropriate accelerometer cut-points and/or impaired cognition and recall bias [175] in difficulty reporting a ubiquitous, prolonged, often incidental low-intensity behaviour [139, 176, 177]. These limitations should be kept in mind when interpreting findings from built environment studies using self-report measures to assess older adults' sedentary behaviour, including television viewing.

Hong Kong Chinese culture also likely plays a part in the low accumulation of sedentary time. Hong Kong is an extremely safe place to live [242, 381] relative to other cities/regions in Western countries [379, 380, 382] and very strong evidence suggests that personal/crime-related safety is positively associated with older adults' total physical activity [101]. This heightened feeling of safety coupled with Chinese older adults' traditional appreciation of an active lifestyle [349, 397], may, therefore, make leaving home more attractive and more a part of everyday life than adults of the same age living in Western countries [239-241]. Also, living in very small apartments may also encourage Hong Kong older adults to spend more time outdoors. Hence the lower estimates of sedentary time in Hong Kong Chinese older adults.

6.5.2 Main effects of perceived neighbourhood attributes

Physical environmental factors may also play a part in Hong Kong Chinese older adults accruing low levels of accelerometer-assessed sedentary time [242]. Indeed, the current study found that three built environmental attributes were significantly negatively associated with sedentary time. Specifically, in order of strongest associations, increased street connectivity, the presence of social disorder and/or littering, and access to a bridge/overpass connection were associated with lower amounts of sedentary time. Presence of people in the streets was the only attribute significantly positively associated with sedentary time.

Findings related to street connectivity agreed with the only other study to assess this attribute via self-reports [241]. Interestingly, it was not in line with the previously published Hong Kong-based study of the same cohort which did not support associations between accelerometer-assessed sedentary time and objectively measured street connectivity [242]. This could be due to perceptions of attributes of the neighbourhood environment being more proximal to an individual's behaviour than objective attributes. That is, in order for an objective built environmental attribute to influence behaviour, it needs to be perceived. This may help to explain stronger associations between perceptions of the neighbourhood environment and behaviour than the 'real' world and behaviour [334, 339]. The amount of walking undertaken in the neighbourhood and how neighbourhood is defined (i.e., 15-20 minutes' walk from home as opposed to, e.g., 400 m or 1 km buffers) may also have an impact, since regular walking and/or contextualising the neighbourhood in terms of walking time rather than distance may allow for more accurate perceptions of an individual's local environment. Differences in associations between environment perceived or objectively measured environmental attributes with outcomes have previously been evidenced in physical activity research [232, 233]. In addition, this study found that moderate- to vigorous-intensity physical activity did not mediate the association between street connectivity and sedentary time and, therefore, decreases in sedentary time are likely due to its displacement with light intensity physical activity. Logically, this makes sense since increases in street connectivity are likely coupled with increases in the number of people, motorised traffic, and a larger number of pedestrian crossings in the given area. These environmental conditions make it more difficult for older adults to walk at a moderate or higher speed because they are required to slow down and stop more often. Or it may be that they simply prefer to walk at a slower pace in areas of the neighbourhood where street connectivity is higher.

It is unclear if the finding of a negative association between signs of neighbourhood social disorder and littering and accelerometer-assessed sedentary time is idiosyncratic of Hong Kong because of the complete lack of other studies from other countries investigating this. Our finding is in agreement with a previously published Hong Kong-based study of the same population (but a different sample) reporting a negative association between self-reported non-transport sitting time and signs of crime/disorder [236]. It may be that lower socio-economic groups living in areas with higher levels of social disorder and littering may be more inclined to avoid the cost of public transport (and thus engage in more active transport than motorised transport) and live in smaller apartments encouraging them to spend time outdoors [236]. Indeed, low socio-economic groups engage in more walking for transport [398] which would likely displace sedentary behaviour. Alternatively, it may be that older adults who walk more in their neighbourhood are more aware of signs of social disorder and litter near their homes [350] or that this neighbourhood attribute assesses aspects of socio-economic status that are not captured by individual- and area-level income and educational attainment [247].

Direct comparisons of this study's finding that increased access to a bridge/overpass connection was associated with lower estimates of sedentary time to other studies are not possible due to a lack of research. In Hong Kong, this type of infrastructure can be found in areas of the neighbourhood with steep terrain and/or heavy traffic. The importance of having this attribute in neighbourhoods was speculated in *Chapter 5* and confirmed in the current study; older adults with access to a local bridge/overpass connection tended to engage in more moderate- to vigorous-intensity physical activity that displaced sedentary time. The higher level of moderate- to vigorous-intensity physical activity was most likely due to engaging in more recreational walking [75].

The only other significant main effect was the positive association between the presence of people in the streets and sedentary time. Again, this has not been investigated in previous studies of the built environment and sedentary time [237-242, 374]. In the current study, the single mediation models indicated that this might have been due to individuals who had a higher number of diagnosed medical conditions participating in less moderate- to vigorous-intensity physical activity when they were more likely to perceive people in the streets. Logically, this seems plausible if we consider the two elements that comprise the item "presence of people in the streets": 1) walkers that can be seen; and 2) people being around to ask for help [246]. More people in the streets might indicate a higher level of social support from others for daily activities. This would likely be particularly important for older adults experiencing multiple chronic conditions because it means they would not have to be as self-reliant in performing activities of daily living and, thus, would have more opportunities to rest (sedentary time).

We did not find an association between diversity of destinations (land-use mix) and sedentary time. This was not consistent with findings from the United Kingdom- [240] and Belgium-based studies [239] where negative associations with sedentary behaviour were found. This may be due to the fact that, in Hong Kong, access to a diversity of destinations is generally higher than in the United Kingdom and Belgium [334] and, therefore, provides more opportunity for older adults to displace sedentary time with physical activity. Differences in sedentary behaviour and environmental measures may also play a role in understanding the inconsistencies in these findings. Neither Shaw et al. [240] or Van Cauwenberg et al. [239] used validated environmental measures to assess the perceived built environment and thus it may lead us to consider the validity of their findings, since using robust measures is particularly important in this demographic due to issues associated with, for example, recall bias [175]. Regarding sedentary behaviour measurement, these two studies assessed time spent in sedentary behaviour differently; Van Cauwenberg et al. [239] using self-reported television viewing and Shaw et al. using an inclinometer. Self-reported television viewing [239] only represents one type of sedentary behaviour and, thus, likely underestimates overall sedentary time [164, 395]. Shaw et al. [240], on the other hand, used an *activ*PAL™ inclinometer to assess sedentary behaviours and this device has been shown to be more valid in measuring sitting time than the ActiGraph GT3X [like the one used in the current study] [197, 399] and, therefore, may have resulted in more valid and accurate sitting time estimates that, in turn, might have increased the power of the study to detect associations.

Those issues aside, light intensity physical activity may play a role in trying to understand the differences in findings between land-use mix and sedentary time in the current Hong Kong-study and those from Western countries [239, 240]. Hong Kong older adults accumulate substantially less sedentary minutes due to displacing this behaviour with high amounts of light intensity physical activity. They accumulate almost double the amount of daily light intensity physical activity than, for example, similarly-aged British (≈342 min·day^{-1} *vs.* ≈180 min·day^{-1} [80]). (Incidentally, we now know from elements of Chapters 4 and 5 that this difference in levels of light intensity physical activity would be larger if the cut-points [2, 372] used in the Davis et al. [80] study were more appropriate (e.g., [225])). We also know from *Chapter 5* that diversity of neighbourhood destinations was an important correlate of moderate- to vigorous-intensity physical activity behaviour in Hong Kong older adults, particularly the eldest older adults (≥75.5 years old). Therefore, we may speculate that elder members of the community in Hong Kong who live in destination-rich neighbourhoods tend to displace light-intensity physical activity (rather than sedentary time—because there was no association between land-use mix and sedentary time) with moderate- to vigorous-intensity physical activity, while the opposite may be true for older adults in the West, who may be more inclined to remain sedentary if access to a range of neighbourhood destinations is not good.

The current study found a nil association between perceived residential density and sedentary time. This result was in agreement with two studies using perceived environmental measures from Taiwan [237] and Australia [238]. In contrast, two studies using objective environmental measures found opposing findings, one from the same cohort in Hong Kong (negative association) [242] and the other from Belgium (positive association) [239]. This study's finding also differed from that of a perceived environment-based study of Icelandic older adults where a positive association was observed in relation to living in more dense apartments versus a villa [374]. Considering two [237, 238] of three perceived environment studies [237, 238, 374] found no association and both objective environment studies found associations, it may be that environmental measurement methods played a role in these differences. For example, it may be more difficult to expect older adults to have an accurate perception of the different numbers of dwellings in their neighbourhood, particularly in Hong Kong because of its extreme denseness compared to other cities, which may induce some measurement error [400].

Considering the Van der Berg et al. [374] study, socio-economic status may explain the differences in findings with the current study because income does not impact residential density in Hong Kong [376] but would probably be negatively related to income in Iceland (those living in villas being of higher socio-economic than those living in apartments). Higher socio-economic status is also associated with a greater likelihood of displacing some sedentary behaviour with active leisure pursuits [377, 378].

Considering the negative association between residential density and moderate- to vigorous-intensity physical activity in *Chapter 5* and the lack of association with sedentary time in this chapter; it leads us to consider an association between this attribute and light intensity physical activity. Indeed, this is partially supported – physical activity measurement issues in mind – by a significantly positive finding of objectively assessed residential density in relation to 'total' estimates of physical activity (i.e., which included light intensity physical activity) in the same cohort, but no association with moderate- to vigorous-intensity physical activity only [242].

6.5.3 Moderators

Single environmental models identified one moderator, the number of diagnosed medical conditions, that showed an interaction with four perceived neighbourhood attributes on sedentary time, specifically: indoor places for walking, the presence of people in the streets, crowdedness, and the presence of a fence/physical barrier separating a footpath from traffic. In the final multiple environmental variable model, only the moderating effects with two neighbourhood attributes remained significant: crowdedness and a fence separating a footpath from traffic.

The only comparable moderator of built environment-sedentary time associations investigated in this study and the two previously published studies was sex, and our non-significant finding was in agreement with the results from Australia [238] and Iceland [374]. In terms of comparisons with the previously published Hong Kong-based study, a higher number of significant interactions were found in that study (n=3: sex, household car ownership, and education) [242] than this one (n=1: number of diagnosed medical conditions). These inconsistencies are likely explained by different sedentary time and environmental measurement methods, for reasons aforementioned (e.g., participants having a different relationship with the perceived environment *vs*. the objective environment [101, 232, 336]). Thus, while, as it stands, the current study is not directly comparable to the Cerin et al. [242] study of the same cohort in terms of cut-points used to classify sedentary time, the difference in the number of moderators found between studies leads us to consider the prospect that the same environment may need to be assessed using perceived and objective environment methods to fully capture differential relationships that sub-groups of the population may have in relation to their neighbourhood environment and its effect on sedentary time.

In the current study, indoor places for walking (e.g., air-conditioned malls) tended to be more important for individuals with the highest number of diagnosed medical conditions (≥5 conditions) since a positive association between this environmental characteristic and sedentary time was observed only in this subgroup. Older people with diagnosed medical conditions may be more affected, for example, by hot and humid subtropical weather typical of Hong Kong and/or by high levels of air pollution [401] and therefore seek shade, coolness, and lower air pollution levels in local, air-conditioned indoor areas where they may find places to sit. These indoor destinations may be attractive to healthy older adults because they provide a comfortable setting to engage in recreational walking [75] and to less healthy older adults because they provide a comfortable place to rest.

Crowdedness is usually associated with high levels of availability of various services and facilities and lack of sitting facilities. Such environments are more likely to attract healthy than unhealthy older adults. Thus, it is not surprising that only older adults with none or 1 medical condition showed a negative association between crowdedness and sedentary time.

The presence of fences/physical barriers separating footpaths from traffic was important for the individuals in our cohort diagnosed with the most medical conditions (≥5 conditions). These particular older adults, likely also experiencing lower physical function, engaged in more sedentary time if they lived in a neighbourhood with a high prevalence of this environmental feature. This suggests that these individuals may have found pavements next to busy roads with heavy traffic – where fences would be more likely – less appealing to walk on [348] and, therefore, were more sedentary as a result. Somewhat in line with this finding is that neighbourhood traffic speed has been identified as a barrier to recreational walking in 'older' Hong Kong elders, those likely to experience higher co-morbidities [75].

6.6 Conclusions

The present study examined the mediating effect of moderate- to vigorous-intensity physical activity on associations between perceived built environmental attributes and accelerometer-assessed sedentary time. Of the three significantly negative associations found in the final multiple environmental variable mediation models of sedentary time (including adjustment for significant interactions) in this study, moderate- to vigorous-intensity physical activity mediated two of them. Specifically, the associations between sedentary time and the presence of social disorder and/or littering and access to a bridge or overpass connection. Thus, this study provides some evidence that associations between the perceived built environment and accelerometer-assessed sedentary time are *not* independent of moderate- to vigorous-intensity physical activity in Hong Kong Chinese older adults. This is a potentially important finding because there is a body of research that purports that these behaviours are independent (e.g., [78, 363, 402]).

“Number of diagnosed medical conditions” was identified as a particularly important moderator, interacting with both sedentary time and moderate- to vigorous-intensity physical activity *(Chapter 5)* and built environmental attributes. However, the general lack of moderating effects found in the current study and *Chapter 5* is positive, because it suggests that modifications to the neighbourhood environment helping to facilitate physical activity behaviour would likely simultaneously reduce sedentary time across demographic sub-groups of older adults. This work adds to the current dearth of literature on the moderators of sedentary time-built environment associations in older adults. That being said, it must be acknowledged that Hong Kong is uniquely [ultra] dense [334, 403] and lack of moderation effects may be due to the generally high level of accessibility to destinations.

In conclusion, neighbourhoods with higher levels of street connectivity, signs of social disorder and littering, and access to a bridge/overpass connection were associated with lower levels of accelerometer-assessed sedentary time in Hong Kong Chinese older adults. However, all but one (street connectivity) of these findings were fully-explained (mediated) by accelerometer-assessed moderate- to vigorous-intensity physical activity, which highlights the importance of considering that, in Hong Kong Chinese older adults, these co-existing behaviours are, on the most part, not independent behaviours.

Chapter 7
General discussion

7.1 Conceptualisation of thesis

The overall aim of this doctoral thesis was to better understand the associations between the perceived built environment and Chinese older adults' accelerometer-assessed physical activity and sedentary time. This in line with world bodies' call for the development of built environments that would facilitate engagement in physical activity behaviour and, in turn, promote healthy ageing and reduce non-communicable disease burden (e.g., [404, 405]). It follows that high quality research must be conducted to identify the most influential built environmental attributes in relation to physical activity and sedentary behaviour levels. High quality research requires that the most valid measures of exposures and outcomes be used [101].

In order to achieve its overall aim, this research program and thesis consisted of six phases, each represented by a chapter: the first three chapters provided the underpinning rationale for the studies outlined in *Chapters 4, 5, and 6,* respectively. Specifically, *Chapter 1* discussed the importance of physical activity, particularly moderate- to vigorous-intensity physical activity, for older adults' health and the ill-effects of sedentary behaviour. Moreover, the role that the built environment plays in influencing these behaviours was also introduced. The narrative literature review presented in *Chapter 1* detailed the benefits of using accelerometry to assess older adults' physical activity and sedentary time rather than self-reported physical activity. In *Chapter 2,* a systematic review and meta-analysis of published articles on older adults' physical activity and the built environment identified gaps in the research (e.g., Western bias in cultures and cities studied, lack of high quality studies and lack of studies using objective physical activity measurement and examining potential moderators of environmental exposures and physical activity outcomes associations) [101]. A key hypothesis emanating from the systematic review and meta-analysis was that using an inappropriate accelerometer cut-point to classify moderate- to vigorous-intensity physical activity behaviour in older adults was partly responsible for the numerous nil findings observed between built environmental attributes and objectively-assessed physical activity [101].The current dearth of sedentary behaviour-built environment studies meant it was not possible to conduct a meta-analysis of this area. In addition to the issues defined by the meta-analysis on older adults' physical activity and the built environment, this thesis set about to further the evidence on whether physical activity and sedentary behaviour are independent behaviours [406]. The addressing of identified research gaps as part of this thesis highlights its unique contribution to the current evidence base.

The initial three 'rationale-building' chapters – *Chapters 1, 2, and 3* – underpinned the proceeding chapters of investigation which consisted of three discrete studies. Specifically, *Chapter 4* presented the findings of a methodological study that developed a new moderate- to vigorous-intensity physical activity accelerometer cut-point appropriate for use in Chinese older adults. *Chapter 5* reported on an epidemiological study that applied this new accelerometer cut-point to understand the association between Chinese older adults' moderate- to vigorous-intensity physical activity and perceived built environmental attributes. Finally, *Chapter 6* presented the findings of an epidemiological investigation aimed at examining the associations between older adults' sedentary time and perceptions of the built environment and whether any of these significant associations were explained (i.e., mediated) by moderate- to vigorous-intensity physical activity.

7.2 Overview and discussion of main findings

The three studies conducted as part of this doctoral thesis — *Chapters 4, 5, and 6* — have their own discussion of the findings related specifically to that study. Therefore, this chapter summarises the main findings from these studies in the context of existing evidence (where possible), and discusses the strengths and limitations of the research conducted as part of this thesis. Lastly, recommendations for future research directions and potential practical implications are proposed and an overall conclusion provided.

The first phase of investigation as part of this thesis found the newly-developed moderate- to vigorous-intensity physical activity accelerometer cut-point for Chinese older adults (i.e., $\geq$1184 counts·min^{-1}) *(Chapter 4)* to be substantially lower than the most commonly-used cut-point in older adult physical activity research (i.e., $\geq$1952 counts·min^{-1} [2]) [118]. One important underpinning mechanism for this finding was the measurement and subsequent adjustment of RMR. Previous calibration studies standardised RMR at 1 metabolic equivalent = 3.5 ml·O_2·kg·min^{-1} (e.g., [2]), which is markedly higher than RMR in older adults (e.g., mean RMR = 2.8-2.9 ml·O_2·kg·min^{-1} [225] *(Chapter 4)*). This was not the only methodological limitation identified in other calibration studies and subsequently addressed as part of the methodological study in *Chapter 4*. For example, treadmills were often used instead of self-propelled walking (e.g., [2, 226, 243]) which has been shown to significantly underestimate accelerometer (specifically, ActiGraph) counts and overestimate energy expenditure [278]. Thus, the moderate- to vigorous-intensity physical activity cut-point developed in this thesis was based on robust methodology based on a [self-propelled] walking protocol; walking being the most prevalent type of physical activity undertaken by older adults [103, 104, 407].

There was no significant difference between the moderate- to vigorous-intensity physical activity cut-point derived from the sample of Chinese older adults used in this program of research (≥1184 counts·min^{-1}) *(Chapter 4)* and that based on a sample of Caucasians of a similar age (≥1013 counts·min^{-1}) from a previous study that employed the same methodology [225]. This leads us to assume that previous physical activity studies in older adults that adopted cut-points higher than ≥1184 counts·min^{-1} to define moderate- to vigorous-intensity physical activity (e.g., ≥1952 counts·min^{-1} [2]), most likely underestimated time spent in this activity intensity and overestimated light intensity physical activity as a consequence. Caution, therefore, should be aired when interpreting findings from any study, including built environment-physical activity studies (e.g., [242, 265-271, 273-276, 408]), that defined moderate- to vigorous-intensity physical activity using such cut-points, because the use of an inappropriate cut-point may have resulted in biased findings (e.g., incorrect estimates of average moderate- to vigorous-intensity physical activity levels, downward-biased associations between environmental attributes and physical activity). Indeed, generally, stronger associations were found for significant built environmental attributes and moderate- to vigorous-intensity physical activity as classified by the new cut-point determined in this thesis, than for the same attributes' and outcome classified using the Freedson et al. cut-point [2] *(Chapter 5)*.

The findings from the methodological study presented in this thesis *(Chapter 4)* raise two additional issues that need to be considered by physical activity researchers. First, the overestimation of light intensity physical activity due to using inappropriate accelerometer cut-points may in part explain the 'independent' health benefits observed for this intensity level of physical activity in some older adult-based research (e.g., [69]). Second, mirroring findings from previous studies (e.g., [225, 409]), a wide range of individual moderate- to vigorous-intensity physical activity cut-points were observed in our sample of 43 older adults *(Chapter 4),* suggesting that, where possible, individual calibration of cut-points should be prioritised in physical activity studies.

This program of research examined a wide range of perceived attributes of the neighbourhood environment as correlates of Hong Kong older adults' objectively-assessed moderate- to vigorous-intensity physical activity and sedentary behaviour. Among these, two perceived neighbourhood built environmental attributes warrant particular attention because they were significantly related to both Hong Kong older adults' moderate- to vigorous-intensity physical activity behaviour and sedentary time: social disorder and/or littering and access to a bridge or overpass connection *(Chapter 6)*. The finding that social disorder and/or littering was positively associated with moderate- to vigorous-intensity physical activity is at odds with a previous study, albeit not directly comparable, of Hong Kong older adults' self-reported recreational physical activity being negatively associated with objectively-measured signs of crime/disorder [74]. These discrepancies in findings may be explained by the different samples studied (e.g., Cerin et al.'s [74] sample did not include older adults with lower physical function and, therefore, may not have been as generalisable as the sample studied in this thesis), the domain-specific nature of the physical activity outcome [100-102], and/or measurement methods used for assessing physical activity and the built environment [101, 336]. Self-reported domain- and/or context-specific physical activity may also help explain the difference between this thesis's positive finding and a previous study that used the same sample but found nil findings in relation to within-neighbourhood walking or non-walking physical activity [348]. The closest comparisons that can be made to other Asia-based studies run at odds to our finding whereby a positive association was reported between aesthetically pleasing neighbourhoods and moderate- to vigorous-intensity physical activity (*Chapter 5's* unpublished meta-analysis of findings from Japan [343, 344, 410], Singapore [345], and South Korea [346]). The current evidence base also supports the notion that more aesthetically-pleasing neighbourhood environments may promote recreational walking [102] and total physical activity [101].

In Hong Kong, older adults accumulate *extremely* high levels of physical activity *(Chapter 5)* and, therefore, it is plausible to assume that, given the amount of time they spend outdoors, they would be highly attuned to noticing signs of social disorder and/or littering in their neighbourhood [350]. Lower socio-economic status may also play a role: neighbourhood areas where signs of social disorder and/or littering were higher might also have been where older adults were more likely to walk for transport, perhaps to avoid the cost of public transport and/or because they live in smaller apartments which encouraged them to spend more time outside of their home being active [236]. Given the very strong evidence that aesthetically pleasing neighbourhoods facilitate total physical activity [101] (likely driven by recreational walking [102]), we might speculate that Hong Kong older adults, particularly those diagnosed with the least chronic conditions *(Chapter 5)*, may be even more active in the presence of cleaner/more aesthetically-pleasing streets. It may be the case, however, that the better upkeep of streets would have a limited effect on Hong Kong older adults' physical activity levels because it is within Chinese culture to value an active lifestyle [349, 397]. Therefore, this demographic may be less concerned by such things as messy streets, which, in contrast, have been highlighted as a barrier to walking in European older adults [92, 411]. Also, Hong Kong is an extremely safe place to live compared to Western cities/regions [379-382] and, thus, feelings of unsafety associated with littering and/or signs of social disorder in the streets may be less present in Hong Kong than in Western cities/regions. Hence older adults in Hong Kong may be more likely to venture out of their homes, both day and night. These cultural factors may help to explain why this neighbourhood attribute appears idiosyncratic of Hong Kong or, alternatively, it could be that this questionnaire item [246] assesses socio-economic aspects of the neighbourhood not accounted for by an individual's level of education or the average income of the area they live in [247].

Neighbourhood bridges and overpass connections were also found to be an important facilitator of Hong Kong older adults' accelerometer-assessed moderate- to vigorous-intensity physical activity. While not directly comparable, our finding is in agreement with previous Hong Kong-based research of a different cohort that found increased access to a bridge and/or overpass connection in the neighbourhood was positively associated with self-reported within-neighbourhood recreational walking [75]. Interestingly, in a previous study of the same sample as this thesis investigating access to a bridge and/or overpass connection and different self-reported modes of walking, nil findings were observed [348]. This may be due to the domain-specificity of the physical activity being investigated [100-102] or, perhaps, issues associated with the lower validity of self-reported physical activity versus objective instruments [175]. No study outside of Hong Kong has examined whether neighbourhood bridges and/or overpass connections influence older adults' physical activity behaviour. In Hong Kong, these highly prevalent modified walkways help individuals navigate the often steep terrain and areas where traffic is heavy, and had popular media nicknaming Hong Kong the 'city of stairs' [412] and a city 'without ground' [413, 414]. Moreover, greater implementation of such walkways in the neighbourhood may also help alleviate problems (i.e., avoidance of walking) for older adults diagnosed with multiple chronic conditions in areas that have a fence/physical barrier separating the footpath from traffic *(Chapter 6)*, because it would perhaps provide a more attractive alternative route.

Two additional built environmental attributes significantly associated with Hong Kong older adults' moderate- to vigorous-intensity physical activity were land-use mix (positive) and residential density (negative) *(Chapter 5)*. These neighbourhood characteristics were not associated with sedentary time *(Chapter 6)* and, therefore, require further examination in relation to light intensity physical activity, as the remaining intensity on the continuum. The finding that a diversity of neighbourhood destinations (land-use mix) was a positive correlate of older adults' participation in moderate- to vigorous-intensity physical activity agrees with the current evidence base [101, 348]. It is also in line with a large built environment-physical activity study of adults recruited in 11 different countries (pooled analysis) [334]. Our finding adds to a current dearth of research in this area in Asia.

Given that neighbourhood shops and commercial destinations have been reported to be particularly important for within-neighbourhood walking for transport [247], it is likely that the accumulation of moderate- to vigorous-intensity physical activity related to increased land-use mix was driven by transport-related walking [100, 251, 348]. Shopping has also been shown to be the main reason for getting out of the house (and thus being more active) in European older adults [115]. In addition, speculatively, the prospect of planners to increase the diversity of destinations in Hong Kong neighbourhoods, shown to be particularly important for facilitating moderate- to vigorous-intensity physical activity in older-aged elders *(Chapter 5),* might also be coupled with incorporating more indoor areas (e.g., air-conditioned shopping malls) as part of that development. This would provide a comfortable setting to rest not only for these older individuals who likely have lower physical function but also for those diagnosed with multiple chronic conditions *(Chapter 6),* whilst simultaneously encouraging recreational walking in healthier individuals [75].

Increased diversity of destinations (land-use mix) was also important when considering the negative association between residential density and older adults' moderate- to vigorous-intensity physical activity. This was because this association only became significant after adjusting for the mutual 'confounding' effects of density and land-use mix *(Chapter 5)*. The finding in this thesis that increased residential density was associated with lower estimates of moderate- to vigorous-intensity physical activity runs contrary to the literature [101]. This was not an entirely surprising finding considering the *extreme* density of Hong Kong neighbourhoods versus other cities [334], which would likely coincide with factors that would require a slower walking pace (e.g., more people in the streets, traffic stops etc.). Alternatively, Hong Kong older adults may simply prefer to walk more slowly in areas with higher residential density. Considering the findings observed in *Chapters 5 and 6,* it is likely that residential density is positively associated with light intensity physical activity, but more research is required to confirm this.

To examine whether particular sub-groups were more sensitive to/affected by neighbourhood built environmental characteristics in relation to their physical activity and sedentary behaviour, the moderating effects of age, sex, education, and number of diagnosed medical conditions were investigated by both epidemiological studies in this thesis *(Chapters 5 and 6)*. It was found that age moderated the association between land-use mix and older adults' moderate- to vigorous-intensity, as defined by our newly-developed accelerometer cut-point *(Chapter 5),* and the number of diagnosed medical conditions significantly interacted with sedentary time in relation to crowdedness and a fence separating the footpath from traffic. The low number of interactions found suggests that neighbourhood built environmental attributes would equally impact moderate- to vigorous-intensity physical activity behaviour across all older adults' socio-demographic sub-groups.

Finally, *Chapter 6* investigated whether moderate- to vigorous-intensity physical activity and sedentary time were independent behaviours. These two behaviours were found to be strongly negatively correlated *(Chapter 6)*. However, they shared only two perceived environmental correlates and no moderators *(Chapters 5 and 6)*. These findings add to the current dearth of evidence on moderators of built environment-sedentary behaviour associations [238, 242, 374] and to a limited evidence base in the physical activity literature [101]. Taken together, the findings of this thesis are encouraging, suggesting that some aspects of Hong Kong neighbourhoods (e.g., bridges/overpass connections) could be modified to facilitate moderate- to vigorous-intensity physical activity and, in turn, reduce individuals' sedentary time.

7.3 Study strengths and limitations

When interpreting the results presented in this thesis, there are study strengths and weaknesses that require consideration. As often as possible, strengths and weaknesses are discussed under the same sub-heading.

7.3.1 Study design

A limitation of the cross-sectional nature of the epidemiological studies in this thesis means causal inference could not be inferred about which built environmental attributes affect physical activity and sedentary behaviour. Therefore, more longitudinal and quasi-experimental research (e.g., natural experiments) is needed to allow for firmer conclusions to be drawn. That being said, cross-sectional studies may help to inform future public health strategies and interventions and research, through contributing to conceptual clarity, hypotheses formulation and testing, and understanding associations between exposures and outcomes [415, 416]. These data may then help inform public health policy and/or a change in policy [415, 416].

7.3.2 Sample sizes

A strength of the studies as part of this thesis was that all were adequately-powered to detect significant findings between exposures and outcomes. Regarding the accelerometer-based methodological study outlined in Chapter 4, details of the sample size calculation can be found in Appendix 10. Our sample size (n=43 participants) allowed for, at least, double the precision (within 15% accuracy *vs.* 30% [282]) in the determination of the moderate- to vigorous-intensity physical activity cut-point. Similar calibration studies determining such cut-points using accelerometer have recruited smaller samples (n=28-38 participants [243, 244, 282]) and/or not detailed information related to sample size calculations [243, 244, 277]. Regarding the epidemiological studies *(Chapters 5 and 6),* a sample size of 400 older adults would allow for the detection of small effect size (i.e., approximately 2.5% of the explained outcome variance) [249]. It is the single largest sample size (n=402 participants) based on built environment-[ActiGraph] accelerometer-assessed physical activity research, outside of the Senior Quality of Life Study [271, 274, 275, 408] and the Belgian Environmental Physical Activity Study in Seniors [101, 268].

7.3.3 Recruitment strategy

A limitation of the methodological study (Chapter 4) was that a snowball sampling strategy was employed. Consequently, the sample may have been biased in terms of health and other demographics. Indeed, our participants were generally high in physical function and, hence, might not be fully representative of all Chinese older adults of the same age living in Melbourne (Chapter 4). A limitation with regards to recruitment strategy for the epidemiological studies is that it was not possible to obtain a comprehensive sampling frame for participant recruitment across Hong Kong neighbourhoods (i.e., personal addresses and contact details could not be directly accessed/acquired) due to privacy ordinance restrictions [249]. Hence, participants had to be recruited in person from elderly health centres (two-thirds of the sample) and community centres (one-third of the sample) [249]. That being said, purposeful recruitment of participants from different socio-economic and environmental strata [249] helped mitigate the demographic bias therein and thus was a methodological strength of these studies [100-102].

7.3.4 Physical activity measurement

A major strength of this doctoral thesis was that the studies were underpinned by the objective measurement of physical activity, specifically, using the ActiGraph accelerometer. This device is the most widely-used in physical activity research in populations of all ages [182-184] and the most valid [141]. Accelerometers overcome issues associated with recall- and social desirability-bias, particularly pertinent in older adult populations [215]. Despite these benefits, there was still scope for improvement with regards to the accurate measurement of physical activity through the development of an appropriate moderate- to vigorous-intensity physical activity cut-point for use in Chinese older adults (Chapter 4). Some limitations, however, could not be addressed by Chapter 4's methodological study and these must be acknowledged. For example, accelerometers are unable to account for surface incline, which may be an issue given the hilliness of Hong Kong. Although, if anything, the extremely high estimates of moderate- to vigorous-intensity physical activity reported in *Chapter 5* would be *underestimated*, considering fewer accelerometer counts are registered on an incline versus a flat surface [417]. A further limitation to consider is that accelerometry cannot provide evidence on type or context of physical activity and sedentary behaviours [148, 220], which might be important for conceptually-driven research and/or informing public health strategies and interventions [221]. Thus, a mixed methods approach to assess physical activity and sedentary behaviours (i.e., accelerometry to assess physical activity intensities and total time *and* questionnaires to assess physical activity domains and/or context) may provide a fuller understanding of these behaviours in older adults.

7.3.5 Sedentary time measurement

The inability of ActiGraph accelerometry to provide contextual and typological information also extends to the measurement of sedentary behaviour. Furthermore, ActiGraph accelerometry cannot differentiate between standing and sitting. One device, the *activ*PAL™ inclinometer, might provide valuable data in addition to questionnaires because it validly assesses *posture* [197, 399]. Specifically, this tool measures time spent in sitting, standing, and laying behaviours and has been evidenced as being more valid in assessing sitting time estimates than the ActiGraph accelerometer [like the one used in the current thesis's research studies] [197, 399]. The increased accuracy and validity of measurement versus the ActiGraph accelerometer may allow for greater power in detecting significant associations between built environmental attributes and specific forms of sedentary time (e.g., sitting). However, in instances where using only one device to assess time spent in different physical activity intensities, including being sedentary, is the most appropriate, then, the ActiGraph is the most valid [197]. Therefore, the use of an ActiGraph accelerometer is a strength of our epidemiological studies *(Chapters 5 and 6)*.

7.3.6 Total and light intensity physical activity

Given some of the results of studies 2 and 3 *(Chapters 5 and 6)*, it is likely that some built environmental attributes (e.g., residential density) are associated with older adults' light-intensity physical activity. However, this was beyond the remit of this thesis and, therefore, should be researched in future studies. Moreover, since it is, ultimately, the total dose of physical activity (i.e., light- and moderate- to vigorous-intensity physical activity combined) that confers benefit/detriment upon health [332], and associations of the built environment with moderate- to vigorous-intensity physical activity and total physical activity have been shown to differ [242], investigating total physical activity as an outcome in future research may prove fruitful.

7.3.7 Perceived environment measurement

A strength of using a valid [246] subjective measure to assess the perceived neighbourhood built environment is that evidence suggests that these exposures are more closely associated with behaviour in older adults than environmental measures based on objective tools [101, 336]. However, limitations of such a measure have been mentioned previously; it is potentially subject to recall and social biases [215]. Notably, the self-reported data in this thesis were recorded with a trained interviewer present at all times which would have improved clarity [418] and, consequently, the accuracy of estimates.

7.3.8 Hong Kong built environment

A strength of assessing the association between the Hong Kong built environment and older adults' physical activity is that it adds to a dearth of evidence from Eastern cities/regions and, thus, increases the variability of geographical settings/contexts for which findings are available [334, 400]. A limitation of Hong Kong's built environment is that it is unique in many ways [246] and important facilitators of moderate- to vigorous-intensity physical activity (e.g., bridge/overpass connections) *(Chapters 5 and 6)* may not be directly comparable to other cities' built environment.

7.3.9 Data analysis

A major strength of this thesis's main analyses conducted in the methodological study (linear mixed models) *(Chapter 4)* and the epidemiological studies (generalised linear models with robust standard errors accounting for clustering at the administrative unit level) *(Chapters 5 and 6)* were that they allowed for more valid and accurate findings because they ensured that intra- (methodological study) [225] and inter-level (epidemiological studies) clustering was accounted for. Notably, regarding the epidemiological studies, neighbourhood self-selection was *not* accounted for in our statistical models because it is likely to be a trivial source of reverse causality. Specifically, Hong Kong's high levels of population density (6760 people·km^2) and low percentage of developed land (<25%) [419] would limit residents' choice of accommodation and 37% of Hong Kong older adults live in public rental housing [420].

7.4 Future research recommendations and directions

7.4.1 High-quality research

Using a quality assessment framework [100-102], the systematic- and narrative-literature reviews as part of this thesis's research program *(Chapter 2)* found a distinct lack of high-quality research in both sets of literature on the built environmental correlates of physical activity and sedentary behaviour (Appendices 6 and 18). More studies based on longitudinal and quasi-experimental research designs are needed to determine causal relationships between built environmental attributes and older adults' physical activity and sedentary behaviour. Aforementioned, assessing and adjusting for residential self-selection would also help mitigate bias and reverse causation and improve research quality (Appendices 6 and 18).

Higher quality research may also come from applying an appropriate accelerometer cut-point to define older adults' moderate- to vigorous-intensity physical activity (Chapter 4) [225]. Studying the independence of physical activity and sedentary behaviours in relation to the built environment would also contribute to the dearth of research in this area and help progress the current contention with regards to this issue among physical activity researchers [406]. Global positioning systems may be used to objectively measure the context in which these behaviours take place. These data would allow for the identification of where behaviours occur (e.g., within/outside of a given neighbourhood) and assess associations between built environmental attributes and moderate- to vigorous-intensity physical activity and sedentary behaviour. Furthermore, investigating whether neighbourhood attributes impact sub-groups of the population differently with regards to their physical activity and sedentary behaviours (i.e., moderation analysis) would also be potentially important information to add to a current lack of evidence in this area [100-102] *(Chapters 2 and 6)*. Improving research quality by implementing some of these suggestions may also enable the pooling of data across various cities and built environments. The increased variability in built environmental data, collected using standardised [valid] environmental and physical activity measures, has recently enabled evidence of curvilinearity of effects/associations to be found [334].

7.4.2 Practical implications from this thesis

With regards to practical implications for physical activity researchers, the findings from this thesis recommend the use of appropriate accelerometer cut-points to define older adults' moderate- to vigorous-intensity physical activity. In addition, the findings as part of this research program may help inform researchers involved with natural experiments on what environmental attributes to measure, since the environmental manipulation itself will be out of their control.

For reasons aforementioned, one might be careful to postulate practical implications from cross-sectional observational research. However, given the high quality of the epidemiological studies conducted as part of this thesis, encouraging the implementation of neighbourhood bridges and overpass connections in Hong Kong can be recommended. These walkways may provide an alternative route 'over' traffic for older adults living with multiple comorbidities in neighbourhoods where, currently, there are fences that separate the footpath from traffic, while facilitating moderate- to vigorous-intensity physical activity and reducing sedentary time in healthier individuals. Moreover, to increase participation in moderate- to vigorous-intensity physical activity and lower sedentary time, respectively, Hong Kong urban planners should prioritise designing neighbourhoods that include a diverse variety of destinations (including indoor areas), are high in street connectivity, but not overly dense in terms of residences alone. Evidence from cities across the world supports the notion that land-use mix is positively associated with older adults' objectively-measured physical activity [101].

7.5 Conclusions

The research program of this doctoral thesis was guided by the identified gaps in the built environment-physical activity literature observed in our systematic review and meta-analysis [101]. The addressing of these issues as part of this thesis provides insight and unique contributions to a growing area of research examining the associations between aspects of the neighbourhood built environment and older adults' accelerometer-assessed physical activity and sedentary time. Our investigation into the independence of physical activity and sedentary behaviours in relation to the built environment added further credence to the contribution of this thesis to the literature.

Findings from our epidemiological studies suggested that neighbourhoods with access to bridges and/or overpass connections and those with litter and/or social disorder were positively associated with moderate- to vigorous-intensity physical activity in Hong Kong

Chinese older adults and also explained their sedentary time. We are thus highlighting the importance of prioritising modified walkways in Hong Kong neighbourhoods and the non-independence of these two co-existing behaviours in this demographic. It was also found that increased diversity of neighbourhood destinations was an important positive correlate of moderate- to vigorous-intensity physical activity only, while increased residential density was negatively associated with the same outcome. Neither of these built environmental attributes was associated with sedentary time. Increased street connectivity was associated with lower estimates of sedentary time but not associated with moderate- to vigorous-intensity physical activity. Some population sub-groups were more sensitive to certain built environmental attributes than others, although the prevalence of these moderating effects was low. All of the moderate- to vigorous-intensity physical activity findings were underpinned by a robustly-developed accelerometer cut-point of $\geq$1184 counts·min^{-1}, which should be used in physical activity studies where Chinese older adults' moderate- to vigorous-intensity physical activity is being investigated. The findings on the examined main, moderating, and mediating effects provided a detailed insight into built environment-physical activity and sedentary behaviours among Hong Kong Chinese older adults.

Future physical activity research in older adults should focus on adopting more valid measures, particularly of moderate- to vigorous-intensity physical activity, and sophisticated data analyses to better understand the complex interactions between the built environment and physical activity and sedentary behaviours and participant characteristics. The roles that total and light intensity physical activity may play in this interplay of factors also warrant investigation.

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Appendices

Appendix 1: List of questionnaires, relevant abbreviations and the corresponding definitions for physical activity and sedentary behaviour questionnaires used in older adult studies

Acronym	Questionnaire	Recall timeframe	Activity domain [a]
7DPAR	Seven-Day Physical Activity Recall	Last 7 days	Exercise/sport (not specified), household, occupation, other
7DR (aka FCPQ)	Seven-Day Recall Questionnaire – also called the Five City Project Questionnaire	Last 7 days	*Not domain-specific per se* – Leisure LPA, MPA, VPA & VVPA, other, sedentary (sleep), total
BAQ-mod	Modified Baecke Activity Questionnaire	Last year	Exercise/sport, household, leisure, occupation, sedentary (sleep)
CAPS-4WR	Cross-Cultural Activity Participation Study – 4 weeks activity Recall	Last 4 weeks	Exercise/sport, household, leisure, occupation, other
CAPS-TWR	Cross-Cultural Activity Participation Study – Typical Week Activity Recall	Typical week	Exercise/sport, household, leisure, occupation, other, transportation
CAQ	College Alumni Questionnaire	Current; past year	*Not domain-specific per se* – walking stairs, walking blocks, exercise/sports
CHAMPS	Community Health Activities Model Program for Seniors	Typical week, last month	Exercise/sport, household, leisure, occupation, other, sedentary
CHAMPS-MMSCV	Community Health Activities Model Program for Seniors – Modified Mailed Self-Complete Version	Last 7 days	Exercise/sport, household, leisure, occupation, other, sedentary
CHAMPS-mod	Modified Community Health Activities Model Program for Seniors	Typical week, last month	Exercise/sport, household, leisure, occupation, other, sedentary
DQ-mod	Modified Dallosso Questionnaire	Typical day, last week; typical week	Household, leisure, walking
EPAQ	European Prospective Investigation of Cancer (EPIC) Physical Activity Questionnaire	Last year	Household, leisure (including exercise/sport), occupation
Pre-EPAQ	Pre-EPIC Physical Activity Questionnaire	Last year	Exercise/sport, household, leisure, occupation, sedentary, transportation
FPACQ	Flemish Physical Activity Computerized Questionnaire	Typical week	Exercise/sport, household, leisure, sedentary, transportation
HAP	Human Activity Profile	Still doing, stopped doing, never did	*Not domain-specific per se* – 94 activities ranging from low- to high-intensity
HAQ	Harvard Alumni Questionnaire	Typical week	*Not domain-specific per se* – Leisure, LPA, MPA, VPA, sedentary (sleep)
IPAQ-E	International Physical Activity Questionnaire – Short version modified for the Elderly	Last 7 days	*Not domain-specific per se* – Walking *for* exercise/sport, household, leisure, occupation and transportation, MPA, VPA, sedentary (sitting)
IPAQ-LC	International Physical Activity Questionnaire – Long version in Chinese	Last 7 days	Household, leisure (including exercise/sport), occupation, sedentary (sitting), transportation

IPAQ-s	International Physical Activity Questionnaire – Short version	Last 7 days	*Not domain-specific per se* – Walking *for* exercise/sport, household, leisure, occupation and transportation, MPA, VPA, sedentary (sitting)
IPAQ-SC	International Physical Activity Questionnaire – Short version in Chinese	Last 7 days	*Not domain-specific per se* – Walking *for* exercise/sport, household, leisure, occupation and transportation, MPA, VPA, sedentary (sitting)
IPEQ	Incidental and Planned Exercise Questionnaire for seniors	Typical week in the last 3 months	*Does not specify domains entirely* – Household (indoor & outdoor), walking (planned & travel), MVPA
LRC	Lipid Research Clinics Questionnaire	Current [daily]	Exercise/sport (VPA only), leisure, occupation
MARCA	Multimedia Activity Recall for Children and Adults	Previous day	Exercise/sport, household, leisure, occupation, other
MLTPAQ	Minnesota Leisure Time Physical Activity Questionnaire	Last year	*Not domain-specific per se* – Household, leisure LPA, MPA & VPA
NWQ-CS	Neighbourhood Walking Questionnaire – Chinese version for Seniors	Usual walking for a typical week	*Not domain-specific per se* – Walking *for* leisure, transportation
OA-ESI	Older Adult Exercise Status Inventory	Each day in last 7 days	Exercise/sport, household, leisure, occupation
PASE	Physical Activity Scale for the Elderly	Last 7 days	Household, leisure (including exercise/sport), occupation
PASE-mod	Modified Physical Activity Scale for the Elderly	Last 7 days	Household, leisure (including exercise/sport), occupation. [*Note:* The authors do not state in which way they modified the PASE]
PAQ-EJ	Physical Activity Questionnaire for Elderly Japanese	Typical week, last month	Exercise/sport, household, leisure, transportation
R24AF	24-hour Physical Activity Recall	Previous day	Exercise/sport, household, leisure, occupation, sedentary (sleep), transportation, other
SBAS	Stanford Brief Activity Survey	Typical day	Leisure (including exercise/sport, household, transportation), occupation
SMC-PAQ	Swedish Mammography Cohort Physical Activity Questionnaire	Last year	Household, leisure (including exercise/sport), occupation, sedentary (TV/reading), walking/bicycling
sPAR	Simplified Physical Activity Record	Daily	Exercise/sport, household, leisure, occupation, sedentary (sleep), other
QAPSE	Questionnaire d'Activite Physique Saint-Etienne	Typical week	Household, leisure (including exercise/sport), occupation, sedentary (sleep), transportation, other
WHI-PAQ	Women's Health Initiative – Physical Activity Questionnaire	Last 7 days	Household, leisure (including exercise/sport), sedentary (sitting & sleep)
YPAS	Yale Physical Activity Questionnaire	Typical week, last month	Exercise/sport, household, leisure, sedentary (sitting)
ZPAQ	Zutphen Physical Activity Questionnaire	Last week, month, and 'usual' activity depending on the activity	*Not domain-specific per se* – Exercise/sport, household, leisure, walking/cycling, other

Notes: Activity domains were reclassified, unless the activities were very different from categories used, according to the following system: 7DPAR [128]: "exercise/sport:" exercise; "household:" home/auto repair, cooking, elder/child care; "occupation:" walking at work; "other:" shopping; 7DR [125]: "Leisure LPA:" light; "[leisure] MPA:" moderate; "[leisure] VPA:" hard; "[leisure] VVPA:" very hard; "sedentary (sleep):" sleep; CHAMPS [126, 129, 131, 133, 141]: "exercise/sport:" e.g. conditioning, dance; gym work; running, walk fast for exercise; "household:" light/heavy housework (e.g., washing windows); "leisure:" going places (e.g., senior centre, religious institution, visiting friends or family etc.), walking leisurely (e.g., during a game of golf, walk uphill); "occupation:" volunteer work; "other:" woodworking, needlework, drawing, or other arts and crafts; "sedentary:" e.g. computer-related sitting, reading; FPACQ [159]:

“exercise/sport:” sports participation; “household:” household and garden activities; “leisure:” leisure time activities, MVPA in leisure time; “sedentary:” e.g. sleeping, watching television or playing computer games; “transportation:” transport in leisure time; HAP [157]: The HAP does not per se – 94 activities ranging from low- to high-intensity; IPAQ-E [154]: “MPA:” all moderate activities, (e.g., carrying light loads, bicycling at a regular pace, doubles tennis (did *not* include walking)); “VPA:” “VPA” all vigorous activities (e.g., heavy lifting, digging, aerobics, fast bicycling); “sedentary (sitting):” e.g. time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television; “walking:” walking *during* exercise/sport, household, leisure, occupation and transportation; IPAQ-LC [151]: “housework:” physical activity as part of housework, gardening, yard work, general maintenance work, and caring for your family; “leisure:” physical activities solely for recreation, sport, exercise or leisure; “occupation” – physical activity as part of paid jobs, farming, volunteer work, course work, and any other unpaid work that you did outside your home. Did *not* include unpaid work you might do around the house, like housework, yard work, general maintenance, and caring for your family; “sedentary (sitting):” time spent sitting while at work, at home, while doing course work and during leisure time (e.g., time spent sitting at a desk, visiting friends, reading or sitting or lying down to watch television); “transportation:” travelling to places like work, stores, movies etc.; *For IPAQ-s [135], IPAQ-s [155] and IPAQ-SC [153] see IPAQ-E description above*; MARCA [143]: “exercise/sport” & “leisure:” sport/recreation; “household:” home activities; “occupation:” occupation; “other:” self-care & other activities; MLTPAQ [125]: “household:” household-related physical activities accrued daily over the past year; “leisure:” daily physical activity accumulated during leisure-time over the past year; NWQ-CS [139]: “walking:” for leisure and transport; OA-ESI [147]: work-time activity and leisure-time physical activity were documented: five categories of indoor and outdoor work activity, along with a list of 38 categories of leisure-time exercise and sport activity were provided; PASE and PASE-mod [127, 130-132, 136, 141]: “household:” activities related to housework, home repair, gardening, and yard work; “leisure (including exercise/sport):” walking outside the home, light moderate and strenuous sports and recreational activities, and muscle strength and/or endurance exercise; “occupation:” work-related activity as a paid employee or volunteer; PAQ-EJ [138]: “exercise/sport:” exercise/sports (light, moderate or somewhat strenuous, and resistance); “household:” housework (light, moderate or somewhat heavy) and labour (work in and around the house or yard); “transportation:” personal transportation; R24AF [144]: “exercise/sport:” physical exercise and sports; “household:” household; “leisure:” leisure; “occupational:” occupational; “sedentary (sleep):” sleep time; “other:” activities of personal hygiene, feeding, and other activities; SBAS [134]: “leisure:” current activity participants particularly did outside of their occupation. Leisure time was usually spent on self-care, household chores, recreation/fitness activities, and transportation; “occupation:” current activity participants did for their occupation; SMC-PAQ [158, 160]: “leisure:” leisure-time activity ‘exercise’; “household:” household work; “occupation:” work/occupation; “sedentary (TV/reading):” leisure-time inactivity (e.g., watching TV/reading); “occupation:” work/occupation (from mostly sitting down to heavy manual labour); sPAR [145]: “exercise/sports:” sports; “household:” house-keeping; “leisure:” leisure; “occupation:” work-related activities; “sedentary (sleep):” sleep and rest; “transportation:” transportation; “other:” *non-listed activities*; QAPSE [124, 125]: “household:” household and related activities of daily living (cooking, repairs, chores); “leisure (including exercise/sport):” sport and non-sport leisure activities; “occupation:” professional (occupational) time spent in associations (social activities-non-sport); “sedentary (sleep):” from the “basic activities of daily living” aspect of the questionnaire; “transport:” transport and moving from place to place – usual form of travel (including walking); “other:” miscellaneous – any other activities not investigated and basic activities of daily living (washing, toilet, meals); WHI-PAQ [146]: “household:” household activities (including yard work); “leisure (including exercise/sport):” grouped exercise or recreational activities (mild, moderate, and strenuous); “sedentary (sitting & sleep):” time spent sitting and lying down (including sleep); YPAS [125, 131, 141, 149, 152, 155]: “exercise/sport:” e.g. brisk walking, yoga, vigorous calisthenics, aerobics, cycling, swimming (laps only), etc.; “household:” laundry, carrying groceries, heavy housework etc.; “leisure:” ‘recreational’ – leisurely walking, needlework, dancing, bowling etc.; “sedentary (sitting)” – time spent sitting; ZPAQ [421]: “exercise/sport:” sporting activities; “household:” gardening; “leisure:” hobbies; “other:” odd jobs; “walking/cycling:” walking and cycling

Appendix 2: Construct validity results of physical activity questionnaires used in older adults (in alphabetical order)

Questionnaire	Reference (first author, year)	Criterion method	Accelerometry criterion intensity threshold	Duration of validation	Validity variables tested	Validity results: Correlation coefficients [a]	Validity results: p-value [b]
7DPAR	Dubbert, 2004 [128]	Acc (Titrac R3D)	-	3 days	TEE ($kJ \cdot kg^{-1} \cdot d^{-1}$) (Q) – counts·$min^{-1}$ (Acc)	*rho* = .49	.01
					Walking ($min \cdot d^{-1}$) (Q) – counts·min^{-1} (Acc)	*rho* = .52	.01
					MPA ($hr \cdot wk^{-1}$) (Q) – counts·min^{-1} (Acc)	*rho* = .47	.01
					VPA ($hr \cdot wk^{-1}$) (Q) – counts·min^{-1} (Acc)	*rho* = .37	.01
7DR (aka FCPQ)	Bonnefoy, 2001 [125]	DLW	*N/A*	14 days	Total energy expenditure ($kJ \cdot d^{-1}$) – TEE (DLW)	*r* = .37	Ø
						rho = .51	.05
BAQ-mod	Bonnefoy, 2001 [125]	DLW	*N/A*	14 days	Activity score (Q) – TEE (DLW)	*r* = .21	Ø
						rho = .28	Ø
	Voorrips, 1991 [140]	Ped	*N/A*	3 days	Activity score (Q) – Steps (Ped)	*r* = .72	-
CAQ	Bonnefoy, 2001 [125]	DLW	*N/A*	14 days	Total energy expenditure ($kcal \cdot d^{-1}$) – TEE (DLW)	*r* = .39	Ø
						rho = .37	Ø
CHAMPS	Colbert, 2011 [141]	DLW	*N/A*	10 days	PAEE (Q) – PAEE (DLW)	*rho* = .28	.04
					PAI (Q) – $PAEE_{adj}$ (DLW)	*rho* = .23	Ø
	Cyarto, 2006 [126]	Physical performance tests	*N/A*	7 days	MVPA ($MET\text{-}hr \cdot wk^{-1}$) (Q) – chair stand	*rho* = .19	.05
					MVPA ($frequency \cdot wk^{-1}$) (Q) – chair stand	*rho* = .16	.05
					All activities ($MET\text{-}hr \cdot wk^{-1}$) (Q) – chair stand	*rho* = .21	≤ .01
					All activities ($frequency \cdot wk^{-1}$) (Q) – chair stand	*rho* = .14	Ø
					MVPA ($MET\text{-}hr \cdot wk^{-1}$) (Q) – step test	*rho* = .32	≤.001
					MVPA ($frequency \cdot wk^{-1}$) (Q) – step test	*rho* = .31	≤.001
					All activities ($MET\text{-}hr \cdot wk^{-1}$) (Q) – step test	*rho* = .28	≤.001
					All activities ($frequency \cdot wk^{-1}$) (Q) – step test	*rho* = .26	≤.01
	Harada, 2001 [131]	ML (Mini-Mitter)	-	7 days	EE (Q) – ankle counts (ML)	*r* = .36	.01
					EE (Q) – waist counts (ML)	*r* = .42	.001
	Stewart, 2001 [133]	With physical performance tests and self-reported physical functioning and	*N/A*	-	MVPA ($cal.exp. \cdot wk^{-1}$) (Q) – physical function [f]	*r* = .30	.001
					MVPA ($frequency \cdot wk^{-1}$) (Q) – physical function [f]	*r* = .30	.001
					All activities ($cal.exp. \cdot wk^{-1}$) (Q) – physical function [f]	*r* = .22	.001
					All activities ($cal.exp. \cdot wk^{-1}$) (Q) – physical function [f]	*r* = .10	Ø

		mental well-being					
CHAMPS-MMSCV	Giles, 2009 [129]	Ped (Yamax)	*N/A*	7 days	*Volume T1*: walking (MET-hr·wk^{-1}) (Q) – step counts (Ped)	*rho* = .40	.01
					Frequency T1: walking (MET-hr·wk^{-1}) (Q) – step counts (Ped)	*rho* = .57	.01
					Volume T2: walking (MET-hr·wk^{-1}) (Q) – step counts (Ped)	*rho* = .53	.01
					Frequency T2: walking (MET-hr·wk^{-1}) (Q) – step counts (Ped)	*rho* = .60	.01
					Frequency T1: HEPA (MET-hr·wk^{-1}) (Q) – step counts (Ped) *Volume*	*rho* = .52	.01
					T1: HEPA (MET-hr·wk^{-1}) (Q) – step counts (Ped)	*rho* = .21	.01
					Frequency T2: HEPA (MET-hr·wk^{-1}) (Q) – step counts (Ped)	*rho* = .52	.01
					Volume T2: HEPA (MET-hr·wk^{-1}) (Q) – step counts (Ped)	*rho* = .38	.01
CHAMPS-mod	Hekler, 2012 [156]	Acc (ActiGraph)	Low-light PA = >100 to <1041 CPM [243]; High-light PA = ≥1041 to <1952 CPM; MVPA = ≥1952 CPM [2]	7 days	*Duration*:		
					Low-light PA (Q) – low-light (Acc)	*rho* = .06	Ø
					High-light PA (Q) – high-light (Acc)	*rho* = .27	.0001
					MVPA (Q) – MVPA (Acc)	*rho* = .37	.0001
					Total activity (Q) – total activity (Acc)	*rho* = .38	.0001
					cal.exp.·wk^{-1}:		
					MVPA (Q) – MVPA (Acc)	*rho* = .38	.0001
					Total activity (Q) – total activity (Acc)	*rho* = .39	.0001
DQ-mod	Bonnefoy, 2001 [125]	DLW	*N/A*	14 days	Total score (Q) – TEE (DLW)	*r* = .21	Ø
						rho = .34	Ø
FPACQ	Matton, 2007 [159]	Acc (RT3) in combination with a 7-d activity record	-	7 days	*Retired men*: TEE (kcal·wk^{-1})(Q) – TEE (kcal·wk^{-1}) (Acc)	*r* = .55	.01
						t-test = 11.48	.001
					Retired women: TEE (kcal·wk^{-1})(Q) – TEE (kcal·wk^{-1}) (Acc)	*r* = .85	.001
						t-test = 10.79	.001
					Retired men: PAL (MET) (Q) – PAL (MET) (Acc)	*r* = .39	.05
						t-test = 11.91	.001
					Retired women: PAL (MET) (Q) – PAL (MET) (Acc)	*r* = .50	.05
						t-test = 13.93	.001
HAP	Bastone, 2014 [157]	Acc (ActiGraph)	MPA = 1953-5724 CPM [2]	7 days	Adjusted activity score (Q) – counts·d^{-1} (Acc)	*r* = .61	.001
					Adjusted activity score (Q) – MPA·d^{-1} (Acc)	*r* = .71	.001
					Adjusted activity score (Q) – steps·wk^{-1} (Acc)	*r* =.75	.001
					Adjusted activity score (Q) – EE·day^{-1} (Acc)	*r* = .52	.001
					Maximum activity score (Q) – counts·day^{-1} (Acc)	*r* = .61	.001
					Maximum activity score (Q) – MPA·wk^{-1}	*r* = .63	.001
					Maximum activity score (Q) – steps·d^{-1} (Acc)	*r* = .69	.001
					Maximum activity score (Q) – EE·wk^{-1} (Acc)	*r* = .55	.001

IPAQ-E	Hurtig-Wennlof, 2010 [154]	Acc (ActiGraph)	MPA = 760-4944 CPM VPA = >4944 CPM	7 days	Walking + MPA (min·d^{-1}) (Q) – mean counts·min^{-1} (Acc)	*rho* = .35 k (95% CI) = .448 (.18, .72)	.01 .001
					MPA min·d^{-1} (Q) – MPA counts·min^{-1} (Acc)	*rho* = .37	.01
					VPA min·d^{-1} (Q) – VPA counts·min^{-1} (Acc)	*rho* = .40	.01
IPAQ-LC	Cerin, 2012 [151]	Acc (ActiGraph)	LPA = 100-1951 CPM; MPA = 1952-5724 CPM; MVPA = ≥1952 CPM [2]	7 days	Total activity (Q) – LPA (Acc)	*r* = .37	.001
					Total activity (Q) – MPA (Acc)	*r* = .25	.05
					Total activity (Q) – MVPA (Acc)	*r* = .25	.05
					Walking (Q) – MVPA (Acc)	*r* = .11	Ø
IPAQ-s	Kolbe-Alexander, 2006 [155]	Acc (ActiGraph)	MPA = 1952-5724 CPM; VPA = ≥5725 CPM [2]	7 days	*Men*: VPA(MET-min·wk^{-1})(Q) – VPA(min·wk^{-1})(Acc)	*rho* = .43	.05
					Women: VPA(MET-min·wk^{-1})(Q) – VPA(min·wk^{-1}) (Acc)	*rho* = .05	Ø
					Men: MPA (MET-min·wk^{-1}) (Q) – MPA (min·wk^{-1}) (Acc)	*rho* = .31	.004
					Women: MPA(MET-min·wk^{-1})(Q) – MPA(min·wk^{-1})(Acc)	*rho* = -.09	Ø
					Men: walking (MET-min·wk^{-1}) (Q) – counts (Acc)	*rho* = .57	<.001
					Women: walking (MET-min·wk^{-1}) (Q) – counts (Acc)	*rho* = .42	.006
	Tomioka, 2011 [135]	Acc (Kenz Lifecorder)	-	14 days	*Young old men*: MET-min·wk^{-1} (Q) – MET-min·wk^{-1} (Acc)	*rho* = .42 k (95% CI) = .49 (.34, .64)	.01
					Young old women: MET-min·wk^{-1} (Q) – MET min·wk^{-1} (Acc)	*rho* = .49 k (95% CI) = .39 (.22, .56)	.01
					Old old men: MET-min·wk^{-1} (Q) – MET-min·wk^{-1} (Acc)	*rho* = .53, k (95% CI) = .39 (.22, .56)	 .01
					Old old women: MET-min·wk^{-1} (Q) – MET-min·wk^{-1} (Acc)	*rho* = .49, k (95% CI) = .47 (.28, .66)	 .01
IPAQ-SC	Deng, 2008 [153]	Ped (Yamax)	*N/A*	7 days	Total PA (MET-min·wk^{-1}) (Q) – steps·wk^{-1} (Ped)	*rho* = .33	.001
					MPA (MET-min·wk^{-1}) (Q) – steps·wk^{-1} (Ped)	*rho* = .05	Ø
					VPA (MET-min·wk^{-1}) (Q) – steps·wk^{-1} (Ped)	*rho* = -.09	Ø
					Walking (MET-min·wk^{-1}) (Q) – steps·wk^{-1} (Ped)	*rho* = .58	.001
IPEQ	Merom, 2014 [142]	Acc (ActiGraph)	LPA = 100-1040 CPM [168], 100-759 CPM [170]; MVPA =	7 days	MVPA (Q) – CPM (Acc)	*rho* = .33	.01
					MVPA (Q) – steps·d^{-1} (Acc)	*rho* = .31	.01
					MVPA (Q) – MVPA (Acc: Copeland cut-point)	*rho* = .33	.01
					MVPA (Q) – LPA (Acc: Copeland cut-point)	*rho* = .12	Ø
					MVPA (Q) – MVPA (Acc: Matthews cut-point)	*rho* = .26	.05

			≥1041 CPM [243], ≥760 CPM [321]		MVPA (Q) – LPA (Acc: Matthews cut-point)	*rho* = -.02	Ø
					Walking (Q) – CPM (Acc)	*rho* = .31	.01
					Walking (Q) – steps·d^{-1} (Acc)	*rho* = .28	.01
					Walking (Q) – MVPA (Acc: Copeland cut-point)	*rho* = .35	.01
					Walking (Q) – LPA (Acc: Copeland cut-point)	*rho* = .03	Ø
					Walking (Q) – MVPA (Acc: Matthews cut-point)	*rho* = .29	.01
					Walking (Q) – LPA (Matthews cut-point)	*rho* = -.07	Ø
					Incidental (Q) – CPM (Acc)	*rho* = .15	Ø
					Incidental (Q) – steps·d^{-1} (Acc)	*rho* = .07	Ø
					Incidental (Q) – MVPA (Acc: Copeland cut-point)	*rho* = .04	Ø
					Incidental (Q) – LPA (Acc: Copeland cut-point)	*rho* = .14	Ø
					Incidental (Q) – MVPA (Acc: Matthews cut-point)	*rho* = .13	Ø
					Incidental (Q) – LPA (Acc: Matthews cut-point)	*rho* = .29	.01
					All PA (Q) – CPM (Acc)	*rho* = .17	Ø
					All PA (Q) – steps·d^{-1} (Acc)	*rho* = .11	Ø
					All PA (Q) – MVPA (Acc: Copeland cut-point)	*rho* = .09	Ø
					All PA (Q) – LPA (Acc: Copeland cut-point)	*rho* = .11	Ø
					All PA (Q) – MVPA (Acc: Matthews cut-point)	*rho* = .15	Ø
					All PA (Q) – LPA (Acc: Matthews cut-point)	*rho* = .23	.01
LRC	Bonnefoy, 2001 [125]	DLW	*N/A*	14 days	Enhanced LRC (Q) – TEE (DLW)	*r* = .33	Ø
						rho = .29	Ø
MARCA	Mace, 2014 [143]	Acc (ActiGraph)	NSPA = ≥100 CPM; MVPA = ≥574 CPM [328], ≥1041 CPM [243], ≥1952 CPM [2]	7 days	*Overall*:		
					NSPA (Q) – NSPA (Acc)	*rho* = .59	.001
					MVPA (Q) – MVPA (Acc: Swartz cut-point)	*rho* = .18	.05
					MVPA (Q) – MVPA (Acc: Copeland cut-point)	*rho* = .14	Ø
					MVPA (Q) – MVPA (Acc: Freedson cut-point)	*rho* = .05	Ø
					Physical activity level (Q) – counts·min^{-1}	*rho* = .36	.05
					Physical activity level (Q) – total counts	*rho* = .34	.05
					Men:		
					NSPA (Q) – NSPA (Acc)	*rho* = .54	.001
					MVPA (Q) – MVPA (Acc: Swartz cut-point)	*rho* = .35	.001
					MVPA (Q) – MVPA (Acc: Copeland cut-point)	*rho* = .21	.05
					MVPA (Q) – MVPA (Acc: Freedson cut-point)	*rho* = -.07	Ø
					Physical activity level (Q) – counts·min^{-1}	*rho* = .31	Ø
					Physical activity level (Q) – total counts	*rho* = .31	.05
					Female:		
					NSPA (Q) – NSPA (Acc)	*rho* = .66	.001
					MVPA (Q) – MVPA (Acc: Swartz cut-point)	*rho* = .03	Ø

					MVPA (Q) – MVPA (Acc: Copeland cut-point) MVPA (Q) – MVPA (Acc: Freedson cut-point) Physical activity level (Q) – counts·min^{-1} Physical activity level (Q) – total counts	*rho* = .09 *rho* = .14 *rho* = .44 *rho* = .34	Ø Ø .001 .05
MLTPAQ	Bonnefoy, 2001 [125]	DLW	*N/A*	14 days	Total activity (kJ·d^{-1}) – TEE (DLW)	*r* = .23 *rho* = .17	Ø Ø
NWQ-CS	Cerin, 2011 [139]	Acc (ActiGraph)	MVPA = ≥1952 CPM [2]	7 days	Total walking (min·wk^{-1}) (Q) – step counts (Acc) Total walking(min·wk^{-1}) (Q) – MVPA (min·wk^{-1}) (Acc) Total walking (min·wk^{-1}) (Q) – mean activity (CPM) (Acc)	*r* = .48 *r* = .26 *r* = .53	.001 .05 .001
OA-ESI	O'Brien-Cousins, 1996 [147]	Other previously-validated PA indicators on the same survey: 7-day recall check list	*N/A*	0-4 weeks	TOTKCAL (Q) *vs.* lifelong activity TOTKCAL (Q) *vs.* frequency of sweating TOTKCAL (Q) *vs.* active days·wk^{-1}	*r* = .45 *r* = .41 *r* = .49	.01 - .001
PAQ-EJ	Yasunaga, 2007 [138]	Acc (Kenz Lifecorder)	LPA = <3 METs; MPA = ≥3 METs	1 month	PAQ-EJ score (Q) – MET-min·d^{-1} (Acc)	*rho* = .41	.05
PASE	Bonnefoy, 2001 [125]	DLW	*N/A*	14 days	Summary index (Q) – TEE (DLW) Total score (Q) – TEE (DLW)	*r* = .11 *rho* = .10 *r* = .28, *rho* = .23	Ø Ø
	Dinger, 2004 [127]	Acc (ActiGraph)	-	7 days	Total PASE score (Q) – mean counts·min^{-1} (Acc)	*rho* = .43	.001
	Hagiwara, 2008 [130]	Acc (Kenz Lifecorder); validated JALSPAQ	-	3 days	Total PASE score (Q) – EE (Acc) Total PASE score (Q) – walking steps (Acc) Total PASE score (Q) – total JALSPAQ (Q)	*rho* = .16 *rho* = .17 *rho* = .48	.02 .01 .001
	Harada, 2001 [131]	ML (Mini-Mitter)	-	7 days	Total PASE score (Q) – ankle counts (ML) Total PASE score (Q) – waist counts (ML)	*r* = .59 *r* = .52	.001 .001
	Schuit, 1997 [132]	DLW	*N/A*	14 days	Total PASE score (Q) – PA ratio (TEE/RMR ratio) (DLW)	*rho* = .68 (.35, .86)	-
	Washburn, 1993 [136]	Questions about health status and physiological measures	*N/A*	3 days	Perceived health (1 = excellent, 5 = poor) Sick impact profile	*r* = -.34 *r* = -.42	.01 .01

	Washburn, 1999 [137]	Acc (ActiGraph)	-	3 days	Total PASE score (Q) – mean counts·5-min epoch^{-1} (Acc)	*rho* = .49	.05
PASE-mod	Colbert, 2011 [141]	DLW	*N/A*	10 days	PAEE (Q) – PAEE (DLW) PAI (Q) – $PAEE_{adj}$ (DLW)	*rho* = .20 *rho* = .11	Ø Ø
QAPSE	Bonnefoy, 1996 [124]	$VO_{2\ max}$, body mass, skinfold thickness, fat-free-mass, body fat	*N/A*	1 week	Mean habitual EE (kJ·d^{-1}) (Q) – body mass (kg) Mean habitual EE (kJ·d^{-1}) (Q) – skinfold thickness (mm) Mean habitual EE (kJ·d^{-1}) (Q) – fat-free mass (kg) Mean habitual EE (kJ·d^{-1}) (Q) – body fat (%) Mean habitual EE (kJ·d^{-1}) (Q) – $VO_{2\ max}$ (ml·kg^{-1}·min^{-1})	*r* = .46 *r* = -.12 *r* = .64 *r* = -.50 *r* = .56	<.001 Ø <.001 <.001 <.001
	Bonnefoy, 2001 [125]	DLW	*N/A*	14 days	Mean habitual DEE (kJ·d^{-1}) – TEE (DLW)	*r* = .32, *rho* = .25	- -
R24AF	Osti, 2014 [144]	Acc (ActiGraph)	SB = <25 CPM; LPA = ≥25-1040 CPM; MPA = ≥1041 CPM [168]	6 days	All days: MPA (Q) – MPA (Acc) LPA (Q) – LPA (Acc) LPA + MPA (Q) – LPA + MPA (Acc) Weekdays: MPA (Q) – MPA (Acc) LPA (Q) – LPA (Acc) LPA + MPA (Q) – LPA + MPA (Acc) Weekend days: MPA (Q) – MPA (Acc) LPA (Q) – LPA (Acc) LPA + MPA (Q) – LPA + MPA (Acc)	 *r* = .38 *r* = .54 *r* = .60 *r* = .26 *r* = .55 *r* = .62 *r* = .56 *r* = .43 *r* = .53	 .039 .002 <.001 Ø .002 .001 .001 .018 .003
SBAS	Taylor-Piliae, 2006 [134]	Other questionnaire: Stanford 7-day Physical Activity Recall	*N/A*	7 days	MVPA (min·wk^{-1}) (Q) – MVPA (min·wk^{-1}) (Stanford 7-day PA recall) EE (kcal·kg^{-1}·d^{-1}) (Q) – EE (kcal·kg^{-1}·d^{-1}) (Stanford 7-day PA recall)	- -	P_{trend} [c] .01 P_{trend} [c] .01
sPAR	Yamada, 2013 [145]	DLW	*N/A*	14 days	TEE (kcal·d^{-1}) (Q) – TEE (kcal·d^{-1}) (DLW) PAEE (kcal·d^{-1}) (Q) – PAEE (kcal·d^{-1}) (DLW) PAL (kcal·d^{-1}) (Q) – PAL (kcal·d^{-1}) (DLW)	*r* = .83 *r* = .67 *r* = .59	.001 .001 .001
SMC-PAQ	Orsini, 2008 [158]	Acc (ActiGraph); 7-day activity log	-	7 days	Total activity (MET-hr·d^{-1}) (Q) – Total activity (MET-hr·d^{-1}) (Acc) Total activity (MET-hr·wk^{-1}) (Q) – total activity (MET-hr·wk^{-1}) (7-day activity log) Leisure-time activity (MET-hr·d^{-1}) (Q) – leisure-time activity (MET-hr·d^{-1}) (Acc) Leisure-time activity (MET-hr·d^{-1}) (Q) – leisure-time activity (MET-hr·d^{-1}) (7-day activity log)	*r* [d] = .38 (.22, .54) *r*[d] = .64 (.45, .83) *r*[d] = .42 (.22, .62)	- - - -

						r^{d} = .52 (.36, .69)	
SUA	Bonnefoy, 2001 [125]	DLW	*N/A*	14 days	MPA (Q) – TEE (DLW)	*r* = .65	.05
						rho = .46	Ø
					VPA (Q) – TEE (DLW)	*r* = .63	.05
						rho = .64	.05
YPAS	Colbert, 2011 [141]	DLW	*N/A*	10 days	PAEE (Q) – PAEE (DLW)	*rho* = .07	Ø
					PAI (Q) – $PAEE_{adj}$ (DLW)	*rho* = .09	Ø
	De Abajo, 2001 [152]	Acc (Caltrac)	-	3 days	Total hr·wk^{-1} (Q) – activity units·d^{-1} (Acc)	*r* = .20	.049
					TEE (Q) – activity units·d^{-1} (Acc)	*r* = .23	.022
					YPAS summary index (Q) – activity units·d^{-1} (Acc)	*r* = .24	.018
					Sitting (Q) – activity units·d^{-1} (Acc)	*r* = -.06	Ø
	DiPietro, 1993 [149]	Acc (Caltrac); $VO_{2\,max}$., resting diastolic blood pressure, BMI, body fat	*N/A*	2.5 days	Total hr·wk^{-1} (Q) – counts·2.5 d^{-1}	*rho* = .08	Ø
					EE (kcal·wk^{-1}) (Q) – counts·2.5 d^{-1}	*rho* = .14	Ø
					YPAS summary index (total units) (Q) – counts·2.5 d^{-1}	*rho* = .37	Ø
					Leisure walk index (units·month^{-1}) (Q) – counts·2.5 d^{-1}	*rho* = .31	Ø
					Vigorous index (units·month^{-1}) (Q) – counts·2.5 d^{-1}	*rho* = .14	Ø
					Moving index (hr·day^{-1}) (Q) – counts·2.5 d^{-1}	*rho* = .13	Ø
					Standing index (hr·day^{-1}) (Q) – counts·2.5 d^{-1}	*rho* = -.13	Ø
	Harada, 2001 [131]	ML (Mini-Mitter)	-	7 days	EE (Q) – ankle counts (ML)	*r* = .46	.001
					EE (Q) – waist counts (ML)	*r* = .61	.001
	Kolbe-Alexander, 2006 [155]	Acc (ActiGraph)	-	7 days	*Men*: total PA (MET-min·wk^{-1}) (Q) – counts (Acc)	*rho* = .54	<.001
					Women: total PA (MET-min·wk^{-1}) (Q) – counts (Acc)	*rho* = .13	Ø

Notes: See Table 1 for definitions of questionnaire acronyms, and measurement timeframes used; d: days; wk: week; Ø: not statistically significant (p >.05); [a] k, *r* and *rho* are sometimes given with 95% confidence intervals (lower, upper); [b] < unless stated otherwise; [c] (researchers were looking for a significant trend across SBAS activity categories); [d] Deattentuated concordance. K: kappa (i.e., Cohen weighted kappa unless specified otherwise), MD: Mean Difference, -: not stated. BMI: body mass index; CI: Confidence Interval (lower; upper); CPM: counts·min^{-1}; DLW: doubly-labelled water; EE: energy expenditure; LoA: Limits of Agreement; MET: Metabolic equivalent; MHDEE: mean habitual daily energy expenditure; MVPA: moderate- to vigorous-intensity physical activity; PA: physical activity; PAL: physical activity level; PAR: physical activity recall; *r:* Pearson correlation coefficient; *rho:* Spearman correlation coefficient; RMR: Resting metabolic rate; RT3: a combination of triaxial accelerometry and a written 7-day activity record; TEE: total energy expenditure; TOTCAL: MILDCAL+MODKCAL+VIGKCAL; UES: unadjusted effect size; VIGKCAL: those with ≥6 METs; VO_2max: maximum oxygen uptake/consumption. Acc: Accelerometry [*Note:* ActiGraph (Model 7164) is a successor of preceding accelerometer called CSA, and MTI]. Accelerometer names as used in the respective papers; T1: time-point 1; T2: time-point 2.
Bonnefoy et al., 2001 [Bonnefoy, et al. [125]]: MLTPAQ total activity: light, moderate, heavy, household activity. YPAS summary index: sum of vigorous, walking, moving, standing, sitting scores. BAQ-mod questionnaire score: sum of household, sports, leisure, activity scores. CAQ total activity: sum of walking, stairs, sports. 7DR total activity: weighted sum of sleep, light moderate, hard, very hard activity. Dallosso-mod total score: weighted sum of walking, standing, productive, leisure, muscle-loading activity. Enhanced LRC score: self-report of usual activity. SUA MPA: six habitual moderate activities. SUA VPA: five habitual vigorous activities. PASE total score: activity weight*frequency across work-related leisure, household activities. QAPSE mean habitual DEE: activity weight*duration as daily energy expenditure; De Abajo et al., 2001 [De Abajo, et al. [152]]: Total hr·wk^{-1}:total activity time. Activity units: kilocalorie score divided by resting metabolic rate. TEE: Total Energy Expenditure: Total Energy Expenditure in kJ/day. YPAS summary index: summed time for each activity, expressed in hours per

week for each subject. Individual indices were created by multiplying a frequency score by a duration score and multiplying again by a weighting factor; Dinger et al., 2004 [Dinger, et al. [127]]: Total PASE score – weighted and summed score of individual items using the PASE scoring algorithm; Giles et al., 2009 [Giles and Marshall [129]]: Volume T1/T2 = walking MET-min per week at first/second administration (T1/T2) of the CHAMPS. Frequency T1/T2: walking sessions per week at first/second administration (T1/T2) of the CHAMPS; Hagiwara et al., 2008 [Hagiwara, et al. [130]]: PASE score was calculated by adding the score for each component determined on the basis of the time spent on each activity or the presence or absence of activity over the past 7 days. EE: Energy Expenditure divided by bodyweight in kcal/day/wt. Walking steps: daily number of walking steps measured by the Lifecorder accelerometer; Harada et al., 2001 [Harada, et al. [131]]: MiniLogger measures activity by counting the number of mercury switch closures, resulting in a 'count' of activity, over a predetermined time interval. EE: Energy Expenditure in kcal·wk^{-1}. Total PASE score: total score computed by 1) multiplying an activity frequency value from a conversion of hours per day in six categories of activity (e.g., moderate sports) by the respective weight and summing over these activities and 2) adding a weight to this summated score for each six other household activities if the activity was reported over the past 7 days; Kolbe-Alexander et al., 2006 [Kolbe-Alexander, et al. [155]]: High counts: counts in high-intensity physical activity. Moderate min: time spent in moderate-intensity activity. Total counts: total counts for physical activity. Sitting: time spent sitting during a weekend day; Matton et al., 2007 [Matton, et al. [159]]: EE: Energy Expenditure in kcal·wk^{-1}. PAL: Physical Activity Level, calculated as total EE divided by 168 (number of hours per week) and the reported body weight. TV hr·wk^{-1}: time per week spent watching television or videos or playing computer games; this time was recalled in the FPACQ and also directly coded in the written activity log of the accelerometer reflecting the same activity domain. T-test = paired t-test to compare the magnitude of activity variables calculated from the RT3 and FPACQ (absolute validity); Tomioka et al., 2011 [Tomioka, et al. [135]]: Young old = aged 65-74 years, old old = aged 75-89 years; Washburn et al., 1999 [Washburn and Ficker [137]]: Total PASE score was computed by multiplying the amount of time spent in each activity (hours·wk^{-1}) or participation (yes/no) in an activity by the empirically derived items weights and summing over all activities. Accelerometer readings are averaged over five-minute epoch periods

Appendix 3: Validity of physical activity and sedentary behaviour questionnaires that assessed the validity of self-reported sedentary behaviour in older adults

Questionnaire	Reference (first author, year)	Criterion method	Criterion intensity threshold	Duration of validation	Validity variables tested	Validity results	
						Correlation coefficients & agreement (if given) [a]	p-value [b]
NN2	Visser, 2013 [150]	Acc (ActiGraph)	<100 CPM	8 days	Set of six sedentary behaviours (Q) – Total sedentary time (Acc)	*rho* = .46	-
CHAMPS-mod	Hekler, 2012 [156]	Acc (ActiGraph)	≤100 CPM	7 days	Total sedentary time (Q) – total sedentary time (Acc)	*rho* = .12	.001
FPACQ	Matton, 2007 [159]	Acc (RT3)	-	7 days	*Retired men*: TV ($hr \cdot wk^{-1}$) (Q) – TV ($hr \cdot wk^{-1}$) (Acc) *Retired women*: TV ($hr \cdot wk^{-1}$) (Q) – TV ($hr \cdot wk^{-1}$) (Acc)	*r* = .78 *r* = .80	.001 .001
HAP	Bastone, 2014 [157]	Acc (ActiGraph)	<100 CPM	7 days	Adjusted activity score (Q) – sedentary activity$\cdot d^{-1}$ (Acc) Maximum activity score (Q) – sedentary activity$\cdot d^{-1}$ (Acc)	*r* = -.47 *r* = -.49	.001 .001
IPAQ-E	Hurtig-Wennlof, 2010 [154]	Acc (ActiGraph)	<100 CPM	7 days	Sitting ($min \cdot d^{-1}$) (Q) – <100 CPM	*rho* = .28	.05
IPAQ-s	Kolbe-Alexander, 2006 [155]	Acc (ActiGraph)	<100 CPM	7 days	*Men*: Sitting ($MET\text{-}min \cdot wk^{-1}$) (Q) – total counts (Acc) *Women*: Sitting ($MET\text{-}min \cdot wk^{-1}$) (Q) – total counts (Acc)	*rho* = -.40 *rho* = -.35	.001 .005
IPAQ-LC	Cerin, 2012 [151]	Acc (ActiGraph)	<100 CPM	7 days	Sitting ($min \cdot d^{-1}$) (Q) – sedentary ($min \cdot d^{-1}$) (Acc)	r_p = .16	Ø
IPAQ-SC	Deng, 2008 [153]	Ped (Yamax)	*N/A*	7 days	Sitting ($MET\text{-}min \cdot wk^{-1}$) (Q) – steps$\cdot wk^{-1}$ (Ped)	*rho* = -.004	Ø
MARCA	Aguilar-Farias, 2014 [165]	Acc (*activ*PAL™)	*N/A*	7 days	Inactivity day before yesterday ($hr \cdot d^{-1}$) (Q) – total sedentary time (Acc) Inactivity yesterday ($hr \cdot d^{-1}$) (Q) – total sedentary time (Acc)	*rho* = .67 *rho* = .49	Ø Ø
SMC-PAQ	Orsini, 2008 [158]	7-d activity log	-	7 days	Leisure-time inactivity ($MET\text{-}hr \cdot d^{-1}$) (Q) – leisure-time inactivity ($MET\text{-}hr \cdot d^{-1}$) (7-day activity log)	r^c = .52 (.36, .69)	-
YPAS	De Abajo, 2001 [152]	Acc (Caltrac)	-	3 days	Sitting (Q) – activity units$\cdot d^{-1}$ (Acc)	*r* = -.06	Ø
	DiPietro, 1993 [149]	Acc (Caltrac)	-	2.5 days	Sitting ($hr \cdot d^{-1}$) (Q) – activity counts$\cdot$2.5 d^{-1}	*rho* = .13	Ø
Sedentary Q' (no name)	Gardiner, 2011 [148]	Acc (ActiGraph)	<100 CPM	4 days	Total sedentary time (Q) – total sedentary time (Acc)	*rho* = .30 (.02, .54)	.05

Notes: See Table 1 for definitions of questionnaire acronyms, and measurement timeframes used; CPM: counts per minute; d: days; hr: hours; wk: week; Ø: not statistically significant ($p > .05$); [a] *r* and *rho* are sometimes given with 95% confidence intervals (lower, upper); [b] < unless otherwise stated; [c] Deattentuated concordance; *r:* Pearson correlation coefficient; *rho:*

Spearman correlation coefficient; Acc: Accelerometry [*Note:* ActiGraph (Model 7164) is a successor of preceding accelerometer by MTI, formerly CSA]. Accelerometer names as used in the respective papers; MD: mean difference; De Abajo et al., 2001 [152]: Activity units: kilocalorie score divided by resting metabolic rate.
Kolbe-Alexander et al., 2006 [155]: High counts: counts in high-intensity physical activity. Moderate min: time spent in moderate-intensity activity. Total counts: total counts for physical activity. Sitting: time spent sitting during a weekend day; Matton et al., 2007 [159]: TV hr/week: time per week spent watching television or videos or playing computer games

Appendix 4: Full manuscript of article "Built environmental correlates of older adults' total physical activity and walking: a systematic review and meta-analysis" [101]

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REVIEW

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Built environmental correlates of older adults' total physical activity and walking: a systematic review and meta-analysis

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Abstract

Background: Identifying attributes of the built environment associated with health-enhancing levels of physical activity (PA) in older adults (≥65 years old) has the potential to inform interventions supporting healthy and active ageing. The aim of this study was to first systematically review and quantify findings on built environmental correlates of older adults' PA, and second, investigate differences by type of PA and environmental attribute measurement.

Methods: One hundred articles from peer-reviewed and grey literature examining built environmental attributes related to total PA met inclusion criteria and relevant information was extracted. Findings were meta-analysed and weighted by article quality and sample size and then stratified by PA and environmental measurement method. Associations ($p < .05$) were found in relation to 26 individual built environmental attributes across six categories (walkability, residential density/urbanisation, street connectivity, access to/availability of destinations and services, infrastructure and streetscape, and safety) and total PA and walking specifically. Reported individual- and environmental-level moderators were also examined.

Results: Positive environmental correlates of PA, ranked by strength of evidence, were: walkability ($p < .001$), safety from crime ($p < .001$), overall access to destinations and services ($p < .001$), recreational facilities ($p < .001$), parks/public open space ($p = .002$) and shops/commercial destinations ($p = .006$), greenery and aesthetically pleasing scenery ($p = .004$), walk-friendly infrastructure ($p = .009$), and access to public transport ($p = .016$). There were 26 individual differences in the number of significant associations when the type of PA and environmental measurement method was considered. No consistent moderating effects on the association between built environmental attributes and PA were found.

Conclusions: Safe, walkable, and aesthetically pleasing neighbourhoods, with access to overall and specific destinations and services positively influenced older adults' PA participation. However, when considering the environmental attributes that were sufficiently studied (i.e., in ≥5 separate findings), the strength of evidence of associations of specific categories of environment attributes with PA differed across PA and environmental measurement types. Future research should be mindful of these differences in findings and identify the underlying mechanisms. Higher quality research is also needed.

Keywords: Older adults, Built environment, Physical activity, Walking, Correlates, Systematic review, Meta-analysis

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Background

Worldwide, the proportion of older adults (65 years or older) is forecast to grow exponentially from 524 million in 2010 to approximately 1.5 billion individuals by 2050 [1]. This will pose a major economic challenge for societies globally, given the healthcare expenditure associated with individuals experiencing age-related chronic diseases [1, 2]. Evidence suggests that regular engagement in PA is particularly important for healthy ageing. For example, it reduces the risk of coronary heart disease, some cancers, type 2 diabetes, depression, cognitive impairment and social isolation [3, 4]. Older adults worldwide, however, are often inactive [4–7]. Thus, it is important to identify modifiable factors with a high level of reach that may help increase total PA in this age group. As it is ultimately the overall dose of PA that confers benefit/detriment upon health [8], irrespective of the domain/s in which it was accrued, it is important to focus on factors contributing to total PA. Furthermore, walking is the most prevalent and preferred form of PA in older adults [9], low-risk and beneficial to health and can contribute substantially to daily energy expenditure [10]. Hence, this review will focus on total PA and total walking.

Socio-ecological models posit that PA behaviour is shaped by complex and dynamic interrelations between individual, social, and environmental factors [11, 12]. The built environment offers substantial public health potential, due to people being regularly exposed to it across their life span. Understanding the impact of built environmental attributes on older adults' PA is particularly pertinent as their diminished physical capacity makes them more vulnerable to the detrimental effects of physically challenging environments (e.g., inclines, uneven surfaces, absence of walk-friendly infrastructure) on PA [13]. In turn, this may lead to less venturing outside of the home due to fear of falls [14]. However, a previous review of the built environment and older adults' PA identified no consistent correlates [15].

One postulated reason for the lack of consistent significant associations between environmental correlates and PA was the relative 'western' bias of the reviewed research – 68% of the 31 articles reviewed by Van Cauwenberg and colleagues were from North America alone [15]. This is an important limitation since homogenously low-density western cities lack environmental variability potentially resulting in the underestimation of the strength of associations between the built environment and PA. Also, western cities differ from the built environments of Africa, Asia, and South America, limiting the generalizability of findings [16–18]. In consideration of the recent growing evidence from non-western countries (e.g., [19–25]), an update of the literature was necessary.

Further reasons for inconsistent findings on the associations between the built environment and PA may relate to the methodologies of the systematic reviews and/or the studies being reviewed. For example, Gebel and colleagues [26] recommended that systematic reviews should: a) consider article/study quality in the synthesis of findings; and b) include relevant data from grey literature. Also, small sample sizes, a large variety of built environmental exposures and PA outcomes [27, 28], and the inappropriate categorisation of continuous variables [29] in examined studies may have contributed to inconsistent findings. To date, no systematic review on the built environment and total PA has considered these issues.

A synthesis of evidence would also need to distinguish between findings based on objective- and self-report measures of exposures (environmental attributes) and outcomes (PA). Self-report measures are more likely to be influenced by culture [30, 31] and, thus, yield different findings across geographical locations due to measurement rather than substantive reasons. Also, perceptions of the local environment may not accurately represent the 'real' environment [32, 33]. Indeed, associations of PA with objective and perceived measures of the built environment tend to differ [34, 35]. This does not necessarily mean that one type of measurement is better than the other, however, as perceived environmental measures may be more closely associated with PA than objective alternatives [27], a consideration of these differences would help better inform policies and interventions.

With regard to measurement of total PA, objective PA measures are considered to provide more valid assessments of intensity, duration, and frequency of PA than subjective alternatives [36]. They are also less likely to be influenced by cultural biases [30]. Additionally, differences in environment-PA associations between self-reported and objectively-measured PA have previously been reported in adults [37]. This indicates that there is a need for a synthesis of findings on built environment correlates of total PA by type of PA assessment (objective and self-reported).

Therefore, this systematic review aimed to provide a timely, robust overview of studies that investigated associations of built environmental attributes and estimates of total PA, including total walking. This included addressing some key methodological limitations of previous reviews by stratifying findings by measurement methods (objective and self-reported) and applying a meta-analytic procedure. The latter incorporated study quality data to more robustly quantify the direction of associations between the built environment and older adults' PA [27] and assisted the formulation of objective conclusions based on statistical theory rather than on subjective criteria (e.g., defining >50% of significant positive associations as convincing evidence of a positive association between a specific environment characteristic and PA).

Methods

This systematic review and meta-analysis was registered in PROSPERO (Registration no. CRD42016051227 [38]) in November 2016.

Literature search strategy

Our systematic literature search followed Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [39] and was an extended update of Van Cauwenberg et al.'s 2011 review [15] including additional electronic databases and search terms to account for grey literature, experimental research, a greater variety of built environmental attributes and older adults' PA. Systematic searches were performed in the following electronic databases (September – November 2016): Cinahl, PubMed, Scopus, SPORTDiscus, TRIS, and Web of Science. An example of the complete search terms syntax (used in PubMed) is presented in the resulting PRISMA flowchart (Fig. 1). All electronic database searches used the same search terms and syntax. However, filters varied depending on available options in each database. Manual searches were then undertaken of previously published systematic reviews, meta-analyses and authors' personal archives. The websites of Active Living Research, SUSTRANS, the National Institute for Health and Clinical Excellence, Heart Foundation, and Open Grey were also searched for grey literature (e.g., unpublished studies, theses and reports).

Selection criteria

Article eligibility for inclusion was based on the following criteria: (1) published in English between 1st January 2000 and 3rd September 2016; (2) quantitative study; (3) study with a cross-sectional, longitudinal or quasi-experimental design; (4) a sample with a mean age ≥ 65 years; (5) investigated the association between any objective or perceived attribute of the built environment and objectively measured or self-reported PA and/or walking that was not specific to a single PA domain only; (6) did not exclusively focus on clinical populations (e.g., overweight, disabled or institutionalised participants); and (7) did not investigate associations between PA and the built environment with an ill-defined aggregated environmental measure that, for example, combined two weakly correlated attributes such as access to/availability of recreational facilities and traffic/pedestrian safety.

Three reviewers independently screened articles for eligibility criteria by title and then by abstract. If abstracts met the inclusion criteria, the article text was independently read by two reviewers, and a decision for inclusion made accordingly. The reviewers discussed and resolved any disputed inclusions. Post article inclusion, first authors' publication histories and eligible articles' reference lists were screened for additional eligible articles. One hundred articles were eligible for inclusion in this review (Fig. 1).

Data extraction

Two reviewers independently extracted all relevant information from eligible papers and cross-checked each other's work upon completion. Any disputes were resolved in consultation with a third member of the team. A table (Additional file 1) was then constructed containing the following data: study name (if any), first author and publication year; participant information – sample size, study setting (e.g., urban or rural), mean age, percentage of females, study response rate, community dwellers or not, geographical location; study design –

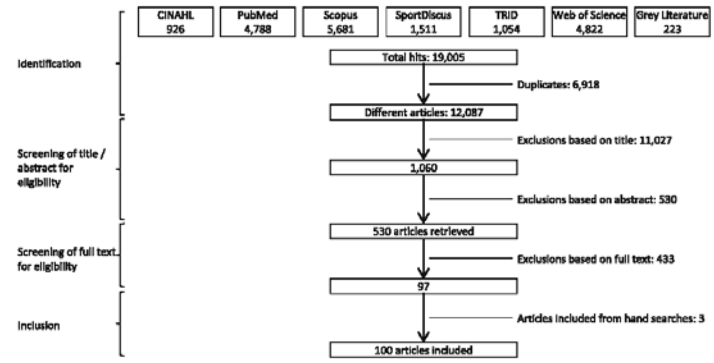

Fig. 1 PRISMA flowchart

sampling method for clusters (areas or neighbourhoods) and individuals, stratification of recruitment site by environmental attribute/s (if any), neighbourhood definition (if any); list of covariates; PA outcome information – type of measurement (objective or self-reported), instrument or device used and whether or not it was validated, how outcome measures were operationalised (e.g., continuously or categorically); environmental exposure information – type of measurement (objective or perceived), name of measure, environmental attributes as named in study and category of environmental attribute according to the classification used in this review (see below); moderator information (if any); analytical approach information; findings; and additional comments important for the assessment or interpretation of the study (if any).

In this review, the variable "Total PA" represents all (combined) PA outcomes relevant to this review and extracted from the selected articles. These include the PA outcomes reported in the selected articles as "Total PA", "Total MVPA" and "Total walking". "Total PA" was then stratified into objective and self-report PA, congruent with study aims. Total walking was also considered separately for reasons aforementioned. Built environmental attributes were categorised according to an expanded list of factors included in the Neighbourhood Environment Walkability Scale (NEWS), which is the most frequently used neighbourhood environment questionnaire internationally [40, 41] (Table 1). The detailed list of measures included under each category of environmental attributes can be found in Supplementary Table S1 (Additional file 1).

Coding and quantification of associations

Following the protocol used by Van Cauwenberg and colleagues in their earlier systematic review [15], associations between built environmental attributes and PA outcomes were categorised as statistically significantly positive (P), significantly negative (N), or not statistically significant (Ø). When available, preference was given to findings within articles that adjusted for socio-demographic covariates and self-selection (i.e., factors that may affect neighbourhood choice and subsequent PA level, for example, preference for PA resources [42]). Often, one article reported multiple environmental attributes that were coded under the same environmental category (e.g., 'absence of litter' and 'presence of trees' would both fall under the common category of 'greenery and aesthetically pleasing scenery'). Similarly, one article may have reported multiple PA outcomes related to the same environmental attribute (e.g., 'total walking' and 'total PA' with 'crime/personal safety'). Four distinct findings would be extracted from these two examples. We then cross-examined other articles from the same dataset (e.g., Senior Neighborhood Quality of Life Study (SNQLS) [43–48]) to avoid duplication of extracted data.

Quantification of buffer effects and/or moderators

Findings from studies reporting associations for a given combination of environmental attribute and PA outcome for multiple environmental buffer sizes or values of a moderator were assigned fractional weights totalling 1.0 (per study). Associations from studies reporting on multiple buffer sizes were each assigned a fractional weight equal to 1 divided by the number of buffer sizes. For example, Nathan and colleagues examined associations for two buffer sizes (400 m and 800 m). They found a nil association for 400 m buffers around the home between access to social infrastructure and total walking and a positive one for 800 m buffers [49]. In this case, a resulting score of 0.5 nil (400 m buffer) and 0.5 positive associations (800 m buffer) was recorded. For studies that examined moderator effects, associations were reported as main effects only if the findings across all examined values of the moderator were consistent in direction and statistical significance. When this did not occur, weights were assigned for each examined value of the moderator dependent upon the (approximate) proportion of the total sample represented by the subgroup of participants. For example, Jefferis and colleagues found a positive association between access to social and leisure activities for males and a nil association for females [50]. Since males represented 65% of the total sample, a fractional weight of 0.65 was assigned to the positive association and a 0.35 weight for the nil association (females). For studies that used a continuous measure of moderators, associations recorded at the average value of the moderator were assigned a weight of 0.60, while those above and below the mean were each assigned a weight of 0.20 (i.e., ±1 standard deviation (SD)). This follows the logic that, if data are normally distributed, ≈20% of values would fall below and 20% above 1SD (accounting for some uncertainty around the value of the moderator at ±1 SD). When an association was moderated by numerous factors, weights were assigned according to the aforementioned procedure and, again, with all fractional weights totalling 1.0.

Article quality and sample size assessment

A checklist for article quality assessment was developed based on ten set criteria [with a maximum total quality score of 9] (Additional file 2): (1) study design [score: cross-sectional = 0, longitudinal = 1, quasi-experimental = 2]; (2) study areas or participant recruitment stratified by key environmental attributes [yes = 1, no = 0]; (3) adequate participant response rate (≥60%) [51] or evidence of a representative sample [yes = 1, no = 0]; (4) outcome measures valid and reliable based on published metric properties of

Table 1 Characteristics of selected articles (*N* = 100)

Characteristic	Number of articles	%	Article reference
Study design[a]			
Cross-sectional	95	94	[19–25, 32, 43–50, 53, 54, 59, 60, 65, 67–80, 87, 92, 93, 100, 118–173]
Longitudinal	5	5	[61–65]
Quasi-experimental	1	1	[66]
Geographical area: continent			
Africa	1	1	[25]
Asia	16	16	[19–22, 60, 73, 75, 80, 124, 139, 142, 146, 160, 164, 169, 173]
Europe	22	22	[50, 66, 74, 79, 87, 119, 120, 123, 129, 136, 137, 147, 148, 152, 154, 156, 157, 162, 163, 165, 166, 170]
North America	46	46	[32, 43–48, 53, 54, 61–65, 67–70, 76, 78, 92, 93, 125–127, 130–135, 138, 140, 141, 143, 144, 149–151, 155, 158, 159, 161, 167, 168, 172]
Oceania	13	13	[49, 59, 71, 72, 77, 100, 118, 121, 122, 128, 145, 153, 171]
South America	2	2	[23, 24]
Geographical area: country			
Australia	13	13	[49, 59, 71, 72, 77, 100, 118, 121, 122, 128, 145, 153, 171]
Belgium	2	2	[74, 170]
Brazil	1	1	[23]
Canada	10	10	[54, 61, 62, 78, 125–127, 135, 138, 172]
China	1	1	[80]
Colombia	1	1	[24]
Czech Republic, Poland, & Slovakia (pooled analysis)	1	1	[154]
Hong Kong, China	2	2	[73, 124]
Iceland	1	1	[119]
Iran	1	1	[146]
Ireland	2	2	[147, 152]
Japan	7	7	[19–22, 160, 164, 169]
Lithuania	1	1	[120]
Malaysia	1	1	[139]
Netherlands	4	4	[123, 136, 137, 166]
Norway	1	1	[157]
Singapore	1	1	[142]
South Africa	1	1	[25]
South Korea	2	2	[75, 173]
Thailand	1	1	[60]
United Kingdom	10	10	[50, 66, 79, 87, 129, 148, 156, 162, 163, 165]
United States of America	36	36	[32, 43–48, 53, 63–65, 67–70, 76, 92, 93, 130–134, 140, 141, 143, 144, 149–151, 155, 158, 159, 161, 167, 168]
Geographical setting			
Urban	56	56	[23–25, 32, 43–48, 50, 53, 59, 61–64, 66, 71, 72, 74, 80, 87, 92, 93, 100, 120–122, 124–127, 129–131, 133, 135–138, 142, 144, 146, 149, 153, 156–158, 161, 164, 165, 167, 170, 172]
Rural	3	3	[67–69]
Mixed	32	32	[19, 21, 22, 49, 54, 60, 75, 76, 79, 118–120, 123, 128, 132, 134, 139, 143, 145, 147, 148, 150, 152, 155, 159, 160, 162, 163, 166, 169, 171, 173]
Not reported	9	9	[65, 70, 77, 78, 140, 141, 151, 154, 168]

Table 1 Characteristics of selected articles (*N* = 100) *(Continued)*

Sample size[b]			
≤ 100	9	9	[19, 25, 53, 61, 66, 118, 127, 135, 161]
101–300	27	27	[32, 43, 53, 59, 60, 67, 69, 76, 87, 119, 120, 122, 123, 129, 132, 133, 140–142, 146, 150, 156, 162–166]
301–500	23	23	[23, 47, 63, 64, 68, 71–75, 93, 100, 121, 124, 126, 131, 134, 153, 154, 160, 167, 169, 170]
501–1000	16	16	[44–46, 48, 62, 78, 79, 92, 125, 128, 138, 144, 147, 148, 158, 159]
1001–2500	11	11	[20, 22, 24, 50, 54, 77, 130, 151, 155, 172, 173]
> 2500	16	16	[21, 49, 54, 65, 70, 80, 136, 137, 139, 143, 145, 149, 152, 157, 168, 171]
Study with multiple articles			
Active Living Study	3	3	[71, 72, 153]
BEPAS Seniors	2	2	[74, 170]
Great Britain older adults 1	2	2	[162, 163]
Health and Wellbeing Surveillance System	2	2	[49, 171]
LL-FDI study (Late-Life Function and Disability Instrument)	2	2	[132, 150]
Melbourne older adults study 1	2	2	[121, 122]
Netherlands Housing Survey (WoON)	2	2	[136, 137]
Nurses' Health Study	2	2	[70, 168]
PACS (Physical Activity Cohort Scotland)	2	2	[79, 148]
Project OPAL (Older People Active Living)	3	3	[87, 129, 165]
SHAPE (Senior Health and Physical Exercise)	4	4	[32, 63, 92, 93]
SNQLS (Senior Neighborhood Quality of Life Study)	6	6	[43–48]
TILDA (The Irish Longitudinal Study on Ageing)	2	2	[147, 152]
VoisiNuAge	2	2	[62, 138]
Single publication (named study)	33	33	[21, 50, 54, 59, 61, 64–66, 73, 77, 78, 80, 100, 124, 128, 130, 133–135, 139, 140, 143–145, 149, 155, 157–159, 166, 169, 172, 173]
Single publication (unnamed study)	31	31	[19, 20, 22–25, 53, 60, 67–69, 75, 76, 118–120, 123, 125–127, 131, 141, 142, 146, 151, 154, 156, 160, 161, 164, 167]
Neighbourhood recruitment stratification[a]			
Environmental attributes	57	57	[19, 21–25, 32, 44–50, 54, 60, 63, 66, 68, 71–76, 78–80, 87, 92, 118, 119, 123, 124, 126, 129, 130, 134, 135, 139, 146–148, 151, 153, 155, 159, 160, 162–166, 168, 170–172]
Urbanisation	22	22	[19, 21, 22, 49, 54, 60, 68, 75, 78, 80, 118, 119, 123, 134, 139, 155, 159, 160, 166, 168, 171, 172]
Area-level socio-economic status	6	6	[23, 25, 87, 129, 151, 165]
Area-level socio-economic status & walkability	12	12	[44–48, 73, 74, 124, 126, 135, 146, 170]
Area-level socio-economic status & urbanisation	10	10	[50, 63, 76, 79, 92, 130, 147, 148, 162, 163]
Walkability	4	4	[32, 71, 72, 153]
Streetscape	2	2	[66, 164]
Demographics	31	31	[20–22, 50, 62, 64, 69, 70, 79, 119, 121, 122, 132–134, 136–138, 141–144, 148, 150, 151, 155, 156, 161–163, 173]
None	21	21	[43, 53, 59, 61, 65, 67, 77, 93, 100, 120, 125, 128, 131, 140, 145, 149, 154, 157, 158, 167, 169]
Neighbourhood definition[a]			
Objective			
Administrative/census area/postal code	25	25	[19, 54, 65, 68, 70, 74, 80, 118, 134, 136–139, 142, 145, 146, 148, 149, 157, 158, 160, 166, 170, 172, 173]

Table 1 Characteristics of selected articles (N = 100) *(Continued)*

Buffer (crow-fly or road-network)			
≤ 250 m	3	3	[21, 64, 171]
300 m	1	1	[123]
400–500 m	16	16	[21, 24, 44, 46–49, 59, 64, 72, 73, 93, 135, 153, 159, 171]
800–1000 m	15	15	[21, 49, 59, 63, 64, 73, 92, 93, 130, 132, 135, 155, 161, 168, 171]
> 1000 m	3	3	[161, 168, 171]
Variable/not fixed	4	4	[32, 135, 151, 164]
Retirement village	3	3	[43, 72, 153]
Unknown (not reported)	3	3	[53, 62, 128]
Perceived			
10–20 min walk from home	24	24	[20, 22, 23, 44–46, 48, 60, 71, 72, 75, 79, 100, 121, 122, 124, 126, 131, 132, 141, 143, 150, 159, 169]
Other participant delineation	22	22	[24, 25, 32, 50, 61, 62, 67, 69, 76, 78, 87, 120, 125, 129, 133, 140, 147, 151, 152, 154, 165, 167]
Retirement village	2	2	[71, 153]
Unknown (not reported)	6	6	[63, 77, 92, 134, 144, 156]
Physical activity outcome by type of measurement and its operationalisation[a]			
Total PA (all PA outcomes from all articles)			
Continuous outcome	59	55.1	[19, 21, 43–48, 54, 59, 60, 62, 63, 65–67, 69, 71, 73, 74, 79, 80, 87, 92, 93, 118, 119, 121, 123–125, 127, 129, 131, 132, 134–138, 140–144, 147–151, 155, 160, 161, 164–166, 170, 173]
Categorical outcome	48	44.9	[20, 22–25, 32, 49, 50, 53, 54, 61, 64, 65, 68, 70, 72, 75–78, 80, 93, 100, 120, 122, 124, 126, 128, 130, 133, 135, 139, 144, 146, 152–154, 156–159, 162, 163, 167–169, 171, 172]
Objective PA	28	27.2	
Continuous outcome	23		[19, 43–48, 59, 73, 74, 79, 118, 127, 129, 132, 135, 141, 148, 150, 164–166, 170]
Categorical outcome	5		[25, 50, 61, 72, 135, 153]
Self-reported PA	75	73.8	
Continuous outcome	37		[19, 21, 54, 60, 62, 63, 65–67, 69, 71, 73, 80, 87, 92, 93, 119, 121, 123–125, 131, 134, 136–138, 140–144, 147, 149, 151, 155, 160, 161, 173]
Categorical outcome	45		[20, 22–25, 32, 49, 53, 54, 64, 65, 68, 70, 72, 75–78, 80, 93, 100, 120, 122, 124, 126, 128, 130, 133, 139, 144, 146, 152–154, 156–159, 162, 163, 167–169, 171, 172]
Total PA (as detailed in article)	31	27.2	
Objective PA	8	8	
Continuous outcome	8	8	[48, 79, 129, 135, 148, 150, 164, 166]
Categorical outcome	0	0	
Self-reported PA	23	23	
Continuous outcome	19	19	[19, 60, 65–67, 69, 73, 87, 119, 121, 125, 136, 137, 141, 143, 147, 151, 160, 161]
Categorical outcome	4	4	[65, 70, 126, 157]
Total walking (as detailed in article)	55	48.2	
Objective PA	9	9	
Continuous outcome	8	8	[19, 118, 127, 129, 132, 135, 141, 165]
Categorical outcome	2	2	[61, 135]
Self-reported PA	47	47	
Continuous outcome	19	19	[21, 62, 63, 65, 67, 71, 80, 92, 93, 123, 124, 131, 134, 138, 142, 144, 149, 155, 173]
Categorical outcome	32	32	[20, 22–24, 32, 49, 53, 64, 65, 70, 72, 75, 76, 80, 93, 100, 122, 124, 130, 144, 146, 153, 154, 158, 159, 162, 163, 167–169, 171, 172]

Table 1 Characteristics of selected articles (*N* = 100) *(Continued)*

Total MVPA[c] (as detailed in article)	28	24.6	
Objective PA	15	15	
Continuous outcome	11	11	[43–48, 73, 74, 129, 166, 170]
Categorical outcome	4	4	[25, 50, 72, 153]
Self-reported PA	14	14	
Continuous outcome	3	3	[54, 140, 173]
Categorical outcome	12	12	[25, 54, 68, 77, 78, 120, 128, 130, 133, 139, 152, 156]
Environmental attribute by type of measurement[a]			
Objective environment	49	48	
Perceived environment	53	52	
Walkability	13	13	
Objective	11	11	[46, 48, 72–74, 146, 153, 155, 167, 171, 172]
Perceived	2	2	[126, 141]
Residential density/urbanisation[d]	35	35	
Objective	21	21	[19, 21, 47, 54, 65, 70, 73, 80, 92, 118, 119, 123, 128, 134, 139, 148, 158–160, 168, 173]
Perceived	15	15	[20, 22, 25, 48, 76, 132, 140, 145, 147, 150, 152, 154, 159, 162, 169]
Street connectivity[d]	24	24	
Objective	10	10	[21, 24, 43, 53, 73, 93, 159, 161, 166, 168]
Perceived	16	16	[20, 23, 25, 48, 53, 71, 76, 79, 127, 132, 140, 142, 150, 154, 159, 170]
Access to/availability of destinations & services[a]	65	65	
Objective	29	29	
Perceived	45	45	
Overall access to destinations & services[d]	24	24	
Objective	6	6	[21, 53, 62, 93, 135, 168]
Perceived	21	21	[20, 23, 25, 48, 50, 53, 62, 67, 71, 76, 87, 100, 126, 127, 131, 132, 140, 141, 150, 154, 159]
Land-use mix—destination diversity[d]	16	16	
Objective	8	8	[49, 72, 80, 123, 135, 153, 159, 161]
Perceived	9	9	[25, 48, 67, 76, 125, 132, 150, 159, 170]
Shops/commercial destinations[d]	26	26	
Objective	17	17	[32, 43, 47, 49, 53, 72, 73, 80, 93, 135, 148, 158, 159, 161, 166, 168]
Perceived	10	10	[22, 23, 32, 75, 129, 141, 142, 156, 165, 169]
Food outlets	11	11	
Objective	8	8	[43, 47, 49, 53, 73, 135, 166, 168]
Perceived	3	3	[23, 141, 142]
Government/finance services	8	8	
Objective	7	7	[43, 47, 49, 53, 73, 135, 158]
Perceived	1	1	[23]
Education	7	7	
Objective	6	6	[21, 132, 135, 158, 161, 168]
Perceived	1	1	[141]
Health & aged care	10	10	
Objective	8	8	[43, 49, 53, 72, 135, 153, 158, 166]
Perceived	2	2	[23, 156]

Table 1 Characteristics of selected articles (*N* = 100) *(Continued)*

Religious	5	5	
Objective	3	3	[43, 135, 161]
Perceived	2	2	[23, 141]
Public transport	18	18	
Objective	8	8	[24, 47, 72, 73, 80, 93, 158, 166]
Perceived	10	10	[22, 23, 48, 50, 62, 68, 100, 141, 156, 169]
Parks/public open space[d]	30	30	
Objective	17	17	[21, 24, 32, 43, 44, 48, 53, 64, 73, 92, 93, 124, 132, 135, 151, 158, 161]
Perceived	15	15	[23, 32, 46, 66, 68, 69, 75, 100, 125, 141, 142, 144, 151, 156, 163]
Recreational facilities	25	25	
Objective	10	10	[43, 47, 64, 72, 73, 124, 132, 135, 153, 168]
Perceived	15	15	[22, 23, 46, 60, 63, 68, 77, 78, 92, 120, 125, 142, 156, 169, 170]
Social recreational facilities	13	13	
Objective	6	6	[43, 49, 73, 135, 138, 166]
Perceived	7	7	[23, 50, 71, 141, 142, 153, 156]
Other destinations	1	1	
Objective	1	1	[43]
Perceived	0	0	
Infrastructure & streetscape[a]	43	43	
Objective	12	12	
Perceived	34	34	
Overall cycle/walk-friendly infrastructure	8	8	
Objective	0	0	
Perceived	9	9	[25, 48, 66, 76, 127, 132, 150, 154, 159]
Walk-friendly infrastructure	21	21	
Objective	7	7	[43, 47, 80, 93, 124, 132, 161]
Perceived	14	14	[22, 44, 53, 61, 62, 68, 69, 71, 100, 121, 125, 142, 169, 170]
Cycle-friendly infrastructure	4	4	
Objective	1	1	[47]
Perceived	3	3	[22, 125, 169]
No physical environmental barriers (e.g., hills)	16	16	
Objective	8	8	[21, 24, 32, 43, 47, 72, 124, 164]
Perceived	9	9	[23, 32, 66, 71, 100, 125, 142, 169, 170]
Pavement/footpath quality	8	8	
Objective	2	2	[47, 124]
Perceived	6	6	[23, 24, 66, 121, 142, 163]
Street lighting	6	6	
Objective	1	1	[124]
Perceived	5	5	[23, 53, 69, 75, 122]
Greenery & aesthetically pleasing scenery[d]	33	33	
Objective	6	6	[32, 43, 47, 80, 124, 161]
Perceived	28	28	[20, 22, 23, 25, 32, 44, 48, 53, 61, 71, 75, 76, 79, 100, 122, 125, 127, 132, 137, 142, 147, 150, 154, 156, 159, 163, 169, 170]

Table 1 Characteristics of selected articles (*N* = 100) *(Continued)*

Pollution (air)	3	3	
Objective	1	1	[124]
Perceived	2	2	[23, 156]
Safety	46	46	
Objective	7	7	
Perceived	40	40	
Traffic/pedestrian safety	28	28	
Objective	4	4	[47, 72, 93, 124]
Perceived	24	24	[22–25, 45, 48, 53, 61, 69, 71, 75, 76, 79, 92, 100, 125, 132, 136, 142, 150, 156, 159, 169, 170]
Crime/personal safety[d]	41	41	
Objective	5	5	[43, 93, 124, 149, 157]
Perceived	37	37	[22, 23, 25, 45, 48, 50, 53, 61, 63, 66, 68, 69, 71, 75, 76, 79, 100, 121, 122, 125, 132–134, 137, 140, 142–145, 150, 156, 157, 159, 163, 167, 169, 170]
Moderator of environmental attribute-PA association[a]	39	39	
Individual factors	24	24	[20–23, 44, 45, 48–50, 59, 69, 70, 73, 77, 79, 100, 122, 125, 131, 144, 152, 155, 157, 159]
Socio-demographics	16	16	[20–23, 45, 49, 50, 69, 70, 73, 122, 125, 144, 152, 155, 157]
Health status/functionality	7	7	[59, 73, 77, 100, 131, 155, 159]
Psychosocial factors	3	3	[44, 79, 100]
Driving status/car ownership	2	2	[48, 73]
Duration of residency	1	1	[21]
Environmental factors	18	18	[19, 21, 25, 45, 46, 64, 66, 74–76, 92, 100, 141, 146, 155, 160, 162, 168]
Socioeconomic status/area-level income	5	5	[25, 45, 64, 74, 146]
Residential density/urbanisation	6	6	[19, 75, 76, 160, 162, 168]
Infrastructure and streetscape aspects (e.g., walkability)	3	3	[46, 92, 100]
Intervention	2	2	[66, 100]
Geographical scale (e.g., 400 m buffer)	6	6	[21, 64, 73, 93, 135, 161]
Tested, but unknown	1	1	[24]
None	61	61	[32, 43, 47, 53, 54, 60–63, 65, 67, 68, 71, 72, 78, 80, 87, 93, 118–124, 126–130, 132–143, 145, 147–151, 153, 154, 156, 158, 163–167, 169–173]

Notes:
[a]Multiple options allowed in single articles
[b]Two articles had instances where environmental attributes were associated with different sample sizes ([53, 54]). Hence, the total number of articles added up separately is 2 units more than the total number of articles. Notably, this was adjusted for in our analysis
[c]One article ([25]) had both objective and self-reported physical activity measures. Hence, the total number of articles is 1 unit smaller than the sum of the articles in these cases
[d]Multiple articles had both objective and perceived environmental measures. Hence, the total number of articles is 1, 2, or 3 unit/s smaller than the sum of the articles in these cases

the instrument used [52], or outcome measures well-established in the field [yes = 1, no = 0]; (5) adjustment for key socio-demographic covariates (at least age, sex, and education considered) [yes = 1, no = 0]; (6) adjustment for self-selection [yes = 1, no = 0]; (7) appropriate analytical approach – adjustment for clustering (if needed) [yes = 1/3, no = 0]; (8) appropriate analytical approach – accounting for distributional assumptions [yes = 1/3, no = 0]; (9) appropriate analytical approach – analyses conducted and presented correctly [yes = 1/3, no = 0]; and (10) did not inappropriately categorise continuous environmental exposures [yes = 1, no = 0]. Higher scores reflect higher quality: 0–3.5 (low quality), 3.6–5.9 (moderate quality), and ≥6 (high quality). Apart from providing descriptive information on article quality, these scores were also used as weights in the meta-analyses described below so that higher quality articles had a greater contribution to the synthesis of findings.

To account for sample size in the meta-analyses, the following weights were assigned to findings: 0.25 (≤100 participants), 0.50 (101–300 participants), 1.00 (301–500 participants), 1.25 (501–1000 participants), 1.50 (1001–2500 participants), and 1.75 (>2500 participants). In two instances, different sample weights were applied to findings derived from the same study because of differences in sample size between objectively assessed and perceived environmental exposures [53] and between data collection periods [54]. A thorough rationale for these weights can be found elsewhere [27].

Data synthesis

Each separate positive, negative, and nil association between a built environmental attribute and PA outcome (either total PA, total MVPA, or total walking) was tallied [27] and, where appropriate, multiplied by a buffer-size or moderator-related fractional weight (see section above on 'Quantification of buffer effects and/or moderators'). All of these findings were then included into a "Total PA" outcome, which was then stratified by PA measurement type (objective or self-report). "Total walking" was considered separately and was based on findings from self-report walking only, as the majority of associations between built environmental attributes and objectively assessed walking was insufficiently examined (i.e., <5 findings) (Additional file 3). The findings related to both "Total PA" and "Total walking" were then stratified by environmental measurement type (objective or perceived).

Due to the large range of different environmental and PA measures reported in the selected articles, it was not possible to conduct a 'traditional' meta-analysis involving the estimation of pooled effect sizes and their 95% confidence intervals. Hence, to quantitatively synthesise the findings, a meta-analytic approach was applied to define conservative estimates of p-values for each examined combination of environmental attribute and PA outcome [27]. These p-values represented the probability of observing a certain distribution of findings (e.g., 4 positive, 2 nil, and 0 negative associations) under a null hypothesis of no association. These computations were undertaken accounting for: (1) sample size and quality scores of included articles (see previous section); (2) sample size score only; (3) article quality score only; and (4) neither – with 2–4 providing a sensitivity analysis on how each of these influenced meta-analytical findings. Associations of specific built environmental attributes with PA outcomes were examined by type of PA and environmental measurement (objective and perceived) only when ≥3 articles provided data on each type of measure, consistent with recommendations for meta-analyses from Cochrane's database of systematic reviews [55]. Environment-PA outcome associations totalling <5 separate findings were deemed as insufficiently studied to reach a robust conclusion [56].

To perform the meta-analyses, we first assigned a z-value to each separate built environmental attribute and PA finding, specifically: 1.96 for a positive; −1.96 for a negative; and 0 for a nil finding [27]. We then calculated a summary two-tailed p-value using Rosenthal's approach [57], reporting a summary weighted z-value and its associated two-tailed probability value as detailed in Cerin et al.'s recent systematic review and meta-analysis of built environmental correlates of active transport [27]. For the sensitivity analysis aforementioned, we also calculated non-weighted z values and their associated two-tailed p-values. All computations were performed in a Microsoft Excel spreadsheet using algorithms developed by the authors. P-values were interpreted as follows: .05 to .01 – evidence of an association; <.01 – strong evidence of an association; and <.001 – very strong evidence of an association [58].

All examined moderators of environment-PA associations were counted and summarised by the category of moderator tested. This included multiple factor (i.e., higher-order) moderating effects, tested formally (e.g., [59]) or not (e.g., [20]). Reporting higher-order moderating effects by moderator category resulted in findings being counted multiple times, i.e., once for each moderator category. For example, Chen and colleagues reported sex by employment status interactions, so the findings were reported twice, once under sex and once under employment status as moderators [20]. For this reason, the total number of moderating effects reported in this review is greater than the number of moderating effects reported in the articles.

Results

Of 19,005 potential articles, we fully read 530 and included 100 in our analysis – two of which were PhD theses [60, 61] (Fig. 1). From the 100 articles, 1553 individual associations were extracted.

Characteristics of included articles

Details of article characteristics can be found in Table 1. Cross-sectional studies accounted for 94% of articles, with five papers reporting longitudinal [61–65] and one quasi-experimental [66] findings. Almost half of all studies (46%) were based in North America, followed by Europe (22%), Asia (16%), Oceania (13%), two studies from South America [23, 24], and one pilot study from South Africa [25]. Regarding countries, the USA (36%), Australia (13%), the UK (10%), and Canada (10%) conducted the most research. Only 3% of articles specifically studied rural participants [67–69], about half researched those from urban settings (56%), and 32% from a mixture of both.

Sample sizes ranged from 44 [25] to 69,253 [70], with over a third of samples (36%) regarded as small (i.e., ≤300 participants). Recruitment of neighbourhoods was stratified by key built environmental attributes in 57% of articles; urbanisation being the most prevalent (22%), followed by area-level socio-economic status (SES) and walkability combined (12%), and area-level SES and urbanisation combined (10%). Neighbourhoods were most frequently defined objectively by administrative and census areas. When buffers were applied to define neighbourhoods, a 400-500 m radius was the most frequently used buffer size. A 10–20 min' walk from home was the most commonly reported perceived neighbourhood definition.

Overall, 66% of articles used a validated or established PA measure. Almost three quarters of articles reported findings based on older adults' self-reported PA (74%). The most commonly reported PA outcome was total walking (55%). Approximately 55% of PA outcomes were operationalised as continuous measures (e.g., minutes/day) and 56% of self-report PA outcomes were measures of total walking. The most commonly reported objective PA outcome was total MVPA (47% of objective PA articles).

Overall, the most researched attributes were crime-related personal safety (41%), residential density/urbanisation (35%), greenery and aesthetically pleasing scenery (33%), access to/availability of parks/public open space (30%), pedestrian-related traffic safety (28%), and access to/availability of shops/commercial destinations (26%). Similarly, the most investigated perceived attributes were crime-related personal safety (38%), greenery and aesthetically pleasing scenery (28%), pedestrian-related traffic safety (25%), access to/availability of parks/public open space and recreational facilities (both 15%). The most commonly evaluated objectively assessed environmental attributes were urbanisation/residential density (21%), and access to/availability of shops/commercial destinations and of parks/public open space (17% each).

Thirty-nine percent of articles investigated moderating effects on associations between built environmental attributes and total PA. At the individual level, socio-demographics were the most frequently examined moderator, and at the environmental level, residential density/urbanisation was the most frequently reported moderator. (Note: Full details of article characteristics can be found in Additional file 1).

Article quality

Only 9% of articles were deemed of high quality, 55% of moderate quality, and the remaining 36% of low quality. Key socio-demographic covariates (i.e., at least age, sex, and education) were adjusted for in 66% of articles; much fewer analyses adjusted for self-selection (12%) (Table 2) [62, 69, 71–80]. Approximately three quarters of the included articles conducted appropriate analyses (76%). (Note: Full details of article quality can be found in Additional file 3).

Built environmental correlates of older adults' PA

Total PA

There was very strong evidence that neighbourhood walkability ($p < .001$), overall access to destinations and services ($p < .001$) and recreational facilities ($p < .001$), and crime-related personal safety ($p < .001$) were positively associated with older adults' total PA (Table 3).

Table 2 Summary of article quality assessment ($N = 100$)

Quality-assessment item [score]	%
1. Study design [cross-sectional: 0; longitudinal: 1; quasi-experimental: 2]	
cross-sectional	94
longitudinal	5
quasi-experimental	1
2. Study areas or participant recruitment stratified by key environmental attributes [1]	56
3. Response rate ≥ 60% or sample representative of the population [1]	32
4. Physical activity measures (outcomes) valid, or well-established in the field [1]	66
5. Analyses adjusted for key socio-demographic covariates (at least age, sex, and education considered) [1]	66
6. Analysis adjusted for self-selection [1]	12
7. Analytical approach – adjustment for clustering (if needed) [1/3]	58
8. Analytical approach – accounting for distributional assumptions [1/3]	84
9. Analytical approach – analyses conducted and presented correctly [1/3]	76
10. Did not, inappropriately, categorise continuous environmental exposure/s [1]	74
Total quality score [theoretical range: 0–9]; mean ± SD	3.9 ± 1.3

Notes: SD Standard deviation

Table 3 Associations of environmental attributes/correlates with older adults' physical activity by physical activity outcomes

Environmental attribute	Total PA[1]					Total walking only				
	P	Ø	N	p_a	D_a	P	Ø	N	p_a	D_a
Walkability	12.33	6.67	0	**<.001**	**P**	4.37	3.63	0	**.001**	**P**
Residential density/urbanisation	11.53	33.50	12.97	.394	Ø	8	14.50	3.50	**.036**	**P**
Street connectivity	8.80	26.06	2.14	.094	Ø	5.80	13.20	2	.185	Ø
Access to/availability of destinations & services										
Overall access to destinations & services	12.55	38.15	0.50	**<.001**	**P**	6.93	25.57	0.50	**.009**	**P**
Land-use mix—destination diversity	5.68	19.32	2	.148	Ø	1	8	2	.439	Ø
Shops/commercial	9.96	57.04	0	**.006**	**P**	8.58	23.42	0	**.001**	**P**
Food outlets	0.72	21.28	1	.932	Ø	0.72	6.28	1	.873	Ø
Government/finance services	0.33	11.67	0	.834	Ø	0	6	0	1.00	Ø
Education	0.31	11.69	0	.765	Ø	0.14	2.85	0	.826	Ø
Health & aged care	4.61	26.39	1	.275	Ø	3.61	7.39	1	.191	Ø
Religious	0	8	0	1.00	Ø	0	1	0	1.00	Ø
Public transport	7.50	25.50	1	**.016**	**P**	5.50	11.50	1	**.011**	**P**
Parks/public open space	11.29	47.54	0.17	**.002**	**P**	6.05	23.78	0.17	**.014**	**P**
Recreational facilities	13.34	39.66	0	**<.001**	**P**	3.07	15.93	0	.135	Ø
Social recreational facilities	4.15	25.95	0	.105	Ø	1.50	10.50	0	.413	Ø
Other destinations	0	3	0	1.00	Ø	-	-	-	-	-
Infrastructure & streetscape										
Overall access to cycle/walk-friendly infrastructure	1	9	0	.612	Ø	0	3	0	1.00	Ø
Walk-friendly infrastructure	9	21.49	1.51	**.009**	**P**	5	15	0	**.042**	**P**
Cycle-friendly infrastructure	0	5	0	1.00	Ø	0	3	0	1.00	Ø
No physical barriers (e.g., hills)	5	20.40	2.60	.208	Ø	2	14.40	0.60	.384	Ø
Pavement/footpath quality	3	6	1	.155	Ø	2	5	0	.169	Ø
Street lighting	3	6	0	.059	Ø	3	4	0	.042	P
Greenery & aesthetically pleasing scenery	13.01	45.49	0.5	**.004**	**P**	10.51	19.49	0	**.002**	**P**
Pollution (air)	0	5	0	1.00	Ø	0	4	0	1.00	Ø
Safety										
Traffic/pedestrian safety	7	47	3	.463	Ø	5	25	3	.705	Ø
Crime/personal safety	20.52	50.48	4	**<.001**	**P**	10.49	28.01	2.50	**.027**	**P**

Notes: [1]Objective and self-report total PA (including total walking) combined. P = positive association; Ø = nil association; N = negative association; *p* = *p*-value; D = direction of association supported by the data; subscript "a" = fully adjusted (for sample size and article quality). In bold font: statistically significant evidence of a directional association that has been sufficiently studied (i.e., ≥5 findings reported on specific combinations of environmental exposure and PA variables)

Moreover, there was strong evidence of positive associations between total PA and access to both parks/public open space (p = .002) and shops/commercial destinations (p = .006), the presence of greenery and aesthetically pleasing scenery (p = .004), and walk-friendly infrastructure (p = .009). In addition, there was evidence that access to public transport was positively associated with total PA (p = .016). No other significant associations were found in relation to built environmental attributes and total PA.

Total walking

We found strong evidence for positive associations between older adults' total walking and neighbourhood walkability (p = .001), access to/availability of shops/commercial destinations (p = .001) and overall destinations and services (p = .009) and more greenery and aesthetically pleasing scenery (p = .002) (Table 3). We also found evidence that access to/availability of neighbourhood public transport (p = .011) and parks/public open space (p = .014), crime/personal safety (p = .027), residential density (p = .036), walk-friendly infrastructure (p = .042), and street lighting (p = .042) were positively associated with total walking. No significant associations were found for the remaining 15 built environmental attributes (Table 3).

Built environmental correlates of older adults' PA by measurement method

PA measurement type (objective and self-report)

Irrespective of the PA measurement type used, neighbourhood walkability (both $p < .001$) and overall access to destinations and services (both $p < .01$) were positively associated with older adults' total PA (Table 4). Seven other positive associations between attributes of the built environment and PA were PA-measurement dependent. Five positive associations were specific to self-reported total PA, namely: greenery and aesthetically pleasing scenery ($p = .001$), access to shops/commercial destinations ($p = .002$), parks/public open space ($p = .002$), recreational facilities ($p = .002$) and public transport ($p = .006$). Two remaining positive associations were in relation to objectively assessed total PA only, specifically: walk-friendly infrastructure ($p = .031$) and destination diversity (land use mix) ($p = .019$).

Environmental attribute measurement type (objective and perceived)

Total PA

For nine out of 18 environmental exposures, associations with total PA differed by environmental measurement type (Table 5). For five environmental attributes, positive associations with total PA were found with perceived but not objectively assessed measures. Perceptions of crime-related personal safety ($p < .001$), access to/availability of recreational facilities ($p < .001$), access to/availability of parks/public open space ($p = .003$), greenery and aesthetically pleasing scenery ($p = .003$), and destination diversity (land-use mix) ($p = .002$) were all positively associated with total PA. Objectively assessed

Table 4 Associations of environmental attributes/correlates with older adults' physical activity by physical activity measurement method (objective and self-report)

Environmental attribute	Total PA									
	Objective					Self-report				
	P	Ø	N	p_a	D_a	P	Ø	N	p_a	D_a
Walkability	5.96	2.04	0	**<.001**	**P**	6.37	4.63	0	**<.001**	**P**
Residential density/urbanisation	1	7	0	.377	Ø	10.53	26.50	12.97	.240	Ø
Street connectivity	3	7.86	0.14	.262	Ø	5.71	18.20	2	.215	Ø
Access to/availability of destinations & services										
Overall access to destinations & services	3.89	8.31	0	**.005**	**P**	8.66	29.84	0.50	**.004**	**P**
Land-use mix—destination diversity	3.17	8.83	0	**.019**	**P**	2.51	12.49	2	.884	Ø
Shops/commercial	1.38	26.62	0	.507	Ø	8.58	29.42	0	**.002**	**P**
Food outlets	0	13	0	1.00	Ø	0.72	8.28	1	.884	Ø
Government/finance services	0.34	5.66	0	.377	Ø	0	6	0	1.00	Ø
Education	0.17	6.83	0	.818	Ø	0.14	4.86	0	.845	Ø
Health & aged care	1	18	0	.612	Ø	3.61	8.39	1	.206	Ø
Religious	0	5	0	1.00	Ø	0	3	0	1.00	Ø
Public transport	1	12	0	.520	Ø	6.50	13.50	1	**.006**	**P**
Parks/public open space	1.75	14.25	0	.296	Ø	9.54	33.29	0.17	**.002**	**P**
Recreational facilities	4.29	16.71	0	.056	Ø	9.05	22.95	0	**.002**	**P**
Social recreational facilities	2.65	12.35	0	.118	Ø	1.50	13.50	0	.432	Ø
Infrastructure & streetscape										
Overall access to cycle/walk-friendly infrastructure	1	5	0	.529	Ø	0	4	0	1.00	Ø
Walk-friendly infrastructure	3	3	0	**.031**	**P**	6	18.49	1.51	.059	Ø
No physical barriers (e.g., hills)	3	5	1	.135	Ø	2	15.40	1.60	.631	Ø
Greenery & aesthetically pleasing scenery	1.50	15	0.50	.741	Ø	11.51	30.49	0	**.001**	**P**
Safety										
Traffic/pedestrian safety	2	14	0	.408	Ø	5	33	3	.737	Ø
Crime/personal safety	3	8	0	.063	Ø	17.52	42.48	4	**.001**	**P**

Notes: P = positive association; Ø = nil association; N = negative association; p = p-value; D = direction of association supported by the data; subscript "a" = fully adjusted (for sample size and article quality). In bold font: statistically significant evidence of a directional association that has been sufficiently studied (i.e., ≥5 findings reported on specific combinations of environmental exposure and PA variables)

Table 5 Associations of environmental attributes/correlates with older adults' physical activity by physical activity and environmental measures (objective and perceived)

Environmental attribute	Total PA[1]					Total walking only				
	P	Ø	N	p_a	D_a	P	Ø	N	p_a	D_a
Walkability	12.33	6.67	0	**<.001**	**P**	4.37	3.63	0	.001	P
Objective	9.05	6.95	0	<.001	P	-	-	-	-	-
Perceived	3	0	0	.003	P	-	-	-	-	-
Residential density/urbanisation	11.53	33.5	12.97	.394	Ø	8	14.5	3.5	.036	P
Objective	10	18.50	11.50	.388	Ø	7	6.50	3.50	**.032**	**P**
Perceived	1.53	15	1.47	.855	Ø	1	8	0	**.652**	**Ø**
Street connectivity	8.71	26.06	2.14	.094	Ø	5.71	13.20	2	.185	Ø
Objective	2.80	14.20	1	.366	Ø	1.80	9.20	1	.543	Ø
Perceived	6	11.86	1.14	.076	Ø	4	4	1	.210	Ø
Access to/availability of destinations & services										
Overall access to destinations & services	12.55	38.15	0.5	**<.001**	**P**	6.93	25.57	0.5	**.009**	**P**
Objective	3.76	12.24	0	.003	P	3.43	9.57	0	**.004**	**P**
Perceived	8.79	25.91	0.50	.008	P	3.50	16	0.50	**.277**	**Ø**
Land-use mix—destination diversity	5.68	19.32	2	.148	Ø	1	8	2	.439	Ø
Objective	1.17	10.83	2	**.504**	**Ø**	-	-	-	-	-
Perceived	4.51	8.49	0	**.002**	**P**	-	-	-	-	-
Shops/commercial	9.96	57.21	0	**.006**	**P**	8.58	23.42	0	.001	P
Objective	8.25	34.75	0	**.006**	**P**	7.08	12.92	0	**<.001**	**P**
Perceived	1.71	21.29	0	**.475**	**Ø**	1.50	10.50	0	**.422**	**Ø**
Food outlets	0.72	21.28	1	.932	Ø	0.72	6.28	1	.873	Ø
Objective	0.72	14.28	0	.685	Ø	-	-	-	-	-
Perceived	0	7	1	.521	Ø	-	-	-	-	-
Education	0.31	11.69	0	.765	Ø	0.14	2.85	0	.826	Ø
Objective	0.31	8.69	0	.727	Ø	-	-	-	-	-
Perceived	0	3	0	1.00	Ø	-	-	-	-	-
Health & aged care	4.61	26.39	1	.275	Ø	3.61	7.39	1	.191	Ø
Objective	4	24	1	.382	Ø	-	-	-	-	-
Perceived	0.61	2.39	0	.290	Ø	-	-	-	-	-
Public transport	7.5	25.6	1	.013	P	5.5	11.5	1	.011	P
Objective	6.50	12.50	0	**.004**	**P**	5.50	5.50	0	**<.001**	**P**
Perceived	1	13	1	**.918**	**Ø**	0	6	1	**.501**	**Ø**
Parks/public open space	11.29	47.54	0.17	.002	P	6.05	23.78	0.17	.014	P
Objective	4.42	28.58	0	**.083**	**Ø**	4.42	13.58	0	**.035**	**P**
Perceived	6.87	18.96	0.17	**.003**	**P**	1.63	10.20	0.17	**.201**	**Ø**
Recreational facilities	13.34	39.66	0	<.001	P	3.07	15.93	0	.135	Ø
Objective	4.58	21.42	0	**.092**	**Ø**	0.29	6.71	0	**.848**	**Ø**
Perceived	8.76	18.24	0	**<.001**	**P**	2.78	9.22	0	**.050**	**P**
Social recreational facilities	4.15	25.95	0	.105	Ø	1.5	10.5	0	.413	Ø
Objective	3.50	14.50	0	.094	Ø	1.50	4.50	0	.291	Ø
Perceived	0.65	11.45	0	.687	Ø	0	6	0	1.00	Ø
Infrastructure & streetscape										
Walk-friendly infrastructure	9	21.49	1.51	.009	P	5	15	0	.042	P

Table 5 Associations of environmental attributes/correlates with older adults' physical activity by physical activity and environmental measures (objective and perceived) *(Continued)*

Objective	5	9	0	**.028**	**P**	3	7	0	.103	Ø
Perceived	4	12.49	1.51	**.137**	**Ø**	2	8	0	.222	Ø
No physical barriers (e.g., hills)	5	20.40	2.61	.208	Ø	2	14.40	0.61	.384	Ø
Objective	5	8.40	1.60	**.048**	**P**	2	4.40	0.60	.227	Ø
Perceived	0	12	1	**.629**	**Ø**	0	10	0	1.00	Ø
Greenery & aesthetically pleasing scenery	13.01	45.49	0.5	.004	P	10.51	19.49	0	.002	P
Objective	3	18	0	**.252**	**Ø**	3	9	0	**.199**	**Ø**
Perceived	10.01	27.49	0.50	**.003**	**P**	7.51	10.49	0	**<.001**	**P**
Safety										
Traffic/pedestrian safety	7	47	3	.463	Ø	5	25	3	.705	Ø
Objective	1	13	3	.407	Ø	0	11	3	**.150**	**Ø**
Perceived	6	34	0	.126	Ø	5	14	0	**.043**	**P**
Crime/personal safety	20.63	50.58	3.99	**<.001**	**P**	10.49	28.01	2.5	**.027**	**P**
Objective	4	5.50	2.50	**.510**	**Ø**	3	5	2	**.627**	**Ø**
Perceived	16.52	44.98	1.50	**<.001**	**P**	7.49	23.01	0.50	**.012**	**P**

Notes: [1]Objective and self-report total PA (including total walking) combined. P = positive association; Ø = nil association; N = negative association; p = *p*-value; D = direction of association supported by the data; subscript "a" = fully adjusted (for sample size and article quality). In bold font: evidence of a difference between environmental measures of an association between a sufficiently studied exposure and PA variable (i.e., ≥3 articles' reported findings on specific combinations of environmental exposure and physical activity variables)

access to/availability of shops/commercial destinations (p = .006) and public transport (p = .004), presence of walk-friendly infrastructure (p = .028), and absence of physical environmental barriers (e.g., hills) (p = .048) were all positively associated with total PA, whereas associations with these attributes were non-significant when using perceived measures.

Total walking
There were five positive PA associations with objectively measured environment variables only and four others with measures based on perceptions only. Evidence of a positive association with total walking was found for perceived measures of neighbourhood greenery and aesthetically pleasing scenery ($p < .001$), crime/personal safety (p = .012), traffic-safety (p = .043), and access to/availability of recreational facilities (p = .050). Regarding objectively measured environmental attributes, access to/availability of shops/commercial destinations ($p < .001$), public transport ($p < .001$), overall destinations and services (p = .004), parks/public open space (p = .035), and residential density/urbanisation (p = .032) were all positively related to total walking.

Sensitivity analyses
None of the significant correlates of total PA, objective total PA or self-report total PA differed based on any adjustment (partial or none) (Additional file 4). Regarding total walking, only two significant correlates differed based on adjustment, namely: residential density/urbanisation (fully-adjusted: p = .036; unadjusted: p = .055) and walk-friendly infrastructure (fully-adjusted: p = .042; article quality-adjusted: p = .057). In addition, some built environmental attributes were significant when unadjusted, but not when taking into account sample size and/or article quality. These were street lighting (total PA and self-report total PA), street connectivity (total walking), and crime/personal safety (objective total PA).

Moderators of environment-PA associations
Sixteen moderators of built environmental attribute-PA associations were examined in 39 articles (Additional file 5). The most frequently examined moderators by number of articles were sex (7 articles), health status/functionality (7 articles), residential density/urbanisation (6 articles), and SES/area-level income (5 articles). Buffer size (121 findings) and sex (83 findings) were the most frequently examined by estimating regression interaction terms. The direction of effects for all significant interaction terms was inconsistent (Additional file 5).

Discussion
In the last decade, world bodies have been advocating the importance of healthy ageing and the enabling role played by PA and built environments (e.g., [81]). As a result, the number of published articles on the associations between built environmental attributes and older adults' PA increased over three times since the last systematic review in 2011 [15]. Moreover, there was a greater percentage of articles from outside of North America, with

notable increases in research conducted in Asia and Europe, which expanded the range of examined geographical settings and cultures. We undertook a systematic review and applied a meta-analytic procedure to statistically identify built environmental attributes related to total PA and total walking, stratifying by measurement method.

In general, while the findings from Van Cauwenberg and colleagues' systematic review published in 2011 were inconclusive [15], we found strong evidence of positive associations between walkability, access to destinations and services, personal safety from crime and PA. Also, while the relatively small number of articles included in Van Cauwenberg and colleagues' review [15] precluded the examination of differences in findings by measurement method, this review and meta-analysis revealed important differences in associations when using objective versus perceived measures of environmental attributes and when using self-report versus objective measures of PA. These new findings and their implications are discussed in detail below.

Built environmental correlates of older adults' PA

Walkability and access to destinations/services

We found strong to very strong evidence supporting the benefits of neighbourhood walkability on total PA and walking, regardless of measurement method. Two of the three components comprising walkability were found to individually relate to PA: strong evidence supported the association between access to destinations and services and total PA, for both objective and perceived environmental and PA measurement types. Evidence was also found supporting the impact of access to destinations and services and residential density on total walking, particularly when these attributes were measured objectively. Our findings highlight the importance of having local neighbourhood destinations for older adults to not only walk to and walk around, but to also engage in other types of PA. Furthermore, local destinations may provide a location for social activity and engagement, potentially reducing risk of social isolation and loneliness [82].

Although easier access to destinations and services tend to be highly correlated with greater residential density [83], our findings suggest that walking may be the only type of PA positively related to residential density. High levels of residential density may not be conducive to other forms of active transport, such as cycling. One study has found that Flemish older adults living in urban areas were less likely to cycle everyday than those living in semi-urban (i.e., less dense) areas [84]. While walking is the most popular type of PA that older adults participate in [9], cycling is also a popular PA mode in European countries such as the Netherlands, Denmark, and Germany, where cycling levels remain high even among older people [85]. Future research examining the differential influence of residential density on different types of PA as well as identifying the optimal threshold of density for supporting all types of PA will be important for informing planning policy and practice [86].

In terms of access to specific types of destinations in the neighbourhood, we found evidence supporting shops and commercial destinations, public transport, parks and public open space, and recreational facilities as possible facilitators of PA. No evidence was found for the seven other destination types examined. Overall, this is in line with the work of others who highlight that certain types of destinations may be more conducive to higher PA levels than other destination types [15, 27].

Shops/commercial destinations and public transport, particularly for objectively assessed measurement types, were positively associated with total walking and total PA, specifically self-reported measures of total PA. The importance of shops and commercial destinations for PA is consistent with findings highlighting that shopping is the most prevalent reason for older adults leaving their homes [87], and thus an important part of daily life. Therefore, ensuring neighbourhoods have ease of access to shops means that health-enhancing levels of PA can be incorporated into daily living. Availability and access to public transport not only facilitates PA levels but has the potential to also reduce car dependence [88] with co-benefits of environmental sustainability [89]. For older adults especially, access to public transport enables those who are not confident with driving or no longer able to drive to still travel outside of home, thus maintaining their mobility and reducing risk of loneliness [90].

We found strong to very strong evidence for parks and public open space and recreational facilities as correlates of total PA, particularly for self-reported types of measurement. This is consistent with findings in adults [91]. When comparing environmental measurement methods, evidence was found for positive associations between total PA and perceived, but not objectively assessed, access to parks, public open space and recreational facilities. Access to parks and public open space was also found to be positively associated with total walking. However, when comparing the environmental measurement type, it was the objectively assessed measures showing a positive association with total walking, not perceptions. Here, it should be noted that most of the objectively assessed positive findings were from studies based in Portland, USA [64, 92, 93], a city renowned for its walk-friendliness and management of parks in the presence of urban growth [94, 95]. Having accessible parks and public open space and recreational facilities in local areas may be beneficial beyond PA, as green spaces and visual cues of nature in parks may impart further psychological benefits on individuals [96, 97]. Moreover, both destinations provide an opportunity for fostering social connectedness/activities (e.g., a walk with friends in a park and a game of squash at a recreational facility).

Infrastructure and streetscape

Pedestrian-friendly infrastructure, particularly when measured objectively, was found to be positively associated with both total PA and total walking. This reflects qualitative [98] and experimental research [99] findings highlighting the importance of pavements/footpaths and other infrastructure, such as benches for resting, for older adults' PA. Ensuring the provision of walk-friendly infrastructure, especially along routes to destinations within the neighbourhood, may be particularly pertinent. It is plausible that the relationship between walk-friendly infrastructure and PA may differ based on physical functionality. However, we identified only one study that had examined this, finding no difference in the associations [100].

We found evidence supporting a positive association between street lighting and total walking only. This highlights the importance of providing street lighting along pedestrian infrastructure so that its use is not dependent on the time of day. For older adults especially, ensuring neighbourhoods are well-lit at night may also contribute to a heightened sense of safety from crime [98]. This is because street lighting helps contribute to natural surveillance by allowing pedestrians to be seen.

We found no evidence of an association between pavement/footpath quality and PA. This is in contrast to qualitative research findings indicating quality of infrastructure to be particularly pertinent in facilitating PA among older adults [98, 99, 101]. Our findings may be explained by the diversity of measures used and/or lack of clear definition of pavement/footpath quality. For example, what constituted 'footpath quality' ranged from "curb quality" (objectively assessed) [47] to "quality and maintenance of sidewalks" (as perceived by study participants) [24].

Strong evidence supported the role of greenery and aesthetically pleasing scenery on levels of total PA (especially self-reported measurement types) and total walking. These findings are in line with recent research highlighting the importance of green, clean, and attractive neighbourhoods and streetscapes in facilitating PA [98, 102]. When stratifying by environmental measurement type, only perceived measures were found to be significant. Beyond facilitating PA, it is plausible that there are synergistic benefits of streetscape trees and vegetation, for example, in reducing urban heat island effect [103] and air pollution [104] – environmental factors linked with premature mortality [105] and global disease burden [106]. Following design principles of 'tactical urbanism', which are low cost interventions to make areas more attractive and pedestrian-friendly [107], environmental modifications such as planting trees and flora are micro-scale interventions that can be more easily implemented than macro-level interventions to street design and layout.

Safety

Safety from crime, especially when perceived measures were used, was found to be positively associated with total PA (primarily self-reported measures) and total walking. This adds to the evidence base as previous research in older adults has mostly shown inconsistent findings [31, 108]. Our findings are in line with the notion that perceptions of crime have more influence on behaviour (e.g., leaving the home) than objective crime rates [109]. This speaks in favour of interventions aimed at positively changing perceptions of safety (when appropriate) and encouraging older people to get out of home. This may be particularly important as the frequency of daily out of home trips is predictive of PA participation in this demographic [87].

Overall, we found no evidence to support the relationship between traffic-related safety and total PA and total walking. However, when only perceived measures of traffic safety were considered, there was evidence of a positive association with total walking only. It is possible that older adults may have no choice other than participating in walking near heavy neighbourhood traffic because they do not own a car and/or have limited access to public transport [73]. It may be that a substantial amount of walking and PA in older adults comes from actively travelling to and from destination-rich areas where traffic is typically heavy [27].

Differences in built environmental correlates by type of PA measurement method

We found more significant environmental correlates for self-reported PA than for objectively measured PA. One reason for this may relate to common method bias associated with self-reported PA and environmental attributes – systematic error variance introduced by measurement methods that do not accurately assess the constructs they represent and may be due to factors such as social desirability [110]. Another reason may be that the environmental attributes measured in these studies primarily influence walking behaviours that may be more easily measured by self-reports than by accelerometry. An additional reason may relate to issues with the accelerometry-based operationalisation of older adults' MVPA. Sixteen of the 28 reviewed articles reporting objective PA findings used accelerometer cut-points and half of those applied an MVPA cut-point of 1952 accelerometer counts per min derived for adults [111]. As older adults have a lower MVPA cut-point due to lower resting metabolic rates [112], using the adult accelerometer cut-point likely resulted in lower estimates of MVPA, potentially masking associations. To accurately classify different intensities of older adults' PA, future research using objectively assessed PA should be underpinned by appropriate cut-points.

Differences in built environmental correlates by type of environmental measurement method

Overall, there were numerous differences in the associations between built environmental attributes and total PA and walking, based on type of environmental measure. Attributes that can be classed within the functional (e.g., pedestrian infrastructure) and destination domains in Pikora's framework tended to be significantly related to PA when objectively assessed [113]. In contrast, those attributes that fall within the safety and aesthetics domains were associated with PA when perceived measures were used. This may be explained by attributes within safety and aesthetics domains being more subjective in their interpretation and thus depend on perceptions that may vary greatly between individuals. Attributes related to function and destinations are more objective and, hence, are associated with lower levels of interpersonal differences in perceptions (e.g., a pavement is either present or it is not).

Effects were generally stronger for associations between the perceived environment and PA, which is consistent with previous research [114]. Unlike the objective environment, perceptions of the same neighbourhood environment can greatly differ across individuals due to differences in socio-demographics (e.g., socioeconomic status), preference, experience, culture and/or amount of walking in the neighbourhood [30]. Regular walkers may have more accurate perceptions of their local environments. Moreover, perceived measures often define neighbourhood in terms of time to reach a destination (e.g., 10–20 min' walk from home) [40, 41], rather than set distances (e.g., objective 400 m home-centred buffers), and therefore may be more closely aligned with the individual and their own definition of 'neighbourhood'.

Implications for future research and planning policy/practice

Socio-ecological models of health behaviour underpin the majority of research undertaken in the built environment and PA field. One of the key tenets of this approach is its emphasis on the importance of behaviour specificity [12], and for PA this means considering the domain in which PA was accrued. While taking a behavioural perspective allows for the pathways or mechanisms through which the built environment influences PA to be understood, it is possible that built environmental attributes may relate differently to different behaviours [115]. Instead, a public health perspective examining built environmental attributes associated with total PA focuses on the identifications of environmental attributes enabling health-enhancing levels of PA, which is accrued across all domains. Notably, nearly all built environmental correlates of older adults' total PA were also identified as being environmental correlates of either active transport [27] and/or leisure-time PA [116], thus explaining the behavioural pathways through which the built form impacts on total levels of PA. There was one exception, however, with crime/personal safety being positively associated with total PA, but no evidence found for a relationship with either active transport [27] or leisure-time PA [116]. Other behavioural or psychosocial factors may explain the associations between crime/personal safety and total PA. Given the medium to strong evidence of these associations, it is especially important for future research to unpack the mechanisms through which crime/personal safety relates to total health-enhancing PA in order to better inform the implementation of suitable interventions. For example, a better understanding of fear of crime and assessment of the emotional rather than cognitive response to crime may be warranted [108]. Moderators of the relationship between safety and PA that warrant further consideration may include self-efficacy and physical functioning/capacity [117].

Research design issues

Longitudinal and quasi-experimental studies are needed to establish causal relationships between the built environment and PA. Insofar as possible, future research designs would also benefit from assessing and adjusting for residential self-selection to account for biases at the individual level (e.g., an older adult who enjoys PA or chooses to live near a park) and thus enabling, to a certain extent, the controlling of reverse causation. The findings of this review may help inform researchers involved with natural experiments on what environmental attributes to measure, given the environmental manipulation itself will be out of their control.

Better quality research may also come from conceptually-driven choices of built environmental attributes and validated PA measures. Where accelerometer cut-points and the classification of older adults' PA intensities are concerned, it is important that the thresholds for moderate intensity activity are appropriate (e.g., 1013 counts per min [112]). Applying suggestions such as these also allows for the possibility of pooling data across countries. For example, there has been evidence of curvilinearity related to perceived access to destinations and services and objectively assessed MVPA in a multi-country study of adults [31]. This finding was only possible because of the use of comparable environmental exposure and PA outcome measures across a large range of diverse geographical locations combined with a high variability in exposures across countries (another issue that future research may care to address). Thus, the multi-country pooling of data based on valid, comparable measures are needed to address issues surrounding limited variability in environmental exposures and non-linear associations between exposures and PA outcomes. Other statistical analysis decisions such as adjusting for key socio-demographic covariates (i.e., age, sex, and education), and not categorising continuous environmental measures would contribute to improving the quality of future research designs.

Strengths and limitations of this review and meta-analysis

This systematic review and meta-analysis has several strengths. It addressed publication bias by including both peer-reviewed scientific articles and grey literature. It provided a quantitative synthesis of associations based on non-standardised environmental and PA measurement instruments and stratified findings by measurement types. It incorporated an extensive article quality assessment into the meta-analytical procedure and, therefore, adjusted the synthesis of evidence for study methodology quality. Limitations include: (1) not accounting for potentially correlated findings from the same article; (2) an inability to account for potential moderating effects of neighbourhood size and definition; (3) using a meta-analytic method that relied on statistical significance testing rather than effect size estimates and, thus, likely underestimating the evidence of environment-PA associations; and (4) including only articles published in English.

Conclusions

Safe, walkable, and aesthetically pleasing neighbourhoods, with access to destinations and services, specifically, recreational facilities, parks/public open space, shops/commercial destinations and public transport facilitated older adults' participation in PA, beyond domain-specificity. However, PA correlates were not consistent across different PA and environmental measurement types. Future research should consider these differences in findings and identify the mechanisms underlying them. Future studies should also strive to undertake higher quality research by implementing longitudinal research designs, adjusting for residential self-selection, conceptually-driven choosing of built environmental attributes, using validated PA measures (including, where necessary, appropriate accelerometer cut-points), pooling data from different countries based on valid standardised measures, adjusting for key socio-demographic covariates, and not inappropriately categorising continuous environmental measures.

Additional files

Additional file 1: Table S1. Reviewed total physical activity articles ($N = 100$) – Information. (DOCX 286 kb)

Additional file 2: Table S3. Reviewed total physical activity articles ($N = 100$) – Quality assessment. (DOCX 106 kb)

Additional file 3: Table S2. Associations between built environmental attributes and older adults' objectively measured walking. (DOCX 16 kb)

Additional file 4: Table S4. Meta-analytic results of significance of associations between built environmental correlates of older adults' PA by outcome and type of adjustment for article characteristics. (DOCX 19 kb)

Additional file 5: Table S5. Overview of moderating effects examined in the association between environmental attributes and older adults' total PA. (DOCX 214 kb)

Abbreviations

MVPA: Moderate- to vigorous-intensity PA; PA: Physical activity; PhD: Doctor of Philosophy; PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses; SD: Standard deviation; UK: United Kingdom of Great Britain and Northern Ireland; USA: United States of America

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Availability of data and materials

All information generated and analysed in this systematic review and meta-analysis are included in this published article and its supplementary information files (Additional files 1, 2, 3, 4 and 5).

Authors' contributions

All authors conceptualised the systematic review. EC developed the review protocol and the meta-analytical approach. DWB conducted the meta-analyses and AN verified its validity. DWB extracted the data from the included articles, drafted the manuscript, and supplementary materials. AB, AN, and JVC verified the validity of the extracted data from the included articles. JVC and AN searched the grey literature. All authors conducted searches, contributed to the screening of article eligibility, revised the manuscript for intellectual content, and approved the final manuscript.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

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Appendix 5. Reviewed total physical activity articles (N=100) – Information

#		Participants [Total sample size; urban, rural, or mixed sample; response rate or proof of representativeness of sample; community dwellers or not; geographical location]	Study design [Cross-sectional, longitudinal, or experimental; sampling method for clusters and individuals; stratification used by environment attributes; neighbourhood definition]	Covariates [Covariates included in the analyses]	Outcome measures [PA outcome measure; instrument; validity]	Environmental exposure variables [Environmental variables, their type (objective vs perceived) and their classification into environmental categories (to assist compilation of summary table)]	Moderators [Moderators examined and breakdown of sample size by qualitative moderator (e.g., sex; educational attainment)]	Analytical approach [Analytical approach; adjustment for clustering; appropriateness (distributional assumptions; moderation analyses) and presentation]	Findings Main effects or moderating effects (conclusion in red)	Comments [Notes important for the assessment or interpretation of the study (if any)]
1	Active Living Study Nathan et al., 2014 [422]	N=323 (urban) Mean age: 77 years 68% female 49% response rate (village) 46% response rate (person) Retirement village dwellers Perth, Australia	Cross-sectional Cluster: purposive Individuals: random and convenience Stratification: walkability Neighbourhood definition: retirement village, 10-15mins walk from village	Age, sex, education, physical functioning, neighbourhood walkability, sampling method, other significant environmental predictors, self-selection	*Self-report [Community Healthy Activities Model Program for Seniors (CHAMPS) questionnaire; validated]:* Brisk walking (150+mins/wk; Yes/No) → Total walking *TotalWalking(150+ mins/wk; Yes/No)*	*Perceived [Neighborhood Environment Walkability Scale (NEWS)—Abbreviated; validated]:* 1. Access to activity centre → Social recreational facilities access/availability 2. Access to services – neighbourhood → Destinations/services (overall/unspecific) access/availability 3. Proximate destinations – village + neighbourhood → Destinations/services (overall/unspecific) access/availability 4. Infrastructure for walking – village +	None	Generalized Estimating Equations with exchangeable correlation matrix to account for clustering	***Main effects with TotalWalking(150+ mins/wk; Yes/No)*** 1. Access to activity centre – village: OR=not reported, p>.05 (Social recreational facilities access/availability **0**) 2. Access to services – neighbourhood: OR=not reported, p>.05 (Destinations/services (overall/unspecific) access/availability **0**) 3. Proximate destinations – village + neighbourhood: Village: OR=0.80 (0.66; 0.98) p<.05 (Destinations/services (overall/unspecific) access/availability -***0.5**)	Treat similar measures on village and neighbourhood environment as two buffers (assign fractional weights). Note that there are multiple measures per environmental construct that need to be summed. Reporting fully adjusted models (with multiple environmental predictors) as these were

						neighbourhood → Walk-friendly infrastructure 5. Aesthetics – village + neighbourhood → Greenery and aesthetically pleasing scenery 6. Safety from crime – village + neighbourhood → Crime/personal safety 7. Safety from traffic – village + neighbourhood → Traffic/pedestrian safety 8. Even gradient – village → No physical barriers to walking 9. Street connectivity – village → Street connectivity 10. Fewer physical barriers – neighbourhood → No physical barriers to walking 11. Orderliness – neighbourhood → Crime/personal safety 12. Age-appropriate infrastructure for walking – neighbourhood → Walk-friendly infrastructure 13. Traffic signal transition – neighbourhood → Traffic/pedestrian safety)			Neighbourhood: OR=not reported, p>.05 (Destinations/services (overall/unspecific) access/availability **0 *0.5**) 4. Infrastructure for walking – village + neighbourhood: Village: OR=not reported, p>.05 Neighbourhood: OR=1.61 (0.76-3.45), p>.05 (Walk-friendly infrastructure **0*0.5; 0*0.5**) 5. Aesthetics – village + neighbourhood: Village: OR=0.86 (0.49; 1.50) p>.05 Neighbourhood: OR=not reported p>.05 (Greenery and aesthetically pleasing scenery **0*0.5; 0*0.5**) 6. Safety from crime – village + neighbourhood: Village: OR=0.43 (0.21; 0.88), p<.05 (Crime/personal safety **- *0.5**) Neighbourhood: OR=not reported, p>.05 (Crime/personal safety **0*0.5**) 7. Safety from traffic – village + neighbourhood: ORs=not reported, p>.05 (Traffic/pedestrian safety **0*0.5; 0*0.5**) 8. Even gradient – village: OR=not reported, p>.05 (No physical barriers to walking **0**)	adjusted for self-selection.

										9. Street connectivity – village: OR=0.71 (0.51; 0.98), p<.05 (Street connectivity -) 10. Fewer physical barriers – neighbourhood: OR=not reported, p>.05 (No physical barriers to walking **0**) 11. Orderliness – neighbourhood: OR=not reported, p>.05 (Crime/personal safety **0**) 12. Age-appropriate infrastructure for walking – neighbourhood: OR=1.51 (0.81; 2.82), p>.05 (Walk-friendly infrastructure **0**) 13. Traffic signal transition – neighbourhood: OR=0.99 (0.66; 1.48), p>.05 (Traffic/pedestrian safety **0**)	
2	Active Living Study Nathan et al., 2014 [265]	N=323 (urban) Mean age: 77 years; 68% female 49% response rate (village) 46% response rate (person) Retirement village dwellers Perth, Australia	Cross-sectional Cluster: purposive Individuals: random and convenience Stratification: walkability Neighbourhood definition: retirement village, 400m street network buffer	Age, sex, physical functionality, sampling method, education	*Self-report [CHAMPS questionnaire; validated]:* Brisk walking (any participation; Yes/No) → Total walking *TotalWalking(Yes/No)* *Objective [ActiGraph accelerometer—validated; Freedson MVPA cutoff point—validated]:*	*Objective [site manager's questionnaire, GIS; unvalidated]:* 1. Age care facility → Health and aged care access/availability 2. Clubhouse → Social recreational facilities access/availability 3. Amenities → Land use mix—destination diversity	None	Generalized Estimating Equations with exchangeable correlation matrix to account for clustering	***Main effects with TotalWalking(Yes/No)*** 1. Age care facility: OR=not reported, p>.05 (Health and aged care access/availability **0**) 2. Clubhouse: OR=not reported, p>.05 (Social recreational facilities access/availability **0**) 3. Amenities: OR=not reported, p>.05 (Land use mix—destination diversity **0**)	Report single attribute rather than fully-adjusted models because results not adjusted for self-selection.

					MVPA (150+ mins/wk; Yes/No) → Total MVPA *TotalMVPAFreedson(150+ mins/wk; Yes/No)*	4. Recreational facilities → Recreational facilities access/availability 5. Neighbourhood walkability → Walkability			4. Recreational facilities: OR=not reported, p>.05 (Recreational facilities access/availability **0**) 5. Neighbourhood walkability: OR=not reported, p>.05 (Walkability **0**) ***Main effects with TotalMVPAFreedson(150+ mins/wk; Yes/No)*** 1. Age care facility: OR=not reported, p>.05 (Health and aged care access/availability **0**) 2. Clubhouse: OR=not reported, p>.05 (Social recreational facilities access/availability **0**) 3. Amenities: OR=not reported, p>.05 (Land use mix–destination diversity **0**) 4. Recreational facilities: OR=not reported, p>.05 (Recreational facilities access/availability **0**) 5. Neighbourhood walkability: OR=not reported, p>.05 (Walkability **0**)	
3	Active Living Study Nathan et al., 2014 [266]	N=323 (urban) Mean age: 77 years; 68% female 49% response rate (village) 46% response rate (person) Retirement village dwellers Perth, Australia	Cross-sectional Cluster: purposive Individuals: random and convenience Stratification: walkability Neighbourhood definition: 10-15mins walk from home;	Age, sex, physical functioning, education, sampling method, other significant environmental predictors, self-selection	*Self-report [CHAMPS questionnaire; validated]:* Brisk walking (150+mins/wk; Yes/No) → Total walking *TotalWalking(150+ mins/wk; Yes/No)* *Objective [ActiGraph accelerometer +*	*Objective [GIS, site manager's questionnaire; unvalidated]:* 1. Distance to local shop → Shops/commercial access/availability 2. Distance to supermarket → Shops/commercial access/availability	None	Generalized Estimating Equations with exchangeable correlation matrix to account for clustering	***Main effects with TotalWalking(150+ mins/wk; Yes/No):*** 1. Distance to local shop—OR (95% CIs): OR=not reported, p>.05 in single attribute models (Shops/commercial access/availability **0**) 2. Distance to supermarket:	Note that there are multiple measures per environmental construct that need to be summed. Do not report perceived measures as they were reported in

			400m street network buffer		*Freedson MVPA cutoff point; validated]:* MVPA (150+ mins/wk; Yes/No) → Total MVPA *TotalMVPA(150+ mins/wk; Yes/No)*	3. Distance to health service → Health and aged care access/availability 4. Distance to entertainment facility → Social recreational facilities access/availability 5. Distance to public transport → Public transport access/availability 6. Distance to public recreation area → Recreational facilities access/availability 7. Traffic-volume exposure → Traffic/pedestrian safety 8. Slope → No physical barriers to walking 9. Age care facility – village → Health and aged care access/availability 10. Clubhouse – village → Social recreational facilities access/availability 11. Amenities – village → Land-use mix—destination diversity 12. Recreational facilities access/availability – village → Recreational facilities access/availability 13. Walkability – neighbourhood → Walkability *Perceived [Neighborhood*			OR=not reported, p>.05 in single-attributes models (Shops/commercial access/availability **0**) 3. Distance to health service: OR=negative, p<.05 in single-attributes models (Health and aged care access/availability **+**) 4. Distance to entertainment facility: OR=not reported, p>.05 (Social recreational facilities access/availability 0) 5. Distance to public transport: OR=0.81 (0.70; 0.94), p=.007 in single-attributes models (Public transport **+**) 6. Distance to public recreation area: OR=not reported, p>.05 (Recreational facilities access/availability **0**) 7. Traffic-volume exposure: OR=not reported, p>.05 (Traffic/pedestrian safety **0**) 8. Slope: OR=not reported, p>.05 (No physical barriers to walking **0**) 9. Age care facility: OR=not reported, p>.05 (Health and aged care access/availability **0**) 10. Clubhouse: OR=not reported, p>.05 (Social recreational facilities	Nathan et al., 2014 (E&B) not adjusted for objective measures. Reporting single-attribute models as self-selection shown not to be related to walking.

						Environment Walkability Scale (NEWS)—Abbreviated; validated]: *Note:* Attributes were included but are not reported here because they were reported in Nathan et al., 2014 (Enviro&Behav) without adjustment for objective environment.			access/availability **0**) 11. Amenities--village: OR=not reported, p>.05 (Land-use mix—destination diversity **0**) 12. Recreational facilities access/availability: OR=not reported, p>.05 (Recreational facilities access/availability **0**) 13. Walkability: OR=not reported, p>.05 (Walkability **0**) ***Main effects with TotalMVPAFreedson(150+ mins/wk; Yes/No):*** 1. Distance to local shop: OR=0.67 (0.50; 0.90), p=.007 in single attribute models (Shops/commercial access/availability **+**) 2. Distance to supermarket: OR=not reported, p>.05 in single-attributes models (Shops/commercial access/availability **0**) 3. Distance to health service: OR=negative, p<. 05 in single-attributes models (Health and aged care access/availability **+**) 4. Distance to entertainment facility: OR=negative, p<.05 (Social recreational facilities access/availability **+**) 5. Distance to public transport:	

										OR=negative, p<.05 in single-attributes models (Public transport **+**) 6. Distance to public recreation area: OR=negative, p<.05 (Recreational facilities access/availability **+**) 7. Traffic-volume exposure: OR=not reported, p>.05 (Traffic/pedestrian safety **0**) 8. Slope: OR=not reported, p>.05 (No physical barriers to walking **0**)	
4	AGES Hanibuchi et al., 2011 [354]	N=9414 (mixed) 65+ years 52% female 48.7% response rate Community-dwellers Chita Peninsula, Japan	Cross-sectional Cluster: purposive Individuals: random Stratification: age and urbanisation Neighbourhood definition: 250m, 500m, and 1000m buffers	Age, sex, education, marital status, household income, having paid work, self-rated health, depression, instrumental activities of daily living (IADL) (physical function)	*Self-report [unnamed questionnaire; validated]:* Walking (mins/d) → Total walking *TotalWalking(mins/d)*	*Objective [ArcGIS, census data, Geospatial Information Authority; unvalidated]:* 1. Population density → Residential density 2. Number of intersections → Street connectivity 3. Number of dead-ends → Street connectivity 4. Number of destinations → Destinations/services (overall/unspecific) access/availability 5. Parks or green spaces → Parks/public open space access/availability 6. Schools → Education facilities access/availability 7. Land slope → No physical barriers to walking	Sex: Male (n=4519), Female (n=4895) Urbanisation: North (urban; n=3856), South (rural; n=5558) Length of neighbourhood residency: <50 years (n=4819), ≥50 years (n=4138)	Multivariate linear regression	***Main and moderated effects with TotalWalking(mins/d):*** 1. Population density—OR (95% CIs): Inc. Males, Females, North, South,< and ≥50y neighbourhood residency + 250, 500 and 1000m buffers: (Residential density **0*0.055; 0*0.055; 0*0.055; 0*0.055; 0*0.055; 0*0.055; 0*0.055; 0*0.055; 0*0.055; 0*0.055; 0*0.055; 0*0.055; 0*0.055; 0*0.055; 0*0.055; 0*0.055; 0*0.055; 0*0.065**) 2. Number of intersections: *Males + 250m:* OR=0.999 (0.993; 1.004), p>.05 (Street connectivity **0*0.055**) *Males + 500m:* OR=0.999 (0.993; 1.002), p>.05 (Street	Buffer and stratification effects. Table 8.

									connectivity **0*0.055**) *Males + 1000m:* OR=1.000 (1.000; 1.001), p<.05 (Street connectivity **+*0.055**) *Females + 250m:* OR=0.995 (0.990; 1.001), p>.05 (Street connectivity **0*0.055**) *Females + 500m:* OR=0.998 (0.996; 1.000), p>.05 (Street connectivity **0*0.055**) *Females + 1000m:* OR=1.000 (0.999; 1.000), p>.05 (Street connectivity **0*0.055**) *North + 250m:* OR=0.999 (0.993; 1.005), p>.05 (Street connectivity **0*0.055**) *North + 500m:* OR=0.999 (0.997; 1.001), p>.05 (Street connectivity **0*0.055**) *North + 1000m:* OR=1.000 (0.999; 1.001), p>.05 (Street connectivity **0*0.055**) *South + 250m:* OR=0.995 (0.989; 1.000), p>.05 (Street connectivity **0*0.055**) *South + 500m:* OR=0.999 (0.997; 1.001), p>.05 (Street connectivity **0*0.055**) *South + 1000m:* OR=1.000 (0.999; 1.000), p>.05 (Street connectivity **0*0.055**) *<50 years + 250m:* OR=1.001 (0.996; 1.007), p>.05 (Street connectivity **0*0.055**) *<50 years + 500m:*	

								OR=1.000 (0.998; 1.002), p>.05 (Street connectivity **0*0.055**) *<50 years + 1000m:* OR=1.000 (1.000; 1.001), p<.05 (Street connectivity **+*0.055**) *≥50 years + 250m:* OR=0.992 (0.986; 0.997), p<.05 (Street connectivity **-*0.055**) *≥50 years + 500m:* OR=0.998 (0.996; 1.000), p>.05 (Street connectivity **0*0.055**) *≥50 years + 1000m:* OR=1.000 (0.999; 1.001), p>.05 (Street connectivity **0*0.065**) 3. Number of dead-ends: Inc. Males, Females, North, South, < and ≥50y neighbourhood residency + 250, 500 and 1000m buffers: (Street connectivity **0*0.055; 0*0.055; 0*0.055; 0*0.055; 0*0.055; 0*0.055; 0*0.055; 0*0.055; 0*0.055; 0*0.055; 0*0.055; 0*0.055; 0*0.055; 0*0.055; 0*0.055; 0*0.055; 0*0.055; 0*0.065**) 4. Number of destinations: Inc. Males, Females, North, South, < and ≥50y neighbourhood residency + 250, 500 and 1000m buffers: (Destinations/services (overall/unspecific) access/availability **0*0.055; 0*0.055;**	

									0*0.055; 0*0.055; **0*0.055; 0*0.055;** **0*0.055; 0*0.055;** **0*0.055; 0*0.055;** **0*0.055; 0*0.055;** **0*0.055; 0*0.055;** **0*0.055; 0*0.055;** **0*0.055; 0*0.065**) 5. Parks or green spaces: Inc. Males, Females, North, South, < and ≥50y neighbourhood residency + 250, 500 and 1000m buffers: (Parks/public open space **0*0.055; 0*0.055;** **0*0.055; 0*0.055;** **0*0.055; 0*0.055;** **0*0.055; 0*0.055;** **0*0.055; 0*0.055;** **0*0.055; 0*0.055;** **0*0.055; 0*0.055;** **0*0.055; 0*0.055;** **0*0.055; 0*0.065**) 6. Schools: Inc. Males, Females, North, South,< and ≥50y neighbourhood residency + 250, 500 and 1000m buffers: (Education facilities access/availability **0*0.055; 0*0.055;** **0*0.055; 0*0.055;** **0*0.055; 0*0.055;** **0*0.055; 0*0.055;** **0*0.055; 0*0.055;** **0*0.055; 0*0.055;** **0*0.055; 0*0.055;** **0*0.055; 0*0.055;** **0*0.055; 0*0.065**) 7. Land slope: *Males+250m:* OR=1.028 (1.000; 1.056), p<.05 (No physical barriers to	

									walking -***0.055**) *Males + 500m:* OR=1.038 (1.002; 1.074), p<.05 (No physical barriers to walking -***0.055**) *Males + 1000m:* OR=1.021 (0.991; 1.053), p>.05 (No physical barriers to walking **0*0.055**) *Females + 250m:* OR=1.045 (1.019; 1.072), p<.05 (No physical barriers to walking -***0.055**) *Females + 500m:* OR=1.058 (1.022; 1.094), p<.05 (No physical barriers to walking -***0.055**) *Females + 1000m:* OR=1.048 (1.019; 1.078), p<.05 (No physical barriers to walking -***0.055**) *North + 250m:* OR=0.997 (0.950; 1.047), p>.05 (No physical barriers to walking **0*0.055**) *North + 500m:* OR=1.004 (0.947; 1.065), p>.05 (No physical barriers to walking **0*0.055**) *North + 1000m:* OR=1.019 (0.948; 1.096), p>.05 (No physical barriers to walking **0*0.055**) *South + 250m:* OR=1.043 (1.022; 1.065), p<.05 (No physical barriers to walking -***0.055**)	

									South + 500m: OR=1.056 (1.028; 1.085), p<.05 (No physical barriers to walking **-*0.055**) *South + 1000m:* OR=1.042 (1.019; 1.066), p<.05 (No physical barriers to walking **-*0.055**) *<50 years + 250m:* OR=1.019 (0.986; 1.054), p>.05 (No physical barriers to walking **0*0.055**) *<50 years + 500m:* OR=1.034 (0.992; 1.077), p>.05 (No physical barriers to walking **0*0.055**) *<50 years + 1000m:* OR=1.026 (0.988; 1.065), p>.05 (No physical barriers to walking **0*0.065**) *≥50 years + 250m:* OR=1.044 (1.020; 1.069), p<.05 (No physical barriers to walking **-*0.055**) *≥50 years + 500m:* OR=1.056 (1.023; 1.090), p<.05 (No physical barriers to walking **-*0.055**) *≥50 years + 1000m:* OR=1.035 (1.008; 1.062), p<.05 (No physical barriers to walking **-*0.055**)	
5	AIBL study Cerin et al., 2016 [423]	N=146 (urban) Mean age=74.8-75.0 years 55.9-57.5% female	Cross-sectional Cluster: purposive Individual: convenience Stratification:	Age, sex, education, median weekly household income, *APOE* ε4 status, time of assessment, *APOE*	*Self-report [IPAQ—Long form; validated]:* Total PA (MET mins/wk) → Total PA *TotalPA(MET mins/wk)*	*Objective [ArcGIS; unvalidated]:* 1. Walkability (inc., residential density, street connectivity, &	Brain imaging outcomes: Right hippocampal volume (n=127); Left	Linear mixed regression models	***PA-mediated indirect effects with TotalPA(MET mins/wk):*** 1. Walkability—b (95% CIs): *0.5km:* Right	Table 2.

		12.5% response rate Community-dwellers Melbourne, Australia	none Neighbourhood definition: 0.5km and 1km buffers	ε4 status by the time of assessment interaction		land-use mix) → Walkability	hippocampal volume (n=127); Gray matter (n=127); Ventricle volume (n=127); Amyloid β burden (n=143)		hippocampal volume: b=0.008 (-0.001; 0.019) [390: $2.0\cdot10^{-5}$], p<.001 *1km:* Right hippocampal volume: b=0.008 (-0.001; 0.019) [362: $2.0\cdot10^{-5}$], p<.001 *0.5km: Left hippocampal volume:* b=0.006 (-0.001; 0.017) [382: $1.7\cdot10^{-5}$], p<.001 *1km:* Left hippocampal volume: b=0.007 (-0.001; 0.017) [353: $1.8\cdot10^{-5}$], p<.001 *0.5km:* Gray matter volume: b=0.42 (-0.21; 1.21) [390: $1.1\cdot10^{-3}$], p<.001 *1km:* Gray matter volume: b=0.47 (-0.10; 1.21) [361: $1.3\cdot10^{-3}$], p<.001 *0.5km:* Ventricle volume: b=-0.16 (-0.67; 0.26) [382: $-4.2\cdot10^{-4}$], p<.001 *1km:* Ventricle volume: b=-0.13 (-0.61; 0.26) [352: $-3.8\cdot10^{-4}$], p<.001 *0.5km:* Amyloid β burden: b=-0.011 (-0.030; 0.001) [342: $-3.3\cdot10^{-5}$], p<.001 *1km:* Amyloid β burden: b=-0.009 (-0.029; 0.002) [309: $-2.8\cdot10^{-5}$], p<.001 (Walkability **+*1**)	
6	ALECS study Cerin et al., 2016 [242]	N=402 (urban) 65+ years 69% female 71% response rate Community-dwellers Hong Kong, China	Cross-sectional Cluster: purposive Individuals: random Stratification: walkability and SES Neighbourhood	Age, sex, education, household car, marital status, housing type, area-level SES, number of diagnosed health problems, Short Physical	*Objective [ActiGraph accelerometer—Freedson cut-points (≥1952 counts/min); validated]:* Total MVPA (min/d) → Total MVPA	*Objective [GIS, census data, Lands Department of Hong Kong data; unvalidated]:* 1. Residential density → Residential density 2. Intersection density	Intersection density*education; Entertainment density*number of diagnosed chronic health problems; Recreation	Generalised additive mixed models	***Moderating effects with TotalMVPAFreedson(mins/d):*** Intersection density (400m)*education—e (95% CIs): Up to primary: e=1.033 (0.857; 1.246), p>.05 Secondary of higher:	Moderating effects (Table 4). Table 3.

			definition: 400m and 1km buffers	Performance Battery Score, type of recruitment centre (Elderly Health Centre vs. community centre), accelerometer wear time	*TotalMVPAFreedson(mins/d)*	→ Street connectivity 3. Retail density → Shops/commercial access/availability 4. Civic destination density → Government/finance services access/availability 5. Entertainment density → Social recreational facilities access/availability 6. Food outlet density → Food outlets access/availability 7. Recreation density → Recreational facilities access/availability 8. Public transit density → Public transport access/availability 9. Public park area → Parks/public open space access/availability 10. Nearest recreation destination → Recreational facilities access/availability 11. Nearest public park → Parks/public open space access/availability 12. Nearest trail → Parks/public open space access/availability 13. Nearest transit stop → Public transport access/availability	density*education, Recreation density*household with car, recreation density*age; Public transit density*household with car; Nearest park*number of diagnosed chronic health problems		e=1.295 (1.031; 1.627), p<.05 Entertainment density (400m)*number of diagnosed chronic health problems: 1 SD below average (1.0 problems): e=0.994 (0.987; 1.002), p>.05 Average (3.1 problems): e=1.001 (0.996; 1.006), p>.05 1 SD above average (5.1 problems): e=1.007 (1.000; 1.015), p<.05 Recreation density (400m)*education: Up to primary: e=1.009 (1.000; 1.017), p<.05 Secondary of higher: e=1.001 (0.992; 1.010), p>.05 Recreation density (400m)*household with car: No: e=1.009 (1.001; 1.015), p<.05 Yes: e=0.999 (0.987; 1.010), p>.05 Recreation density (400m)*age: 1 SD below average (69.3 y): e=0.997 (0.992; 1.003), p>.05 Average (75.5 y): e=1.002 (1.001; 1.003), p<.001 1 SD above average (81.7 y): e=1.003 (1.001; 1.012), p<.05 Public transit density (1km)*household with car: No: e=0.989 (0.984; 0.994), p<.001 Yes: e=1.012 (1.002;	

									1.021), p<.05 Nearest park (100m)*number of diagnosed chronic health problems: 1 SD below average (1.0 problem): e=1.027 (1.003; 1.050), p<.05 Average (3.1 problems): e=1.010 (0.994; 1.027), p>.05 1 SD above average (5.1 problems): e=0.994 (0.974; 1.015), p>.05 ***Main and moderated effects with TotalMVPAFreedson(mins/d):*** 1. Residential density: *1km:* e=1.000 (0.996; 1.004), p=.979 *400m:* e=1.000 (0.999; 1.001), p=.815 (Residential density **0*0.5; 0*0.5**) 2. Intersection density: *1km:* e=1.206 (0.911; 1.594), p=.300 (Street connectivity **0*0.5**) *400m:* e=1.138 (0.980; 1.321), p=.090 (Street connectivity **0*0.25; 0*0.25**) 3. Retail density: *1km:* e=0.999 (0.997; 1.001), p=.294 *400m:* e=0.999 (0.996; 1.002), p=.444 (Shops/commercial access/availability **0*0.5; 0*0.5**) 4. Civic destination density: *1km:* e (95% CIs)=1.001	

									(0.997; 1.005), p=.553 *400m:* e (95% CIs)=0.999 (0.998; 1.001), p=.334 (Government/finance services access/availability **0*0.5; 0*0.5**) 5. Entertainment density: *1km:* e=0.991 (0.968; 1.001), p=.483 (Social recreational facilities access/availability **0*0.5**) *400m:* e=1.001 (0.995; 1.006), p=.800 (Social recreational facilities access/availability **0*0.17; 0*0.33**) 6. Food outlet density: *1km:* e=0.998 (0.992; 1.004), p=.564 *400m:* e=0.999 (0.993; 1.005), p=.732 (Food outlets access/availability **0*0.5; 0*0.5**) 7. Recreation density: *1km:* e=1.005 (0.998; 1.012), p=.154 (Recreational facilities access/availability **0*0.5**) *400m:* e=1.003 (1.000; 1.007), p=.040 (Recreational facilities access/availability **+*0.29; 0*0.21**) 8. Public transit density: *1km:* e=0.995 (0.991; 1.000), p=.052 (Public transport access/availability **0*0.25; 0*0.25**) *400m:* e=0.995 (0.990; 1.001), p=.058	

										(Public transport access/availability **0*0.5**) 9. Public park area: *1km:* e=1.000 (0.998; 1.002), p=.919 *400m:* e=0.995 (0.990; 1.001), p=.058 (Parks/public open space access/availability **0*0.5; 0*0.5**) 10. Nearest recreation destination: e=1.000 (0.999; 1.000), p=.888 (Recreational facilities access/availability **0**) 11. Nearest public park: e=1.000 (0.999; 1.001), p=.120 (Parks/public open space access/availability **0*0.33; 0*0.67**) 12. Nearest trail: e=1.000 (0.999; 1.000), p=.294 (Parks/public open space access/availability **0**) 13. Nearest transit stop: e=1.000 (0.999; 1.001), p=.512 (Public transport access/availability **0**)	
7	Australian Time Use Survey 2006 Espinel et al., 2015 [424]	N=992 (mixed) 65+ years 56% female 82.5% response rate Community-dwellers *All states,* Australia	Cross-sectional Cluster: none Individuals: random Stratification: none Neighbourhood definition: not reported	Age, sex, education, SES, geographic remoteness, marital status, living alone, self-rated health, disability or long-term health condition	*Self-report [PA diary; unvalidated]:* MVPA (30+ mins/d; Yes/No) → Total MVPA *TotalMVPA(30+ mins/d; Yes/No)*	*Objective [Accessibility/Remoteness Index of Australia; unvalidated]:* 1. Geographic remoteness → Urbanisation	None	Multivariate logistic regression	***Main effects with TotalMVPA(30+ mins/d; Yes/No):*** 1. Geographic remoteness (Ref: Major cities)—OR (95% CIs): Inner regional or other: OR=1.03 (0.68; 1.55), p>.05 (Urbanisation **0**)	Table 3.
8	Behavior Change Consortium Initiative –	N=109 (not reported)	Cross-sectional Cluster: none Individual: convenience	Age, education	*Self-report [CHAMPS questionnaire; validated]:*	*Perceived [NEWS questionnaire; validated]:*	None	Multivariate linear regression	***Main effects with TotalMVPA(mins/wk):*** 1. Residential density:	Note that there are multiple measures per

	Rhode Island Trail King et al., 2006 [425]	Mean age=75 years 65% women 36.9% response rate Community-dwellers Rhode Island, USA	Stratification: none Neighbourhood definition: participant delimitation		Total MPA or VPA (mins/wk) → Total MVPA *TotalMVPA(mins/wk)*	1. Residential density → Residential density 2. Land use mix: access → Destinations/services (overall/unspecific) access/availability 3. Street connectivity → Street connectivity 4. Seeing and speaking with others when walking in the neighbourhood → Crime/personal safety 5. Loose or unattended dogs → Crime/personal safety			b=not reported, p>.05 (Residential density **0**) 2. Land use mix—access: b=not reported, p>.05 (Destinations/services (overall/unspecific) access/availability **0**) 3. Street connectivity: b=not reported, p>.05 (Street connectivity **0**) 4. Seeing and speaking with others when walking in the neighbourhood: b=not reported, p>.05 (Crime/personal safety **0**) 5. Loose or unattended dogs: b=not reported, p>.05 (Crime/personal safety **0**)	environmental construct that need to be summed.
9	BEPAS Seniors Van Cauwenberg et al., 2016 [267]	N=391 (urban) 65+ years; 54% women 45% response rate Community-dwellers Ghent, Belgium	Cross-sectional Cluster: purposive Individual: random Stratification: walkability and median household income Neighbourhood definition: statistical sectors (administrative/census area)	Age, sex, marital status, education, physical functioning, number of motorised vehicles in household, residential self-selection	*Objective [ActiGraph—validated; Freedson and Copeland MVPA cutoff points—validated]:* Freedson MVPA (mins/d) → Total MVPA *TotalMVPAFreedson(mins/d)* Copeland MVPA (mins/d) → Total MVPA *TotalMVPACopeland(mins/d)*	*Objective [GIS; unvalidated]:* 1. Walkability → Walkability	Area-level income: Low (n=189), High (n=202)	Multilevel linear regression accounting for clustering and moderating effects	***Moderating effect with TotalMVPAFreedson(mins/d):*** 1. Walkability*income (ref.=low)—OR (90% CIs): OR=-5.0 (-10.5; 0.6) p<.10 ***Moderating effect with Total MVPACopeland(mins/d):*** 1. Walkability*income (ref.=low): OR=-27.9 (-61.5; 5.7) p<.10 ***Moderated effect with TotalMVPAFreedson (mins/d):*** 1. Walkability—OR (95% CIs) (ref=high income): *Low income:* OR=5.6	Income effects.

									(1.6; 9.6) p<.01 (Walkability **+*0.48; 0*0.52**) ***Moderated effect with TotalMVPACopeland(mins/d):*** 1. Walkability: *Low income:* OR=27.2 (2.4; 52.0) p<.05 (Walkability **+*0.48; 0*0.52**)	
10	BEPAS Seniors Van Holle et al., 2016 [268]	N=438 (urban) 65+ years; 54% women 45% response rate Community-dwellers Ghent, Belgium	Cross-sectional Cluster: purposive Individual: random Stratification: walkability and median household income Neighbourhood definition: statistical sectors (administrative/census area)	Age, sex, living situation, education, neighbourhood income	*Objective [ActiGraph—validated; Freedson MVPA cutoff point; validated]:* Freedson MVPA (mins/wk) → Total MVPA *TotalMVPAFreedson(mins/wk)*	*Perceived [NEWS; validated]:* 1. Land use mix—diversity → Land-use mix—destination diversity 2. Access to recreational facilities → Recreational facilities access/availability 3. Connectivity → Street connectivity 4. Physical barriers to walking → No physical barriers to walking 5. Walking infrastructure → Walk-friendly infrastructure 6. Aesthetics → Greenery and aesthetically pleasing scenery 7. Safety from crime → Crime/personal safety 8. Safety traffic speeding → Traffic/pedestrian safety *Objective [GIS; unvalidated]:*	None	Multilevel linear regression accounting for clustering - squared root of outcome	***Main effects with TotalMVPAFreedson(mins/wk):*** 1. Land-use mix—diversity: b=1.38 (SE=0.45), p<.05 (Land-use mix—destination diversity **+**) 2. Access to recreational facilities: b=0.33 (SE=0.20), p>.05 (Recreational facilities access/availability **0**) 3. Connectivity: b=0.29 (SE=0.29), p>.05 (Street connectivity **0**) 4. Physical barriers to walking: b=0.18 (SE=0.5), p>.05 (No physical barriers to walking **0**) 5. Walking infrastructure: b=0.97 (SE=0.45), p<.05 (Walk-friendly infrastructure **+**) 6. Aesthetics: b=0.33 (SE=0.37), p>.05 (Greenery and aesthetically pleasing scenery **0**) 7. Safety from crime: b=0.37 (SE=0.34), p>.05 (Crime/personal safety	Supplementary Table 3. Walkability not extracted as reported in Van Holle et al., 2014.

						Note: Walkability not extracted as reported in Van Holle et al., 2014.			**0**) 8. Safety traffic speeding: b=0.23 (SE=0.23), p>.05 (Traffic/pedestrian safety **0**)	
11	British Regional Heart Study & British Women's Heart Health Study Jefferis et al., 2014 [357]	N=2426 (urban) 70+ years 35% female 29-51% response rate Community-dwellers *24 British towns,* United Kingdom	Cross-sectional Cluster: purposive Individuals: random Stratification: population size, representative of the region in terms of: cardiovascular mortality rates, water quality, socio-economic activity, high mobility towns (Lawlor, Bedford, Taylor, & Ebrahim, 2003; Walker, Whincup, & Shaper, 2004) Neighbourhood definition: participant delineation	Age, season, region, average monitor wear time	*Objective [ActiGraph accelerometer; validated; Copeland & Esliger MVPA cutoff point (>1040 counts/min; validated]:* MVPA (150+ mins/wk of 10+ min/bout; Yes/No) → Total MVPA *TotalMVPACopeland(150+ mins/wk; Yes/No)*	*Perceived [unnamed questionnaire; unvalidated]:* 1. Social and leisure activities → Social recreational facilities access/availability 2. Facilities for people your age → Destinations/services (overall/unspecific) access/availability 3. Local transport → Public transport access/availability 4. Somewhere nice to go for a walk → Destinations/services (overall/unspecific) access/availability 5. Feel safe walking alone in the daytime → Crime/personal safety 6. Feel safe walking alone after dark → Crime/personal safety	Sex: Males (n=1577), Female (n=849)	Multivariate logistic regression	***Main and moderated effects with TotalMVPACopeland(150+ mins/wk; Yes/No):*** Males: 1. Social and leisure activities—OR (95% CIs): *Males:* OR=1.48 (1.11; 1.97), p<.05 (Social recreational facilities access/availability **+*0.65**) *Females:* OR=1.54 (0.94; 2.52), p>.05 (Social recreational facilities access/availability **0*0.35**) 2. Facilities for people your age: *Males:* OR=1.25 (0.94; 1.66), p>.05 (Destinations/services (overall/unspecific) access/availability **0*0.65**) *Females:* OR=1.70 (1.01; 2.87), p>.05 (Destinations/services (overall/unspecific) access/availability **+*0.35**) 3. Local transport: *Males:* OR=1.04 (0.76; 1.42), p>.05 *Females:* OR=0.83 (0.49; 1.41), p>.05 (Public transport access/availability	Sex effects. Table 3 – Model 1.

										0*0.65; 0*0.35) 4. Somewhere nice to go for a walk: *Males:* OR=1.90 (1.20; 3.02), p<.05 (Destinations/services (overall/unspecific) access/availability **+*0.65**) *Females:* OR=1.91 (0.92; 3.98), p>.05 (Destinations/services (overall/unspecific) access/availability **0*0.35**) 5. Feel safe walking alone in the daytime: *Males:* OR=2.15 (0.76; 6.10), p>.05 *Females:* OR=2.50 (0.33; 19.07), p>.05 (Crime/personal safety **0*0.65; 0*0.35**) 6. Feel safe walking alone after dark: *Males:* OR=2.59 (1.77; 3.81), p<.05 *Females:* OR=2.81 (1.73; 4.54), p<.05 (Crime/personal safety **+*0.65; +*0.35**)	
12	Canada's General Social Survey Time Use Spinney & Millward 2014 [426]	1992: N=1992 (mixed) 1998: N=1889 (mixed) 2005: N=3589 (mixed) 2010: N=3639 (mixed) 65+ years 1992: 66% female 1998: 63% female 2005: 60% female	Cross-sectional at four time points Cluster: purposive Individuals: random Stratification: urbanisation Neighbourhood definition: census level	Age, sex, education, household income, activity limitation, living situation, season (logistic regression only)	*Self-report [General Social Survey Time Use questionnaire; unvalidated]:* MVPA (21+ mins/d; Yes/No) → Total MVPA *TotalMVPA(21+ mins/d; Yes/No)* *TotalMVPA(median mins/d)* MVPA (median mins/d) → Total MVPA	*Objective [census data; unvalidated]:* 1. Urbanisation → Urbanisation	None	Mann Whitney *U* test, multivariate logistic regression	***Main effects with TotalMVPA(21+ mins/d; Yes/No):*** 1. Urbanisation—OR (95% CIs): 1992: OR=1.452 (1.050; 2.009), p<.01 (Urbanisation -) 1998: OR=1.529 (1.088; 2.149), p<.05 (Urbanisation -) 2005: OR=1.091 (0.880; 1.352), p>.05 (Urbanisation **0**) 2010: OR=1.326 (1.091;	Table 2 and 3.

		2010: 59% female Response rates not reported Community-dwellers *10 provinces*, Canada			*TotalMVPA(median mins/d)*				1.612), p<.01 (Urbanisation -) ***Main effects with TotalMVPA(median mins/d):*** 1. Urbanisation (urban vs. rural): 1992: 75 mins vs. 120 mins, p=.001 (Urbanisation -) 1998: 90 mins vs. 120 mins, p=.175 (Urbanisation **0**) 2005: 105 mins vs. 120 mins, p=.042 (Urbanisation -) 2010: 100 mins vs. 120 mins, p=.001 (Urbanisation -)	
13	CCHS 2008/2009 Winters et al., 2015 [427]	N=1309 (urban) Mean age: 75 years 55% female 74% response rate Community-dwellers British Columbia, Canada	Cross-sectional Cluster: purposive Individuals: random Stratification: urbanisation (urban only) Neighbourhood definition: census metropolitan area	Age, sex, education, country of birth, mobility, fear of falls	*Self-report [CCHS questionnaire; unvalidated]:* Outdoor walking (150+ mins/wk; Yes/No) → Total walking *TotalWalking(150+ mins/wk; Yes/No*	*Objective [Street Smart Walk Score; validated]:* 1. Walkability → Walkability	None	Multivariate logistic regression	***Main effects with TotalWalking(150+ mins/wk; Yes/No):*** 1. Walkability—OR (95% CIs): OR=1.17 (1.07; 1.27), p<.05 (Walkability **+**)	Table 2—Adjusted.
14	CHIS 2003 data Li et al., 2015 [428]	N=965 (sub-sample; urban) 65+ years 56% female 60% response rate Community-dwellers California, USA	Cross-sectional Cluster: purposive Individuals: random Stratification: ethnicity (Asian) Neighbourhood definition: not defined	Age, sex, education, immigration status, marital status, poverty level, employment status, health conditions (asthma and heart disease), instrumental activities of daily living, BMI	*Self-report [CHIS questionnaire; unvalidated]:* Total walking (mins/wk) → Total walking *TotalWalking(mins/wk)* Total walking (non-walkers) → Total walking	*Perceived [CHIS questionnaire; unvalidated]:* 1. Nearby park/playground → Parks/public open space access/availability 2. Safe neighbourhood → Crime/personal safety	Ethnicity: Chinese (n=355), Filipino (n=173), Japanese (n=164), Korean (n=140), Vietnamese (n=133)	Zero-inflated negative binomial regression	***Main and moderated effects with TotalWalking(mins/wk):*** 1. Nearby park/playground (Ref: no)—IRR (95% CIs): *Chinese:* IRR=1.25 (1.03; 1.51), p<.05 (Parks/public open space access/availability **+*0.367**) *Filipino:* IRR=1.17 (0.74; 1.83), p>.05	Ethnicity effects. Table 3.

					TotalWalking(non-walkers; Yes/No)				(Parks/public open space access/availability **0*0.179**) *Japanese:* IRR=0.54 (0.31; 0.96), p<.05 (Parks/public open space access/availability **-*0.170**) *Korean:* IRR=1.99 (1.05; 2.77), p<.05 (Parks/public open space access/availability **+*0.145**) *Vietnamese:* IRR=1.39 (0.85; 2.28), p>.05 (Parks/public open space access/availability 0***0.139**) 2. Safe neighbourhood (Ref: no): *Chinese:* IRR=1.13 (0.94; 1.36), p>.05 (Crime/personal safety **0*0.367**) *Filipino:* IRR=1.99 (1.27; 3.12), p<.01 (Crime/personal safety **+*0.179**) *Japanese:* IRR=0.91 (0.51; 1.63), p>.05 (Crime/personal safety **0*0.170**) *Korean:* IRR=0.77 (0.49; 1.23), p>.05 (Crime/personal safety **0*0.145**) *Vietnamese:* IRR=0.78 (0.47; 1.30), p>.05 (Crime/personal safety **0*0.139**) ***Main effects with TotalWalking(non-walkers; Yes/No):*** 1. Nearby park/playground (Ref:	

										no): *Chinese:* OR=1.15 (95% CI=0.46; 2.88), p>.05 *Filipino:* OR=1.56 (95% CI=0.41; 5.90), p>.05 *Japanese:* IRR=0.96 (95% CI=0.30; 3.09), p>.05 *Korean:* OR=1.65 (95% CI=0.30; 9.16), p>.05 *Vietnamese:* OR=3.00 (95% CI=0.81; 11.19), p>.05 (Parks/public open space access/availability **0*0.367; 0*0.179; 0*0.170; 0*0.145; 0*0.139**) 2. Safe neighbourhood (Ref: no): *Chinese:* OR=0.95 (95% CI=0.46; 1.94), p>.05 *Filipino:* OR=0.60 (95% CI=0.17; 2.11), p>.05 *Japanese:* IRR=0.37 (95% CI=0.12; 1.13), p>.05 *Korean:* OR=3.59 (95% CI=0.55; 23.66), p>.05 *Vietnamese:* IRR=2.52 (95% CI=0.55; 11.60), p>.05 (Crime/personal safety **0*0.367; 0*0.179; 0*0.170; 0*0.145; 0*0.139**)	
15	CNDS Mendes de Leon et al., 2009 [429]	N=4317 (urban) Mean age: 75 years 61% female 78.9% response rate Community-dwellers Chicago, USA	Cross-sectional Cluster: convenience Individuals: all invited to participate Stratification: none Neighbourhood definition: census block	Age, sex, education, income, marital status, years of residence in the neighbourhood, medical condition, season	*Self-report [Health Interview Survey 1985; unvalidated]:* Total walking (mins/2 wks) → Total walking *TotalWalking(mins/2 wks)*	*Objective [unnamed questionnaire; unvalidated]:* 1. Neighbourhood-level disorder → Crime/personal safety	None	Multilevel linear regression accounting for clustering, square root transformation of outcome variable	***Main effects with TotalWalking(mins/2 wks):*** 1. Neighbourhood-level disorder: b=-2.78, p<.01 (Crime/personal safety +)	Table 2—Model 2.

16	DIY Streets Thompson et al., 2012 [430]	Pre-intervention: N=96 (urban) Post-intervention: N=61 (urban) Mean age: 74-77 years 51-65% female Response rate not reported England, Scotland, and Wales, United Kingdom	Intervention study Cluster: purposive Individuals: convenience Stratification: street wide enough + not a major route; comparison streets matched by housing type, street layout and SES Neighbourhood definition: not defined	Age, instrumental activities of daily living	*Self-report [unnamed questionnaire; unvalidated]:* Time spent outdoors → Total PA *TotalPA(duration)*	*Perceived [unnamed questionnaire; unvalidated]:* 1. Pleasant local open space → Parks/public open space 2. Barriers/nuisance in local open space and neighbourhood → Crime/personal safety 3. Bad footways/paths → Pavement/footpath quality 4. Easy to get out and about → No physical barriers to walking 5. Good paths and cycleways → Cycle/walk-friendly infrastructure	Intervention	Multivariate linear regression	***Main and intervention effects with TotalPA(duration):*** 1. Pleasant local open space: *Pre-intervention:* b=not reported, p>.05 *Post-intervention:* b=not reported, p>.05 (Parks/public open space access/availability **0*1**) 2. Barriers/nuisance in local open space and neighbourhood: *Pre-intervention:* b=not reported, p>.05 *Post-intervention:* b=-0.309, p<.05 (Crime/personal safety **+*1**) 3. Bad footways/paths: *Pre-intervention:* b=not reported, p>.05 *Post-intervention:* b=not reported, p>.05 (Pavement/footpath quality **0*1**) 4. Easy to get out and about: *Pre-intervention:* b=.228 (standardised b=.236), p<.05 *Post-intervention:* b=not reported, p>.05 (No physical barriers to walking **-*1**) 5. Good paths and cycleways: *Pre-intervention:* b=not reported, p>.05 *Post-intervention:* b=0.293, p<.05 (Cycle/Walk-friendly infrastructure **+*1**)	Intervention effects. Table 4.

17	Easy Steps to Health Merom et al., 2015 [358]	N=301 (urban) 65+ years 73% female Response rate not reported Community-dwellers Sydney, Australia	Cross-sectional (not an environmental intervention) Cluster: convenience Individuals: convenience Stratification: none Neighbourhood definition: 15-20mins walk from home	Age, sex, education, intervention, recurrent fallers, self-rated health, self-efficacy, fear of falling, unable to walk 30 min, *interaction term: pedestrian-orientated neighbourhood (walkability)*intervention*	*Self-report [Incidental and Planned Exercise Questionnaire; validated]:* Planned walking (2.5+ hr/wk; Yes/No) → Total walking *TotalWalking(2.5+ hr/wk; Yes/No)*	*Perceived [NEWS-AUS questionnaire; validated]:* 1. Many places to go within easy walking distance → Destinations/services (overall/unspecific) access/availability 2. Easy to walk to a public transport stop → Public transport access/availability 3. Footpaths on most of the streets → Walk-friendly infrastructure 4. Crosswalks and pedestrian signals → Traffic/pedestrian safety 5. Neighbourhood streets non-hilly → No physical barriers to walking 6. Walkers in neighbourhood easily seen → Crime/personal safety 7. Lots of greenery in local area → Greenery and aesthetically pleasing scenery 8. Many interesting things to look at → Greenery and aesthetically pleasing scenery 9. Not much traffic along nearby streets → Traffic/pedestrian safety 10. Local parks and walking trails → Parks/public open space	Fear of falling (n=310), Health status (n=315), Intervention group (n=145), Pedestrian-orientated neighbourhood (n=314)	Generalised linear models with binominal distribution	*No significant moderating effects.* ***Main effects with TotalWalking(2.5+ h/wk; Yes/No):*** 1. Many places to go within easy walking distance—OR (95% CIs): OR=0.65 (0.30; 1.40), p>.05 (Destinations/services (overall/unspecific) access/availability **0**) 2. Easy to walk to a public transport spot: OR=1.90 (0.63; 5.72), p>.05 (Public transport access/availability **0**) 3. Footpaths on most of the streets: OR=1.65 (0.74; 3.65), p>.05 (Walk-friendly infrastructure **0**) 4. Crosswalks and pedestrian signals: OR=0.93 (0.43; 2.04), p>.05 (Traffic/pedestrian safety **0**) 5. Neighbourhood streets non-hilly: OR=0.94 (0.38; 2.33), p>.05 (No physical barriers to walking **0**) 6. Walkers in neighbourhood easily seen: OR=1.03 (0.45; 2.31), p>.05 (Crime/personal safety **0**) 7. Lots of greenery in	Table 2–adjusted.

						access/availability 11. Crime rate → Crime/personal safety			local area: OR=3.33 (1.11; 9.98), p<.05 (Greenery and aesthetically pleasing scenery **+**) 8. Many interesting things to look at: OR=0.55 (0.21; 1.45), p>.05 (Greenery and aesthetically pleasing scenery **0**) 9. Not much traffic along nearby streets: OR=1.98 (1.00; 3.91), p<.05 (Traffic/pedestrian safety **+**) 10. Local parks and walking trails: OR=0.55 (0.22; 1.39), p>.05 (Parks/public open space access/availability **0**) 11. Crime rate: OR=0.30 (0.09; 1.05), p>.05 (Crime/personal safety **0**)	
18	EPOSA – Dutch trial Timmermans et al., 2016 [431]	N=247 (mixed) Mean age: 75 years 50% female 84.1% response rate Dwelling not reported Amsterdam, Netherlands	Cross-sectional Cluster: purposive Individuals: random (original study); convenience (data drawn from larger study) Stratification: region and urbanisation Neighbourhood definition: postal	Age, sex, education, partner status, urbanisation, body mass index, no. of chronic diseases other than lower limb osteoarthritis (LLOA), anxiety, depression, functional limitations, wear time of accelerometer, LLOA (Note. LLOA as a covariate was	*Objective [ActiGraph accelerometer—validated; Matthews MVPA cutoff point≥2020 cpm and LPA cutoff point>100 cpm—validated]:* Total PA mins/d → Total PA *TotalPA(mins/d)* MVPA mins/d → Total MVPA *TotalMVPAMatthews(mins/d)*	*Objective [ArcGIS, Statistics Netherlands, The Netherlands' Cadastre, Land Registry, Mapping Agency; unvalidated]:* 1. Street connectivity → Street connectivity 2. Distance to general practice → Health and aged care access/availability 3. Distance to general practice centre → Health and aged care	None	Multivariate linear regression	***Main effects with TotalPA(mins/d):*** 1. Street connectivity: b=0.08 (SE=0.05) p>.05 (Street connectivity **0**) 2. Distance to general practice: b=1.75 (SE=4.92) p>.05 (Health and aged care access/availability **0**) 3. Distance to general practice centre: b=0.49 (SE=1.15) p>.05 (Health and aged care access/availability **0**) 4. Distance to pharmacy:	Table 4—Model 2.

			code	not included in models for general practice, pharmacy, and supermarket due to an interaction effect between those destinations and PA)		access/availability 4. Distance to pharmacy → Health and aged care access/availability 5. Distance to hospital, with outside clinic → Access to/availability of Health and aged care access/availability 6. Distance to hospital, without outside clinic → Health and aged care access/availability 7. Distance to physiotherapist → Health and aged care access/availability 8. Distance to supermarket → Shops/commercial access/availability 9. Distance to grocery store → Shops/commercial access/availability 10. Distance to department store → Shops/commercial access/availability 11. Distance to pub → Social recreational facilities access/availability 12. Distance to cafeteria → Food outlets access/availability 13. Distance to restaurant → Food outlets access/availability 14. Distance to train station → Public transport access/availability			b=0.22 (SE=4.27) p>.05 (Health and aged care access/availability **0**) 5. Distance to hospital with outside clinic: b=-0.66 (SE=1.46) p>.05 (Health and aged care access/availability **0**) 6. Distance to hospital without outside clinic: b=0.47 (SE=1.13) p>.05 (Health and aged care access/availability **0**) 7. Distance to physiotherapist: b=0.52 (SE=6.27) p>.05 (Health and aged care access/availability **0**) 8. Distance to supermarket: b=1.60 (SE=4.66) p>.05 (Shops/commercial access/availability **0**) 9. Distance to grocery store: b=-0.95 (SE=3.26) p>.05 (Shops/commercial access/availability **0**) 10. Distance to department store: b=1.54 (SE=1.49) p>.05 (Shops/commercial access/availability **0**) 11. Distance to pub: b=-2.00 (SE=3.11) p>.05 (Social recreational facilities access/availability **0**) 12. Distance to cafeteria: b=0.28 (SE=5.46) p>.05 (Food outlets access/availability **0**) 13. Distance to restaurant: b=-8.71 (SE=7.57) p>.05 (Food outlets	

						15. Distance to important transfer station → Public transport access/availability			access/availability **0**) 14. Distance to public transport: b=-0.64 (SE=0.89) p>.05 (Public transport access/availability **0**) 15. Distance to important transfer station: b=0.62 (SE=0.59) p>.05 (Public transport access/availability **0**) ***Main effects with TotalMVPAMatthews(mins/d):*** 1. Street connectivity: b=0.01 (SE=0.02) p>.05 (Street connectivity **0**) 2. Distance to general practice: b=1.75 (SE=4.92) p>.05 (Health and aged care access/availability **0**) 3. Distance to general practice centre: b=-0.10 (SE=0.35) p>.05 (Health and aged care access/availability **0**) 4. Distance to pharmacy: b=0.51 (SE=1.30) p>.05 (Health and aged care access/availability **0**) 5. Distance to hospital with outside clinic: b=0.28 (SE=0.44) p>.05 (Health and aged care access/availability **0**) 6. Distance to hospital without outside clinic: b=-0.11 (SE=0.34) p>.05 (Health and aged care access/availability **0**) 7. Distance to physiotherapist: b=-3.32 (SE=1.90) p>.05	

									(Health and aged care access/availability **0**) 8. Distance to supermarket: b=0.87 (SE=1.42) p>.05 (Shops/commercial access/availability **0**) 9. Distance to grocery store: b=1.18 (SE=0.98) p>.05 (Shops/commercial access/availability **0**) 10. Distance to department store: b=-0.19 (SE=0.45) p>.05 (Shops/commercial access/availability **0**) 11. Distance to pub: b=0.48 (SE=0.95) p>.05 (Social recreational facilities access/availability **0**) 12. Distance to cafeteria: b=-0.87 (SE=1.66) p>.05 (Food outlets access/availability **0**) 13. Distance to restaurant: b=-4.96 (SE=2.29) p>.05 (Food outlets access/availability **0**) 14. Distance to public transport: b=0.30 (SE=0.27) p>.05 (Public transport access/availability **0**) 15. Distance to important transfer station: b=0.62 (SE=0.59) p>.05 (Public transport access/availability **0**)	
19	Great Britain older adults 1 (name assigned)	N=264 (mixed) 65+ years 57% female 10% response	Cross-sectional Cluster: purposive Individuals:	None	*Self-report [unnamed questionnaire; unvalidated]:*	*Perceived [unnamed questionnaire; unvalidated]:*	Urbanisation: Urban (n=205), Rural (n=59)	Chi-square test	***Main effect with TotalWalking(2.5+ hrs/wk; Yes/No):*** 1. Living in an	In-text, Section 2.3: sentence beginning

	Sugiyama & Ward Thompson 2007 [432]	rate England, Scotland, and Wales, United Kingdom	random Stratification: urbanisation, SES, functional status, living arrangements and cultural background Neighbourhood definition: local authority		Summer and Winter outdoor walking (2.5+ hrs/wk; Yes/No) → Total Walking *TotalWalking(2.5+ hrs/wk; Yes/No)*	1. Living in an urban/rural area → Urbanisation			urban/rural area: X^2=not reported, p>.05 (Urbanisation **0**)	"Ethnicity and living in urban or rural…"
20	Great Britain older adults 1 (name assigned) Sugiyama et al., 2009 [433]	N=271 (mixed) 65+ years 60% female 14% response rate England, Scotland, and Wales, United Kingdom	Cross-sectional Cluster: purposive Individuals: random Stratification: urbanisation, SES, functional status, living arrangements and cultural background Neighbourhood definition: participant delineation	Age, education, physical function	*Self-report [unnamed questionnaire; unvalidated]:* Summer and Winter outdoor walking (2.5+ hrs/wk; Yes/No) → Total Walking *TotalWalking(2.5+ hrs/wk; Yes/No)*	*Perceived [unnamed questionnaire; unvalidated]:* 1. Pleasantness of neighbourhood open space → Greenery and aesthetically pleasing scenery 2. Nuisance in neighbourhood open space → Crime/personal safety 3. Quality of paths to neighbourhood open space → Pavement/footpath quality 4. Distance to neighbourhood open space → Parks/public open space access/availability	None	Multivariate logistic regression	***Main effects with TotalWalking(2.5+ hrs/wk; Yes/No):*** 1. Pleasantness of neighbourhood open space (Ref: Low): High: OR=1.68 (95% CI=0.87; 3.23), p>.05 (Greenery and aesthetically pleasing scenery **0**) 2. Nuisance in neighbourhood open space (Ref: High): Low: OR=1.18 (95% CI=0.62; 2.24), p>.05 (Crime/personal safety **0**) 3. Quality of paths to neighbourhood open space (Ref: Low): High: OR=1.96 (95% CI=1.03; 3.74), p<.05 (Pavement/footpath quality **+**) 4. Distance to neighbourhood open space (Ref:>10 mins walk away): Within 10 mins walk: OR=1.61 (95% CI=0.85; 3.07), p>.05 (Parks/public open space access/availability **0**)	Table 3.

21	HAN Walking Study Satariano et al., 2010 [359]	N=884 (mixed) 65+ years 77% female Response rate not reported Community-dwellers California, Pennsylvania, Illinois, and North Carolina, USA	Cross-sectional Cluster: purposive Individuals: random Stratification: residential density Neighbourhood definition: 15-20mins walk from home (perceived); 400m buffer (objective)	Age, sex, education, study site, race, income, lower-body function, and drive/access to a driver	*Self-report [unnamed questionnaire; unvalidated]:* Total walking (<150 mins/wk; Yes/No) → Total walking *TotalWalking(<150 mins/wk; Yes/No)*	*Objective [GIS—census data, RAND Center for Population Health and Health Disparities; unvalidated]:* 1. Street connectivity → Street connectivity 2. Housing unit density → Residential density 3. Number of retail businesses within the buffer → Shops/commercial access/availability 4. Primary type of buildings in neighbourhood → Land-use mix—destination diversity *Perceived [NEWS questionnaire; validated]:* 5. Residential density → Residential density 6. Land-use mix: access → Destinations/services (overall/unspecific) access/availability 7. Land-use mix: diversity → Land-use mix—destination diversity 8. Street connectivity → Street connectivity 9. Walking/cycling facilities → Cycle/walk-friendly infrastructure 10. Aesthetics → Greenery and aesthetically pleasing scenery 11.	Physical function**all environmental exposure variables*	Generalised logistic estimating equation	*No significant moderating effect for* physical function*crime safety: OR=2.31 (95% CI=1.22; 4.38), p=.12 Significant moderating effect for physical function*housing unit density: OR=2.35 (95% CI=1.06; 5.21), p=.06 ***Main and moderated effects with TotalWalking(<150 mins/wk; Yes/No):*** 1. Street connectivity + 8. Street connectivity: *Objective (#1):* OR=not reported, p>.05 *Perceived (#8):* OR=not reported, p>.05 (Street connectivity **0*1; 0*1**) 2. Housing unit density + 5. Residential density: *Objective (#2):* OR=not reported, p>.05 (Residential density **0*0.25; 0*0.75**) *Perceived (#5):* OR=not reported, p>.05 (Residential density **0*1**) 3. Number of retail businesses: *Objective:* OR=not reported, p>.05 (Shops/commercial access/availability **0**) 4. Primary type of buildings in neighbourhood (Ref: Commercial or a mix of residential and commercial) + 7. Land-	Moderating effects. Table 2–adjusted models.

						Pedestrian/automobile traffic safety → Traffic/pedestrian safety 12. Crime safety → Crime/personal safety			use mix—destination diversity: *Objective (#4):* Residential: OR=1.54 (95% CI=1.05; 2.25), p=.03 (Land-use mix—destination diversity **+**) *Perceived (#7):* OR=not reported, p>.05 (Land-use mix—destination diversity **0**) 6. Land-use mix: access: *Perceived:* OR=not reported, p>.05 (Destinations/services (overall/unspecific) access/availability **0**) 9. Walking/cycling facilities: *Perceived:* OR=not reported, p>.05 (Cycle/Walk-friendly infrastructure **0**) 10. Aesthetics: *Perceived:* OR=not reported, p>.05 (Greenery and aesthetically pleasing scenery **0**) 11. Pedestrian/automobile traffic safety: *Perceived:* OR=not reported, p>.05 (Traffic/pedestrian safety **0**) 12. Crime safety (Ref: Feel safe from crime in neighbourhood): *Perceived:* Feel somewhat safe: OR=1.53 (95% CI=1.04; 2.25), Feel unsafe: OR=1.51 (95% CI=1.04; 2.25), p=.04	

									(Crime/personal safety +)	
22	Harvard Alumni Study Lee et al., 2009 [333]	Cross-sectional: 1988: N=4918 1993: N=4997 (likely mixed/not reported) Longitudinal: (N=3448) (likely mixed/not reported) Mean age: 70 years 0% female 71% response rate Community-dwellers *Multiple locations,* USA	Cross-sectional at two time-points and longitudinal Cluster: convenience Individuals: not reported Stratification: none Neighbourhood definition: county level	Age, smoking	*Self-report [HAHS questionnaire; validated]:* Total PA (30+ mins/d*5 d/wk; Yes/No) → Total PA *TotalPA(30+ mins/d*5d/wk; Yes/No)* Total walking (30+ mins/d*5 d/wk; Yes/No) → Total walking *TotalWalking(30+ mins/d*5 d/wk; Yes/No)* Total PA change (kcal/wk) (longitudinal) → Total PA *TotalPAChange(kcal/wk)* Mean distance walked (miles/wk) (longitudinal) → Total walking *TotalWalkingChange(kcal/wk)*	*Objective [Sprawl Index; unvalidated]:* 1. Urban sprawl → Urbanisation	None	Multivariate logistic regression	***Moderated effects with TotalPA(30+ mins/d*5d/wk; Yes/No):*** Cross-sectional: 1. 1988: Urban sprawl (Ref: high sprawl, n=497)—OR (95% CIs): Medium sprawl (n=3042): OR=0.93 (0.75; 1.14), Low sprawl (n=1379): OR=1.15 (0.92; 1.45), p=.01 (Urbanisation **0*0.10; 0*0.62; 0*0.28**) 1. 1993: Urban sprawl (Ref: high sprawl, n=551): Medium sprawl (n=3126): OR=1.02 (95% CI=0.84; 1.25), Low sprawl (n=1320): OR=1.10 (95% CI=0.88; 1.37), p=.30 (Urbanisation **0*0.11; 0*0.63; 0*0.26**) ***Main effects with TotalWalking(30+ mins/d*5d/wk; Yes/No):*** 1. 1988: Urban sprawl (Ref: high sprawl, n=497)—OR (95% CIs): Medium sprawl (n=3042): OR=1.01 (0.80; 1.28), Low sprawl (n=1379): OR=1.53 (1.19; 1.96), p<.001 (Urbanisation **+*0.10; +*0.62; +*0.28**) 1. 1993: Urban sprawl	Cross-sectional results: Table 2. Longitudinal results: Table 3.

									(Ref: high sprawl, n=551): Medium sprawl (n=3126): OR=1.02 (0.81; 1.27), Low sprawl (n=1320): OR=1.38 (1.09; 1.76), p<.001 (Urbanisation **+*0.11; +*0.63; +*0.26**) ***Main effects with TotalPAChange(kcal/wk):*** Longitudinal: 1. Urban sprawl: Moved to more sprawling country (n=135): 230 (208), P>.05 (Urbanisation **0*0.04**) Remained at same sprawl (n=3240): -76 (42), P>.05 (Urbanisation **0*0.94**) Remained at same sprawl (n=73): -157 (283), P>.05 (Urbanisation **0*0.02**) ***Main effects with TotalWalkingChange(miles/wk):*** Longitudinal: 1. Urban sprawl: Moved to more sprawling country (n=135): 0.08 (0.5), P>.05 (Urbanisation **0*0.04**) Remained at same sprawl (n=3240): 0.03 (0.1), P>.05 (Urbanisation **0*0.94**) Remained at same sprawl (n=73):	

									-0.6 (0.7), P>.05 (Urbanisation **0*0.02**)	
23	Health and Retirement study Latham et al., 2015 [434]	N=5922 (mixed) Mean age: 70 years 67% female 71% response rate Community-dwellers *Multiple locations,* USA	Cross-sectional Cluster: purposive Individuals: random (original study); convenience Stratification: age Neighbourhood definition: 20mins walk from home	Age, sex, socioeconomic status (included education), race/ethnicity, married/partner status	*Self-report [unnamed questionnaire; unvalidated]:* Frequency of PA (score index) → Total PA *TotalPA(score)*	*Perceived [adapted from Project on Human Development in Chicago Neighbourhoods; reliable]:* 1. Physical disorder, comprising a) vandalism/graffiti, b) rubbish/litter, c) vacant/deserted homes, and d) crime → Crime/personal safety	None	Ordinary least squares regression *Note. PA outcome given intensity weights, however, these produced small estimates and increased skewness – therefore, scaled weights were used which improved model fit (specific data not reported).*	***Main effect with TotalPA(score):*** 1. Physical disorder: b=-0.07 (SE=0.03), p>.05 (Crime/personal safety **0**)	Table 4—Model 7.
24	Health and Wellbeing Surveillance System Nathan et al., 2012 [355]	N=2918 (mixed) 65+ years 56% female 80-84% response rates Community-dwellers Western Australia, Australia	Cross-sectional Cluster: none Individuals: random Stratification: urbanisation and health service area Neighbourhood definition: 400m and 800m buffers	Age, sex, education, marital status, self-rated health, use of assistive equipment	*Self-report [Active Australia Survey; validated]:* Walking (150+ mins/wk; Yes/No) → Total walking *TotalWalking(150+ mins/wk; Yes/No)* Walking (some; Yes/No) → Total walking *TotalWalking(some; Yes/No)*	*Objective [GIS; Sensis Pty. Ltd. Data—Australian Yellow Pages; unvalidated]:* 1. Food retail → Food outlets access/availability 2. General retail → Shops/commercial access/availability 3. Medical care services → Health and aged care access/availability 4. Financial services →	Sex: Male (n=1287), Female (n=1631)	Multivariate logistic regression	*No significant moderating effects.* ***Main effects with TotalWalking(some; Yes/No):*** 1. Food retail—OR (95% CIs): *400m:* OR=1.05 (0.84; 1.30), p=.676 *800m:* OR=0.98 (0.83; 1.15), p=.767 (Food outlets access/availability **0*0.5; 0*0.5**) 2. General retail:	Buffer effects. Table 3 and 4.

						Government/finance services access/availability 5. General services → General services access/availability 6. Social infrastructure → Social recreational facilities access/availability 7. Destination mix → Land-use mix—destination diversity			*400m:* OR=1.00 (0.77; 1.29), p=.979 *800m:* OR=1.00 (0.85; 1.18), p=.996 (Shops/commercial access/availability **0*0.5; 0*0.5**) 3. Medical care services: *400m:* OR=0.96 (0.80; 1.15), p=.653 *800m:* OR=1.01 (0.85; 1.20), p=.893 (Health and aged care access/availability **0*0.5; 0*0.5**) 4. Financial services: *400m:* OR=1.10 (0.71; 1.70), p=.675 *800m:* OR=0.93 (0.75; 1.15), p=.507 (Government/finance services access/availability **0*0.5; 0*0.5**) 5. General services: *400m:* OR=1.33 (1.07; 1.66), p=.011 *800m:* OR=1.20 (1.02; 1.42), p=.027 (Destinations/services (overall/unspecific) access/availability **+*0.5; +*0.5**) 6. Social infrastructure: *400m:* OR=1.02 (0.83; 1.24), p=.884 (Social recreational access/availability **0*0.5**) *800m:* OR=1.19 (1.01; 1.40), p=.043 (Social recreational access/availability **+*0.5**) 7. Destination mix: *400m:* OR=1.02 (0.97; 1.08), p=.473 *800m:* OR=1.02 (0.98;	

									1.06), p=.473 (Land-use mix—destination diversity **0*0.5; 0*0.5**) ***Main effects with TotalWalking(150+ mins/wk; Yes/No):*** 1. Food retail: *400m:* OR=0.86 (0.69; 1.08), p=.188 *800m:* OR=0.87 (0.74; 1.03), p=.109 (Food outlets access/availability **0*0.5; 0*0.5**) 2. General retail: *400m:* OR=0.80 (0.62; 1.05), p=.107 *800m:* OR=0.90 (0.76; 1.07), p=.248 (Shops/commercial access/availability **0*0.5; 0*0.5**) 3. Medical care services: *400m:* OR=0.76 (0.63; 0.92), p=.005 *800m:* OR=0.83 (0.70; 0.99), p=.036 (Health and aged care access/availability **-*0.5; -*0.5**) 4. Financial services: *400m:* OR=0.85 (0.55; 1.33), p=.480 *800m:* OR=0.96 (0.77; 1.20), p=.738 (Government/finance services access/availability **0*0.5; 0*0.5**) 5. General services: *400m:* OR=1.00 (0.81; 1.24), p=.971 *800m:* OR=1.06 (0.89; 1.25), p=.526	

									(General services access/availability **0*0.5; 0*0.5**) 6. Social infrastructure: *400m:* OR=1.02 (0.83; 1.24), p=.861 *800m:* OR=0.90 (0.76; 1.06), p=.194 (Social recreational access/availability **0*0.5; 0*0.5**) 7. Destination mix: *400m:* OR=0.96 (0.90; 1.01), p=.124 *800m:* OR=0.97 (0.94; 1.01), p=.178 (Land-use mix—destination diversity **0*0.5; 0*0.5**)	
25	Health and Wellbeing Surveillance System Villanueva et al., 2014 [435]	n=3611 (sub-sample; mixed) 65+ years 56% female 80-84% response rates Community-dwellers Western Australia, Australia	Cross-sectional Cluster: none Individuals: random Stratification: urbanisation and health service area Neighbourhood definition: 200m, 400m, 800m, and 1600m buffers	Age, sex, education, area-level SES	*Self-report [Active Australia Survey; validated]:* Walking (>0 mins/wk; Yes/No) → Total walking *TotalWalking(>0 mins/wk; Yes/No)*	*Objective [ArcGIS; adapted version of Frank et al.'s walkability index; unvalidated]:* 1. Walkability → Walkability	None	Binary logistic regression	***Main effects with TotalWalking(>0mins/wk; Yes/No):*** 1. Walkability—OR (95% CIs): 200m: OR=1.06 (1.02; 1.11), p=.008 400m: OR=1.08 (1.03; 1.13), p=.001 800m: OR=1.07 (1.02; 1.11), p=.003 1600m: OR=1.08 (1.04; 1.13), p<.001 (Walkability **+*0.25; +*0.25; +*0.25; +*0.25**)	Table 2.
26	Hong Kong Elderly Study Cerin et al., 2013 [376]	N=484 (urban) 65+ years 58% female 78% response rate Community-dwellers Hong Kong, China	Cross-sectional Cluster: purposive Individuals: random Stratification: walkability and SES Neighbourhood definition: 10-15mins walk from home	Age, sex, education	*Self-report [Neighbourhood Walkability Questionnaire-Chinese Seniors version; validated]:* Within-neighbourhood walking (mins/wk) → Total walking *TotalWalking(mins/wk)*	*Objective [Environment in Asia Scan Tool—Hong Kong version; reliability-tested]:* 1. Stray animals → Crime/personal safety 2. Street lights → Street lighting 3. Signs of crime → Crime/personal safety 4. Pedestrian safety →	None	Zero-inflated negative binomial regression models accounting for clustering and positive skewness of within-	***Main effects with TotalWalking(mins/wk):*** 1. Stray animals—e (95% CIs): e=0.985 (0.970; 0.999), p<.05 (Crime/personal safety +) 2. Street lights: e=1.005 (1.002; 1.008), p<.001 (Street lighting +)	Table 3.

					Within-neighbourhood walking (mins/wk; odds of being a walker) → Total walking *TotalWalking(Non-WalkerOdds; Yes/No)*	Traffic/pedestrian safety 5. Traffic hazards → Traffic/pedestrian safety 6. Good path conditions → Pavement/footpath quality 7. Physical barriers to walking → No physical barriers to walking 8. Public facilities → Walk-friendly infrastructure 9. Indoor covered places for walking → Walk-friendly infrastructure 10. Natural sites → Greenery and aesthetically pleasing scenery 11. Trees → Greenery and aesthetically pleasing scenery 12. Park → Parks/public open space access/availability 13. Building attractiveness → Greenery and aesthetically pleasing scenery 14. Litter → Greenery and aesthetically pleasing scenery 15. Recreational facilities other than parks → Recreational facilities access/availability 16. Perceptible pollution → Pollution		neighbourh ood walking	3. Signs of crime: e=1.040 (1.017; 1.063), p<.001 (Crime/personal safety -) 4. Pedestrian safety: e=not reported, p>.05 (Traffic/pedestrian safety **0**) 5. Traffic hazards: e=not reported, p>.05 (Traffic/pedestrian safety **0**) 6. Good path conditions: e=not reported, p>.05 (Pavement/footpath quality **0**) 7. Physical barriers to walking: e=not reported, p>.05 (No physical barriers to walking **0**) 8. Public facilities: e=not reported, p>.05 (Walk-friendly infrastructure **0**) 9. Indoor covered places for walking: e=not reported, p>.05 (Walk-friendly infrastructure **0**) 10. Natural sites: e=not reported, p>.05 (Greenery and aesthetically pleasing scenery **0**) 11. Trees: e=not reported, p>.05 (Greenery and aesthetically pleasing scenery **0**) 12. Park: e=not reported, p>.05 (Parks/public open space access/availability **0**) 13. Building attractiveness:	

										e=not reported, p>.05 (Greenery and aesthetically pleasing scenery **0**) 14. Litter: e=not reported, p>.05 (Greenery and aesthetically pleasing scenery **0**) 15. Recreational facilities other than parks: e=not reported, p>.05 (Recreational facilities access/availability **0**) 16. Perceptible pollution: e=not reported, p>.05 (Pollution **0**) ***Main effects with TotalWalking(Non-WalkerOdds; Yes/No):*** 1. Stray animals: e=1.055 (1.000; 1.067), p<.05 (Crime/personal safety **+**) 2. Street lights: e=not reported, p>.05 (Street lighting **0**) 3. Signs of crime: e=0.774 (0.682; 0.878), p<.001 (Crime/personal safety **-**) 4. Pedestrian safety: e=not reported, p>.05 (Traffic/pedestrian safety **0**) 5. Traffic hazards: e=not reported, p>.05 (Traffic/pedestrian safety **0**) 6. Good path conditions: e=0.940 (0.894; 0.987), p<.05 (Pavement/footpath quality **+**)	

									7. Physical barriers to walking: e=1.037 (1.010; 1.064), p<.01 (No physical barriers to walking **+**) 8. Public facilities: e=not reported, p>.05 (Walk-friendly infrastructure **0**) 9. Indoor covered places for walking: e=not reported, p>.05 (Walk-friendly infrastructure **0**) 10. Natural sites: e=not reported, p>.05 (Greenery and aesthetically pleasing scenery **0**) 11. Trees: e=not reported, p>.05 (Greenery and aesthetically pleasing scenery **0**) 12. Park: e=not reported, p>.05 (Parks/public open space access/availability **0**) 13. Building attractiveness: e=not reported, p>.05 (Greenery and aesthetically pleasing scenery **0**) 14. Litter: e=not reported, p>.05 (Greenery and aesthetically pleasing scenery **0**) 15. Recreational facilities other than parks: e=not reported, p>.05 (Recreational facilities access/availability **0**) 16. Perceptible pollution:	

									e=not reported, p>.05 (Pollution **0**)	
27	Kasama Study Tsunoda et al., 2012 [347]	N=421 (mixed) 65+ years 52.5% female 20.9% response rate Community-dwellers Kasama City and a rural region in Ibaraki Prefecture, Japan	Cross-sectional Cluster: none Individuals: random Stratification: none Neighbourhood definition: 10-15mins walk from home	Age, sex, education, work status, clinical histories: heart disease, stroke, low back disease, knee disease, hip disease	*Self-report [PASE questionnaire—Japanese version; validated]:* Walking (60+ mins/wk; Yes/No) → Total walking *TotalWalking(60+ mins/wk; Yes/No)* Walking (150+ mins/wk; Yes/No) → Total walking *TotalWalking(150+ mins/wk; Yes/No)*	*Perceived [IPAQ—Japanese version; validated]:* 1. Residential density → Residential density 2. Access to shops → Shops/commercial access/availability 3. Access to public transport → Public transport access/availability 4. Access to recreational facilities → Recreational facilities access/availability 5. Presence of sidewalks → Walk-friendly infrastructure 6. Presence of bike lanes → Cycle-friendly infrastructure 7. Traffic safety → Traffic/pedestrian safety 8. Crime safety → Crime/personal safety 9. Presence of hills → No physical barriers to walking 10. Seeing people exercise → Crime/personal safety 11. Aesthetics → Greenery and aesthetically pleasing scenery	None	Multivariate logistic regression. Continuous environmental exposure variables categorised.	***Main effects with TotalWalking(60+ mins/wk; Yes/No):*** 1. Residential density (Reference: high)—OR (95% CIs): Low: OR=0.96 (0.43; 2.16), p>.05 (Residential density **0**) 2. Access to shops (Reference: poor): Good: OR=1.02 (0.65; 1.60), p>.05 (Shops/commercial access/availability **0**) 3. Access to public transport (Reference: poor): Good: OR=0.78 (0.48; 1.24), p>.05 (Public transport access/availability **0**) 4. Access to recreational facilities (Reference: poor): Good: OR=1.15 (0.74; 1.81), p>.05 (Recreational facilities access/availability **0**) 5. Presence of sidewalks (Reference: no): Yes: OR=0.72 (0.44; 1.18), p>.05 (Walk-friendly infrastructure **0**) 6. Presence of bike lanes (Reference: no): Yes: OR=0.97 (0.62; 1.53), p>.05 (Cycle-friendly infrastructure **0**) 7. Traffic safety (Reference: not safe): Safe: OR=1.64 (1.03;	Table 3.

									2.60), p<.05 (Traffic/pedestrian safety **+**) 8. Crime safety (Reference: not safe): Safe: OR=0.69 (0.41; 1.15), p>.05 (Crime/personal safety **0**) 9. Presence of hills (Reference: yes): No: OR=1.44 (0.77; 2.69), p>.05 (No physical barriers to walking **0**) 10. Seeing people exercise (Reference: no): Yes: OR=0.89 (0.49; 1.60), p>.05 (Crime/personal safety **0**) 11. Aesthetics (Reference: poor): Good: OR=2.12 (1.34; 3.36), p<.05 (Greenery and aesthetically pleasing scenery **+**) ***Main effects with TotalWalking(150+ mins/wk; Yes/No):*** 1. Residential density (Reference: high): Low: OR=0.82 (0.39; 1.72), p>.05 (Residential density **0**) 2. Access to shops (Reference: poor): Good: OR=0.67 (0.45; 1.02), p>.05 (Shops/commercial access/availability **0**) 3. Access to public transport (Reference: poor):	

									Good: OR=0.64 (0.42; 0.98), p<.05 (Public transport access/availability -) 4. Access to recreational facilities (Reference: poor): Good: OR=1.20 (0.80; 1.80), p>.05 (Recreational facilities access/availability **0**) 5. Presence of sidewalks (Reference: no): Yes: OR=0.73 (0.48; 1.13), p>.05 (Walk-friendly infrastructure **0**) 6. Presence of bike lanes (Reference: no): Yes: OR=0.95 (0.63; 1.43), p>.05 (Cycle-friendly infrastructure **0**) 7. Traffic safety (Reference: not safe): Safe: OR=1.46 (0.96; 2.21), p>.05 (Traffic/pedestrian safety **0**) 8. Crime safety (Reference: not safe): Safe: OR=0.94 (0.60; 1.48), p>.05 (Crime/personal safety **0**) 9. Presence of hills (Reference: yes): No: OR=1.12 (0.63; 2.02), p>.05 (No physical barriers to walking **0**) 10. Seeing people exercise (Reference: no): Yes: OR = 1.04 (0.62; 1.76), p>.05 (Crime/personal safety	

									0) 11. Aesthetics (Reference: poor): Good: OR=2.00 (1.33; 3.02), p<.05 (Greenery and aesthetically pleasing scenery **+**)	
28	KNHANES 2007/2008 Yeom et al., 2011 [436]	N=2241 (mixed) 65+ years 60% female 97.7% response rate Community-dwellers *Multiple locations,* South Korea	Cross-sectional at two time points Cluster: purposive Individuals: purposive Stratification: age and 20 households from 192 regions selected Neighbourhood definition: province level	None	*Self-report [World Health Organization's IPAQ; validated]:* MPA (mins/wk) → Total MVPA *TotalMVPA(mins/wk)* Walking (mins/wk) → Total walking *TotalWalking(mins/wk)*	*Objective [GIS—Korean Government data; unvalidated]:* 1. Living in metropolitan cities → Urbanisation	None	Chi-square test	***Main effect with TotalMVPA(mins/wk):*** 1. Urbanisation: X^2=7.8, p=.005 (Urbanisation **-**) ***Main effect with TotalWalking(mins/wk):*** 1. Urbanisation: X^2=0.9, p=.346 (Urbanisation **0**)	Table 3.
29	LL-FDI study Morris et al., 2008 [437]	n=136 (sub-sample) (mixed) Mean age: 69.6 years 100% female 51.4% response rate Community-dwellers *Undisclosed location,* USA	Cross-sectional Cluster: convenience Individuals: purposive Stratification: sex and multiple sclerosis diagnosis (related to a different sub-sample than this older women cohort) Neighbourhood definition: 10-15mins walk from home	None	*Objective [ActiGraph accelerometer; validated]:* Mean accelerometer counts/d → Total PA *TotalPA(counts/d)*	*Perceived [NEWS questionnaire; validated]:* 1. Residential density → Residential density 2. Land-use mix—diversity → Land-use mix—diversity 3. Access to services → Destinations/services (overall/unspecific) access/availability 4. Street connectivity → Street connectivity 5. Walking/cycling facilities → Cycle/walk-friendly infrastructure 6. Aesthetics → Greenery and aesthetically pleasing scenery 7. Safety from traffic →	None	Pearson's correlation	***Main effects with TotalPA(counts/d):*** 1. Residential density: r=.05, p>.05 (Residential density **0**) 2. Land-use mix—diversity: r=.04, p>.05 (Land-use mix—destination diversity **0**) 3. Access to services: r=.08, p>.05 (Destinations/services (overall/unspecific) access/availability **0**) 4. Street connectivity: r=.25, p<.01 (Street connectivity **+**) 5. Walking/cycling facilities: r=.21, p<.05 (Cycling/Walk-friendly infrastructure **+**)	Table 3. *Note.* Pearson's correlation results were retained vs. multiple regression because the latter did not adjust for key sociodemographics

						Traffic/pedestrian safety 8. Safety from crime safety → Crime/personal safety			6. Aesthetics: r=.21, p<.05 (Greenery and aesthetically pleasing scenery **+**) 7. Safety from traffic: r=.11, p>.05 (Traffic/pedestrian safety **0**) 8. Safety from crime: r=.00, p>.05 (Crime/personal safety **0**)	
30	LL-FDI study Hall & McAuley, 2010 [438]	n=128 (sub-sample) (mixed) Mean age: 70 years 100% female 51.4% response rate Community-dwellers *Undisclosed location,* USA	Cross-sectional Cluster: none Individuals: convenience Stratification: sex and multiple sclerosis diagnosis (related to a different sub-sample than this older women cohort) Neighbourhood definition: 10-15mins walk from home (perceived); 1km buffer (objective)	None	*Objective [ActiGraph accelerometer; validated]:* Steps/d → Total walking *TotalWalking(steps/d)*	*Objective [GIS; unvalidated]:* 1. Number of schools → Education facilities access/availability 2. Number of parks → Parks/public open space access/availability 3. Number of walking paths → Walk-friendly infrastructure 4. Number of exercise/gym facilities → Recreational facilities access/availability 5. Number of recreation areas → Recreational facilities access/availability *Perceived [NEWS questionnaire; validated]:* 6. Residential density → Residential density 7. Land-use mix: access → Destinations/services (overall/unspecific)	None	MANOVA	***Main effects with TotalWalking(steps/d):*** Objective environment: 1. Number of schools: <10,000 steps/d (1.57±2.00) vs. 10,000+ steps/d (1.66±1.95), f=0.05, p=.83 (Education facilities access/availability **0**) 2. Number of parks: <10,000 steps/d (2.53±2.55) vs. 10,000+ steps/d (3.29±2.81), f=2.13, p=.15 (Parks/public open space access/availability **0**) 3. Number of walking paths: <10,000 steps/d (1.18±1.40) vs. 10,000+ steps/d (1.89±1.62), f=5.88, p=.02 (Walk-friendly infrastructure **+**) 4. Number of exercise/gym facilities: <10,000 steps/d (0.35±0.67) vs. 10,000+ steps/d (0.43±0.74), f=0.29, p=.59 (Recreational facilities access/availability **0**)	Table 2.

						access/availability 8. Land-use mix: diversity → Land-use mix—destination diversity 9. Street connectivity → Street connectivity 10. Walking/cycling facilities → Cycle/walk facilities/infrastructure 11. Aesthetics → Greenery and aesthetically pleasing scenery 12. Pedestrian safety from traffic → Traffic/pedestrian safety 13. Safety from crime → Crime/personal safety			5. Number of exercise/gym facilities: <10,000 steps/d (0.35±0.67) vs. 10,000+ steps/d (0.43±0.74), f=0.0029, p=.90 (Recreational facilities access/availability **0**) Perceived environment: 6. Residential density: <10,000 steps/d (187.48±22.33) vs. 10,000+ steps/d (193.06±39.22), f=1.01, p=.32 (Residential density **0**) 7. Land-use mix – access: <10,000 steps/d (2.53±0.59) vs. 10,000+ steps/d (2.66±0.63), f=1.18, p=.28 (Destinations/services (overall/unspecific) access/availability **0**) 8. Land-use mix – diversity: <10,000 steps/d (2.84±1.08) vs. 10,000+ steps/d (2.82±0.99), f=0.01, p=.93 (Land-use mix—destination diversity **0**) 9. Street connectivity: <10,000 steps/d (2.45±0.65) vs. 10,000+ steps/d (2.77±0.66), f=6.04, p=.02 (Street connectivity **+**) 10. Walking/cycling facilities: <10,000 steps/d (2.30±0.98) vs. 10,000+ steps/d (2.66±0.92), f=3.53, p=.06 (Cycling/Walk-friendly	

									infrastructure **0**) 11. Aesthetics: <10,000 steps/d (3.11±0.60) vs. 10,000+ steps/d (3.26±0.64), f=1.41, p=.24 (Greenery and aesthetically pleasing scenery **0**) 12. Pedestrian safety from traffic: <10,000 steps/d (2.77±0.60) vs. 10,000+ steps/d (3.04±0.78), f=4.39, p=.04 (Traffic/pedestrian safety +) 13. Safety from crime: <10,000 steps/d (3.26±0.49) vs. 10,000+ steps/d (3.33±0.55), f=0.50, p=.48 (Crime/personal safety **0**)	
31	Malaysian National Health and Morbidity Survey III 2006 data Kaur et al., 2015 [439]	N=4831(mixed) 60-80+ years 53% female 97.5% response rate Community-dwellers *Multiple locations,* Malaysia	Cross-sectional Cluster: purposive Individuals: purposive Stratification: urbanisation Neighbourhood definition: enumeration block (80-120 living quarters with ≈600 individuals)	Age, sex, education, ethnicity, marital status, household income	*Self-report [World Health Organization STEPS questionnaire; validated]:* Inactivity (<150 mins/wk) → Total MVPA *TotalMVPA(<150 mins/wk; Yes/No)*	*Objective [Malaysian Department of Statistics; unvalidated]:* 1. Locality → Urbanisation	None	Multivariate logistic regression	***Main effects with TotalMVPA(<150 mins/wk; Yes/No):*** 1. Locality (Ref: Rural)—OR (95% CIs): Urban: OR=1.318 (1.025; 1.696), p=.031 (Urbanisation -)	Table 3.
32	Melbourne older adults study 1 (name assigned) Bird et al., 2009 [440]	N=333 (urban) Mean age: 72 years 59% female Response rate not reported Community-dwellers apart	Cross-sectional Cluster: purposive Individuals: convenience Stratification: cultural group Neighbourhood	Age, number of years in Australia, self-reported health, cultural group (Anglo vs. non-Anglo)	*Self-report [International Physical Activity Questionnaire (IPAQ); validated]:* Total PA (mins/wk) → Total PA	*Perceived [NEWS questionnaire—modified version—unvalidated; St. Louis Scale—modified version—unvalidated]:* NEWS items:	None	Hierarchical regression. Outcome square root transformed as not normally distributed.	***Main effects with TotalPA(mins/wk):*** 1. Well maintained footpaths—b (95% CIs): b=-0.15 (-6.81; -1.25), p<.001 (Pavement/footpath quality -)	Table 7—model 3.

		from n=1 (nursing home) Melbourne, Australia	definition: 15-20mins walk from home		*TotalPA(mins/wk)*	1. Well maintained footpaths → Pavement/footpath quality 2. Trees shading footpaths → Walk-friendly infrastructure 3. Seeing and speaking to others when neighbourhood walking → Crime/personal safety St. Louis item: 4. No safe place to exercise → Crime/personal safety		No adjustment for LGA cluster	2. Trees shading footpaths: b=-0.15 (-6.81; -1.25), p=.01 (Walk-friendly infrastructure -) 3. Seeing and speaking to others when neighbourhood walking: b=0.04 (-1.99; 4.52), p=.45 (Crime/personal safety **0**) 4. No safe place to exercise: b=-0.18 (-7.33; -1.74), p<.001 (Crime/personal safety **+**)	
33	Melbourne older adults study 1 (name assigned) Bird et al., 2010 [441]	N=268 (urban) Mean age: 72 years % female: not reported Community-dwellers Melbourne, Australia	Cross-sectional; Cluster: convenience Individuals: convenience Stratification: cultural group Neighbourhood definition: 15-20mins walk from home	Age, number of years in Australia, self-reported health, cultural group (Anglo vs. non-Anglo)	*Self-report [IPAQ—translated version; validated]:* Total walking (150+ mins/wk; Yes/No) → Total walking *TotalWalking(150+ mins/wk; Yes/No)*	*Perceived [NEWS questionnaire—validated; St. Louis Scale—validated]:* NEWS items: 1. Unsafe to walk at night → Crime/personal safety 2. Safe to walk during day → Crime/personal safety 3. Crime rate → Crime/personal safety 4. Attractive natural sights → Greenery and aesthetically pleasing scenery 5. Streets well lit at night → Street lighting	None	Chi-square test, Mann-Whitney test, Kruskal-Wallis test *Note: Walk mins/week non-normally distributed, therefore data described as medians and interquartile ranges. Environmental data also non-normally distributed (fails to explicitly mention*	***Main effects with TotalWalking(150+ mins; Yes/No):*** 1. Unsafe to walk at night: X^2=4.75, p=.093 (Crime/personal safety **0**) 2. Safe to walk during day: X^2=3.19, p=.074 (Crime/personal safety **0**) 3. Crime rate: X^2=5.07, p=.079 (Crime/personal safety **0**) 4. Attractive natural sights: <150 min: U=157 vs. ≥150 min: U=177, p=.048 (Greenery and aesthetically pleasing scenery +) 5. Streets well lit at night: ≥10 min <150 min:	*Two paragraphs above Discussion sub-heading.*

								which attributes…)	H=125 vs. ≥150 min: H=140, p=.095 (Street lighting **0**)	
34	MOBILIZE Boston study Procter-Gray et al., 2015 [442]	N=745 (urban) Mean age: 78 years 64% female 68% response rate Community-dwellers Boston, USA	Cross-sectional Cluster: convenience (8km radius from research institute) Individuals: random Stratification: none Neighbourhood definition: census block	Age, sex, ethnicity, BMI alcohol use, balance, unable to do the chair-stand test without arms, gait speed, activities of daily living, short performance battery score, illness, bodily pain, comorbidities, self-rated health, peripheral neuropathy, foot pain, daily medications, impaired cognition, falls efficacy score	*Self-report [unnamed questionnaire; unvalidated]:* Habitual walking (5+ d/wk; Yes/No) → Total walking *TotalWalking(5+ d/wk; Yes/No)*	*Objective [GIS—Massachusetts GIS, InfoUSA, US Post Office; unvalidated]:* 1. Bus stop → Public transport access/availability 2. Subway → Public transport access/availability 3. Hospital → Health and aged care access/availability 4. Shopping centre or mall → Shops/commercial access/availability 5. Post office → Shops/commercial access/availability 6. Public park (1+ acre) → Parks/public open space access/availability 7. Grocery/convenience store → Shops/commercial access/availability 8. Town hall → Government/finance services access/availability 9. Public library → Education facilities access/availability 10. % housing units vacant → Residential density	None	Multivariate logistic regression	***Main effects with TotalWalking(5+ d/wk; Yes/No):*** 1. Nearest bus stop—OR (95% CIs): OR=0.74 (0.52; 1.04), p>.05 (Public transport **0**) 2. Nearest subway: OR=0.88 (0.79; 0.97), p<.01 (Public transport **+**) 3. Nearest hospital: OR=0.84 (0.76; 0.94), p<.01 (Health and aged care access/availability **+**) 4. Nearest shopping centre or mall: OR=0.93 (0.85; 1.02), p>.05 (Shops/commercial access/availability **0**) 5. Nearest post office: OR=0.82 (0.73; 0.92), p<.01 (Shops/commercial access/availability **+**) 6. Nearest public park (1+ acre): OR=0.77 (0.53; 1.13), p>.05 (Parks/public open space access/availability **0**) 7. Nearest grocery/convenience store: OR=0.77 (0.61; 0.99), p<.05 (Shops/commercial access/availability **+**) 8. Nearest town hall: OR=0.93 (0.86; 1.02),	Table 2

									p>.05 (Government/finance services access/availability **0**) 9. Nearest public library: OR=0.95 (0.76; 1.18), p>.05 (Education facilities access/availability **0**) 10. % housing units vacant (Ref: <5%): *5-10%:* OR=1.59 (1.11; 2.29), p<.05 (Residential density - ***0.5**) *>10%:* OR=1.31 (0.83; 2.07), p>.05 (Residential density **0*0.5**)	
35	Neighbourhoods and Physical Activity in Elderly Men Michael et al., 2010 [443]	N=422 (urban) 65+ years 0% female 10-15% response rate Community-dwellers Portland, USA	Longitudinal Cluster: convenience Individuals: purposive Stratification: clinical site (Portland only) and ethnicity (minorities represented) Neighbourhood definition: 0.125mile, 0.25mile, and 0.5mile buffers	Age, education, race, occupation, marital status, self-rated health, BMI, smoking, alcohol/wk, chronic conditions, physical function *Note. Following variables were not explicitly reported, authors' reported adjusting for covariate sets including demographic and socioeconomic characteristics, health behaviours, chronic conditions and self-reported health, and physical function.*	*Self-report [2 questions from PASE questionnaire; validated]:* Change in total walking (30+ mins/d; Yes/No) → Total walking *TotalWalking(change; 30+ mins/d; Yes/No)*	*Objective [GIS, Regional Land Scale Information Database; unvalidated]:* 1. Number of recreational facilities → Recreational facilities access/availability 2. Park proximity → Parks/public open space access/availability 3. Trail proximity → Parks/public open space access/availability	SES: Low (n=211), High (n=211) Park proximity*SES Trail proximity*SES	Log-binomial regression	*Significant moderating effects for:* *Park proximity (0.125 mile)*SES:* p<.10 *Trail proximity (0.5 mile)*SES:* p<.10 ***Main and moderated effects with*** ***TotalWalking(change; 30+ mins/d; Yes/No)*:** 1. Number of Recreational facilities—RR (95% CIs): *Total participants + 0.25 mile:* RR=not reported, p>.05 *Total participants + 0.5 mile:* RR=not reported, p>.05 (Recreational facilities access/availability **0*0.5; 0*0.5**) 2. Park proximity: *High SES + 0.125 mile:* RR=1.22 (1.01; 1.47), p<.05	Moderating and buffer effects. In-text, pp. 657.

									(Parks/public open space access/availability **+*0.167**) *Low SES + 0.125 mile:* RR=0.89 (0.70; 1.13), p>.05 *Total participants + 0.25 mile:* RR=not reported, p>.05 *Total participants + 0.5 mile:* RR=not reported, p>.05 (Parks/public open space access/availability **0*0.833**) 3. Trail proximity: *Total participants + 0.25 mile:* RR=not reported, p>.05 *High SES + 0.5 mile:* RR=1.34 (1.16; 1.55), p<.05 (Parks/public open space access/availability **+*0.25**) *Low SES + 0.5 mile:* RR=0.93 (0.71; 1.23), p>.05 (Parks/public open space access/availability **0*0.75**)	
36	Netherlands Housing Survey (WoON) data Jongeneel-Grimen et al., 2013 [444]	n=6830 (2006; sub-sample)), n=8994 (2009; sub-sample) (urban) 60-84 years 53-56% female 62.6-70.9% response rate Community-dwellers *Multiple municipalities,* Netherlands	Cross-sectional measured at two time-points Cluster: purposive Individuals: random Stratification: age, gender, country of birth and municipality Neighbourhood definition: postal code	Age, sex education, employment status, household income	*Self-report (WoON questionnaire; unvalidated):* Total PA (hrs/wk) → Total PA *TotalPA(hrs/wk—prevalence)* *TotalPA(hrs/wk—frequency)*	*Perceived [WoON questionnaire; unvalidated]:* 1. Traffic safety → Traffic/pedestrian safety 2. Change in traffic safety → Traffic/pedestrian safety	None. *Notes:* Age: *In 2006:* 18-34 y (n≈7408), 35-59 y (n≈11,070), 60-84 y (n≈6830) *In 2009:* 18-34 y (n≈9134), 35-59 y	Multilevel logistic regression, multilevel zero-truncated negative binomial regression	***Main effect with TotalPA(hrs/wk—prevalence):*** 1. Traffic safety—OR (95% CIs): OR=1.028 (0.953; 1.107), p>.05 (Traffic/pedestrian safety **0**) *Main effect with TotalPA(hrs/wk—frequency):* 1. Traffic safety: Activity intensity	Table 5.

							(n≈13,648), 60-84 y (n≈8994)		ratio=1.017 (0.983; 1.052), p>.05 (Traffic/pedestrian safety **0**) *Main effects with TotalPA(hrs/wk—prevalence):* 2. Change in traffic safety: OR=1.042 (0.964; 1.125), p>.05 (Traffic/pedestrian safety **0**) *Main effects with TotalPA(hrs/wk—frequency):* 2. Change in traffic safety: Activity intensity ratio=1.013 (0.978; 1.049), p>.05 (Traffic/pedestrian safety **0**)	
37	Netherlands Housing Survey (WoON) data Jongeneel-Grimen et al., 2014 [445]	n=6830 (2006; sub-sample), n=8994 (2009; sub-sample) (urban) 60-84 years 53-56% female 62.6-70.9% response rate Community-dwellers *Multiple municipalities,* Netherlands	Cross-sectional measured at two time-points Cluster: purposive Individuals: random Stratification: age, gender, country of birth and municipality Neighbourhood definition: postal code	Age, sex education, employment status, household income, urbanisation of municipality	*Self-report (WoON questionnaire; unvalidated):* Total PA (hrs/wk) → Total PA *TotalPA(hrs/wk—prevalence)*	*Perceived [WoON questionnaire; unvalidated]:* 1. No fear of crime → Crime/personal safety 2. Change in no fear of crime → Crime/personal safety 3. Absence of physical disorder → Greenery and aesthetically pleasing scenery 4. Change in absence of physical disorder → Greenery and aesthetically pleasing scenery 5. Absence of social disorder → Crime/personal safety	None. *Notes:* Age: *In 2006:* 18-34 y (n≈7408), 35-59 y (n≈11,070), 60-84 y (n≈6830) *In 2009:* 18-34 y (n≈9134), 35-59 y (n≈13,648), 60-84 y (n≈8994)	Multilevel multivariate logistic regression	***Main effects with TotalPA(hrs/wk—prevalence):*** 1. No fear of crime—OR (95% CIs): OR=1.32 (1.16; 1.50), p≤.05 (Crime/personal safety **+**) 2. Change in no fear of crime: OR=1.02 (0.87; 1.20), p>.05 (Crime/personal safety **0**) 3. Absence of physical disorder: OR=1.11 (1.01; 1.23), p≤.05 (Greenery and aesthetically pleasing	Table 4.

						6. Change in absence of social disorder → Crime/personal safety			scenery +) 4. Change in absence of physical disorder: OR=1.02 (0.91; 1.15), p>.05 (Greenery and aesthetically pleasing scenery **0**) 5. Absence of social disorder: OR=1.26 (1.11; 1.42), p ≤ .05 (Crime/personal safety +) 6. Change in absence of social disorder: OR=1.06 (0.94; 1.21), p>.05 (Crime/personal safety **0**)	
38	*No study name* Aird et al., 2015 [446]	N=48 (mixed) Mean age: 72 years 50% female Response rate not reported Community-dwellers Queensland, Australia	Cross-sectional Cluster: purposive Individuals: convenience Stratification: population density/urbanisation Neighbourhood definition: statistical local areas	None	*Objective [GPS in conjunction with travel diary; unvalidated]:* Total walking (mins/d) → Total walking *TotalWalking(mins/d)*	*Objective [used statistical information based on population density; unvalidated]:* 1. Urbanisation → Urbanisation	None	Kruskal-Wallis test	***Main effect with TotalWalking(mins/d)*:** 1. Urbanisation: Inner city=26.38, City suburban=21.92, Regional city=23.46, Rural town=26.25 (Urbanisation **0**)	None
39	*No study name* Arnadottir et al., 2009 [447]	N=186 (mixed) 65+ years 48% female 78-80% response rates Community-dwellers *Multiple locations,* Iceland	Cross-sectional Cluster: purposive Individuals: random Stratification: population density and occupation (farming) Neighbourhood definition: *macro*	Education, depression, physical function (timed up and go test)	*Self-report [PASE questionnaire; validated]:* Total PA (score) → Total PA *TotalPA(score)*	*Objective [National Registry data; unvalidated]:* 1. Residency → Urbanisation	None	Analysis of covariance *Note. Positively-skewed Total PASE data—log transformation undertaken*	***Main effects with TotalPA(score)*:** 1. Urbanisation: f=0.93, p=.336 (Urbanisation **0**)	Table 2.

			level—not defined							
40	*No study name* Asawachaisuwikrom 2001 [448]	N=112 (mixed) Mean age: 71 years 50% female Response rate not reported Community-dwellers Chonburi Province, Thailand	Cross-sectional Cluster: random Individuals: random Stratification: urbanisation Neighbourhood definition: 15-20mins walk from home	Gender, education, income, perceived benefits, perceived barriers, self-efficacy, family support	*Self-report [Physical Activity Questionnaire (PAQ); validated]:* Total PA (score) → Total PA *TotalPA(score)*	*Perceived [Convenient Facilities Scale; validated]:* 1. Convenient Facilities Score: scale comprised of a list of facilities that can be utilised for PA → Recreational facilities access/availability	None	Hierarchical regression. No adjustment for village cluster	***Main effects with TotalPA(score):*** 1. Convenient facilities: t=2.93, p=.00 (Recreational facilities access/availability **+**)	Results from Table 13 used because it is the only model to include gender and education as covariates.
41	*No study name* Baceviciene & Alisauskas 2013 [449]	N=160 (urban) Mean age: 71 years 61% female Response rate not reported Community-dwellers Kaunas City, Lithuania	Cross-sectional Cluster: none Individuals: random Stratification: none Neighbourhood definition: participant delineation	None	*Self-report [IPAQ; validated]:* Active (30+ MVPA mins/d*4+ d/wk) → Total MVPA *TotalMVPA(30+ mins/d*4+ d/wk; Yes/No)*	*Perceived [unnamed questionnaire; validated]:* 1. Unsuitable environment/exercise facilities are too far away → Recreational facilities access/availability	None	Chi-square test	***Main effects with TotalMVPA(30+ mins/d*4+ d/wk; Yes/No):*** 1. Exercise facilities are too far away: Active (n=3) vs. Inactive (n=6): 3.9% vs. 7.2%, p>.05 (Recreational facilities access/availability **0**)	Table 2.
42	*No study name* Bocker et al., 2016 [450]	N=147 (mixed) 65+ years 63% female Response rate not reported Dwelling not reported Rotterdam, Netherlands	Cross-sectional Cluster: none Individuals: random Stratification: urbanisation Neighbourhood definition: 300m buffer	Age, sex, education, ethnicity, household income, household size, # of cars, bicycle availability, public transport card owner, obesity, disability, trip distance, trip motive, travel company, weekend day, daily air temperature, daily precipitation level, daily wind speed, snow cover	*Self-report [travel diary; unvalidated]:* Walking (trips/d) → Total walking *TotalWalking(trips/d)*	*Objective [GIS; unvalidated]:* 1. Address density → Residential density 2. Building diversity → Land-use mix 3. Surface % green space → Access to/availability of parks/public space	None	Zero-inflated negative binomial regression, with robust standard errors to adjust for within-cluster correlation	***Main effects with TotalWalking(trips/d):*** 1. Address density: b=-0.003, z=-0.03, p>.05 (Residential density **0**) 2. Building diversity: b=1.749, z=1.79, p<.10 (Land-use mix—destination diversity **0**) 3. Surface % green space: b=0.004, z=0.33, p>.05 (Parks/public open space access/availability **0**)	Table 3.
43	*No study name* Carvalho	N=95 (mixed) Mean age: 73.7 years	Cross-sectional Cluster: none Individuals:	None	*Objective [Yamax Pedometer; validated]:*	*Objective [classification following Bibby & Shephard, 2005;*	Urbanisation: Rural (n=54), Urban (n=41)	Independent t-test, Mann-	***Main effects with TotalWalking(steps/d):*** 1. Urbanisation:	Table 3.

	Sampaio et al., 2012 [451]	100% female Response rate not reported Community-dwellers Kyoto, Japan	convenience Stratification: urbanisation Neighbourhood definition: rural (<9000/15.2km^2), urban (Kyoto City—not defined)		Total steps → Total walking *TotalWalking(steps/d)* *Self-report [unnamed questionnaire; unvalidated]:* Total PA (no; almost everyday; 2-3/wk; 1-2/month) → Total PA *TotalPA(frequency)*	*unvalidated]:* 1. Urbanisation → Urbanisation		Whitney U test	Urban: 5791 (3992-7634) vs. Rural: 6734 (5447-7794), p=.07 (Urbanisation **0*0.568; 0*0.432**) ***Main effects with TotalPA(frequency):*** 1. Urbanisation: *Urban:* No: 17.9% vs. Almost everyday: 20.5%, 2-3/wk: 46.2%, 1-2/month: 15.4% vs. *Rural:* No: 35.4% vs. Almost everyday: 6.3%, 2-3/wk: 52.1%, 1-2/month: 6.3%, p=.05 (Urbanisation **0*0.568; 0*0.432**)	
44	*No study name* Chad et al., 2005 [353]	N=658 (urban) Mean age: 77 years 80% female 73% response rate (community level) Community-dwellers *Mid-sized city,* Canada	Cross-sectional Cluster: none Individuals: convenience Stratification: none Neighbourhood definition: participant delineation	None	*Self-report [Physical Activity Scale for the Elderly (PASE) questionnaire; validated]:* Total PA (score) → Total PA *TotalPA(score)*	*Perceived [unnamed questionnaire; reliable]:* 1. Hills → No physical barriers to walking 2. Enjoyable scenery → Greenery and aesthetically pleasing scenery 3. Sidewalks → Walk-friendly infrastructure 4. Biking lanes or trails → Cycle-friendly infrastructure 5. Walking/hiking trails → Parks/public open space access/availability 6. Water fountains → Greenery and aesthetically pleasing scenery 7. Benches to sit on → Walk-friendly infrastructure 8. Street lights →	Age: 65-79 y (n=324), 80+ y (n=311)	Independent t-test/one-way ANOVA (when assumptions met) or Mann-Whitney U test/Kruskal-Wallis test (when assumptions not met). No formal testing of moderating effects.	***Main and moderated effects with TotalPA(score):*** 1. Hills—Absent vs. Present (applies to all exposures): *65-79 years (n=324):* 127.6±66.9 vs. 134.1±62.2, p>.05 *80+ years (n=311):* 81.2±49.5 vs. 89.3±50.3, p>.05 (No physical barriers to walking **0*0.51; 0*0.49**) 2. Enjoyable scenery: *65-79 years (n=324):* 124.6±64.8 vs. 130.8±65.6, p>.05 *80+ years (n=310):* 77.5±53.5 vs. 84.8±48.5, p>.05 (Greenery and aesthetically pleasing scenery **0*0.51; 0*0.49**) 3. Sidewalks: *65-79 years (n=324):* 122.5±59.2 vs.	Moderating effects. Table 6.

						Crime/personal safety 9. Golf course → Recreational facilities access/availability 10. Public park → Parks/public open space access/availability 11. Skating rink → Recreational facilities access/availability 12. Swimming pool → Recreational facilities access/availability 13. Tennis courts → Recreational facilities access/availability 14. Dance studio → Recreational facilities access/availability 15. Public recreation centre → Recreational facilities access/availability 16. Heavy traffic → Traffic/pedestrian safety 17. Dogs that are unattended → Crime/personal safety 18. Frequently see active people → Crime/personal safety 19. High crime → Crime/personal safety 20. Type of neighbourhood → Land-use mix—destination diversity			130.2±65.9, p>.05 *80+ years (n=311):* 91.2±70.8 vs. 83.0±47.2, p>.05 (Walk-friendly infrastructure **0*0.51; 0*0.49**) 4. Biking lanes or trails: *65-79 years (n=324):* 124.7±62.6 vs. 137.7±69.2, p>.05 *80+ years (n=311):* 82.4±50.6 vs. 87.7±47.6, p>.05 (Cycle-friendly infrastructure **0*0.51; 0*0.49**) 5. Walking/hiking trails: *65-79 years (n=323):* 122.2±59.2 vs. 130.2±65.9, p>.05 (Parks/public open space access/availability **0*0.51**) *80+ years (n=311):* 74.8±46.1 vs. 95.3±52.0, p<.05 (Parks/public open space access/availability **+*0.49**) 6. Water fountains: *65-79 years (n=324):* 129.4±64.2 vs. 132.0±74.8, p>.05 *80+ years (n=310):* 85.9±50.3 vs. 70.3±44.8, p>.05 (Greenery and aesthetically pleasing scenery **0*0.51; 0*0.49**) 7. Benches to sit on: *65-79 years (n=324):* 150.3±74.2 vs. 122.4±60.5, p<.05 (Walk-friendly infrastructure **-*0.51**)	

										80+ years (n=311): 82.5±52.6 vs. 84.1±49.0, p>.05 (Walk-friendly infrastructure **0*0.49**) 8. Street lights: *65-79 years (n=324):* 116.8±58.6 vs. 131.5±66.2, p>.05 *80+ years (n=311):* 82.3±53.6 vs. 84.1±49.0, p>.05 (Street lighting **0*0.51; 0*0.49**) 9. Golf course: *65-79 years (n=324):* 126.4±126.4 vs. 144.5±144.5, p>.05 *80+ years (n=311):* 82.1±49.1 vs. 101.1±54.5, p>.05 (Recreational facilities access/availability **0*0.51; 0*0.49**) 10. Public park: *65-79 years (n=324):* 112.6±54.1 vs. 134.3±67.5, p<.05 *80+ years (n=311):* 72.6±49.2 vs. 90.7±49.0, p<.05 (Parks/public open space access/availability **+*0.51; +*0.49**) 11. Skating rink: *65-79 years (n=324):* 125.2±63.3 vs. 147.4±70.6, p<.05 (Recreational facilities access/availability **+*0.51**) *80+ years (n=310):* 81.2±47.3 vs. 99.8±60.7, p>.05 (Recreational facilities access/availability	

									0*0.49) 12. Swimming pool: *65-79 years (n=324):* 132.1±67.1 vs. 125.9±62.6, p>.05 (Recreational facilities access/availability **0*0.51**) *80+ years (n=310):* 78.8±49.0 vs. 96.1±50.1, p<.05 (Recreational facilities access/availability **+*0.49**) 13. Tennis courts: *65-79 years (n=324):* 126.1±58.5 vs. 139.8±81.0, p>.05 (Recreational facilities access/availability **0*0.51**) *80+ years (n=311):* 80.4±48.0 vs. 98.0±54.8, p<.05 (Recreational facilities access/availability **+*0.49**) 14. Dance studio: *65-79 years (n=324):* 129.8±65.7 vs. 129.4±63.5, p>.05 (Recreational facilities access/availability **0*0.51**) *80+ years (n=311):* 80.8±48.4 vs. 111.2±55.0, p<.05 (Recreational facilities access/availability **+*0.49**) 15. Public recreation centre: *65-79 years (n=324):* 129.3±64.7 vs. 130.5±67.0, p>.05 *80+ years (n=311):*	

									81.7±51.2 vs. 89.1±46.1, p>.05 (Recreation facilities access/availability **0*0.51**; **0*0.49**) 16. Heavy traffic: *65-79 years (n=324):* 129.9±70.2 vs. 129.6±61.3, p>.05 *80+ years (n=311):* 80.1±48.8 vs. 86.9±50.5, p>.05 (Traffic/pedestrian safety **0*0.51; 0*0.49**) 17. Dogs that are unattended: *65-79 years (n=324):* 128.3±65.3 vs. 136.5±66.3, p>.05 (Crime/personal safety **0*0.51**) *80+ years (n=310):* 79.8±45.4 vs. 104.9±65.2, p<.05 (Crime/personal safety **-*0.49**) 18. Frequently see active people: *65-79 years (n=324):* 117.8±58.7 vs. 132.6±66.7, p>.05 (Crime/personal safety **0*0.51**) *80+ years (n=311):* 71.8±45.7 vs. 87.6±50.5, p<.05 (Crime/personal safety **+*0.49**) 19. High crime: *65-79 years (n=324):* 130.7±65.7 vs. 122.5±63.9, p>.05 *80+ years (n=311):* 83.6±49.4 vs. 85.2±53.2, p>.05 (Crime/personal safety	

									0*0.51; 0*0.49) 20. Type of neighbourhood: *65-79 years:* Residential (n=208): 137.2±67.7 vs. commercial (n=3): 151.9±57.4 vs. mixed (n=107): 116.5±91.5, p<.05 (Land-use mix—destination diversity **+*0.51**) *80+ years:* Residential (n=208): 87.4±51.4 vs. commercial (n=3): 61.6±43.6 vs. mixed (n=107): 75.3±41.3, p>.05 (Land-use mix—destination diversity **0*0.49**)	
45	*No study name* Chaudhury et al., 2016 [452]	N=434 (urban) 60+ years (no mean age reported) 64% female 6% response rate Dwelling not reported Portland, USA, and Vancouver, Canada	Cross-sectional Cluster: purposive Individuals: random Stratification: population density (proxy for walkability *in article*) and median household income Neighbourhood definition: 15-20mins walk from home	Age, education, marital status, household income, self-rated health, physical functioning limitations, membership in a sports group or recreational organisation, walking with a neighbour	*Self-report [unnamed questionnaire; unvalidated]:* Total PA (5+ hr/wk; Yes/No) → Total PA *TotalPA(5+ hr/wk; Yes/No)*	*Perceived [NEWS questionnaire; validated]:* 1. Neighbourhood walkability → Walkability 2. Neighbourhood amenities and accessibility → Destinations/services (overall/unspecific) access/availability	None	Multivariate logistic regression	***Main effects with TotalPA(5+ hr/wk; Yes/No):*** 1. Neighbourhood walkability: b=not reported, p>.05 (Walkability **0**) 2. Neighbourhood amenities and accessibility: b=not reported, p>.05 (Destinations/services (overall/unspecific) access/availability **0**)	Table 4.
46	*No study name* Chen et al.,2013 [343]	n=1701 (sub-sample; urban) Mean age: 70 years 50% female Response rate not reported	Cross-sectional Cluster: purposive Individuals: random Stratification: age and sex Neighbourhood	Age, automobile commuting	*Self-report [unnamed questionnaire; validated]:* Daily walking (mins/d) → Total walking *TotalWalking(60+ mins/d; Yes/No)*	*Perceived [NEWS questionnaire—Japanese version; validated]:* 1. Density of dwelling → Residential density 2. Proximity of services	Sex: Male (n=846), Female (n=855) Age: 20-39 y (n=633), 40-59 y (n=1472),	Multivariate logistic analysis	***Main effects with TotalWalking(60+ mins/d; Yes/No):*** 1. Density of dwelling (Ref: Low)—OR (95% CIs): *Males + employed (60-79 y):* High OR=1.27 (0.52;	Table 2.

		Community-dwellers Tsuruoka City, Japan	definition: 10mins walk from home			facilities → Destinations/services (overall/unspecific) access/availability 3. No. of service facilities within 10 mins → Destinations/services (overall/unspecific) access/availability 4. Street connectivity → Street connectivity 5. Places for walking → Destinations/services (overall/unspecific) access/availability 6. Good view → Greenery and aesthetically pleasing scenery	60-79 y (n=1701) Employment status: Employed (n=604), Unemployed (n=1097)		3.09), p>.05 *Males + unemployed:* High OR=0.89 (0.35; 2.25), p>.05 *Females + employed (60-79 y):* High OR=0.85 (0.26; 2.81), p>.05 *Females + unemployed:* High OR=0.99 (0.46; 2.17), p>.05 (Residential density **0*0.244; 0*0.253; 0*0.133; 0*0.370**) 2. Proximity to service facilities (Ref: Low): *Males + employed (60-79 y):* High OR=0.69 (0.34; 1.39), p>.05 *Males + unemployed:* High OR=1.63 (0.69; 3.85), p>.05 *Females + employed (60-79 y):* High OR=1.07 (0.41; 2.80), p>.05 *Females + unemployed:* High OR=0.87 (0.43; 1.75), p>.05 (Destinations/services (overall/unspecific) access/availability **0*0.244; 0*0.253; 0*0.133; 0*0.370**) 3. Number of service facilities within 10 mins (Ref: Low): *Males + employed (60-79 y):* High OR=0.66 (0.33; 1.36), p>.05 *Males + unemployed:* High OR=0.93 (0.39; 2.24), p>.05 *Females + employed (60-79 y):* High OR=0.98 (0.38; 2.53), p>.05 *Females + unemployed:* High OR=1.06 (0.53;	

									2.13), p>.05 (Destinations/services (overall/unspecific) access/availability **0*0.244; 0*0.253; 0*0.133; 0*0.370**) 4. Street connectivity (Ref: Low): *Males + employed (60-79 y):* High OR=0.73 (0.36; 1.50), p>.05 *Males + unemployed:* High OR=2.22 (0.93; 5.32), p>.05 *Females + employed (60-79 y):* High OR=1.50 (0.57; 3.95), p>.05 *Females + unemployed:* High OR=0.74 (0.35; 1.54), p>.05 (Street connectivity **0*0.244; 0*0.253; 0*0.133; 0*0.370**) 5. Places for walking (Ref: Low): *Males + employed (60-79 y):* High OR=0.90 (0.44; 1.85), p>.05 *Males + unemployed:* High OR=0.47 (0.20; 1.10), p>.05 *Females + employed (60-79 y):* High OR=0.88 (0.33; 2.31), p>.05 *Females + unemployed:* High OR=1.15 (0.56; 2.35), p>.05 (Destinations/services (overall/unspecific) access/availability **0*0.244; 0*0.253; 0*0.133; 0*0.370**) 6. Good view (Ref: Low): *Males + employed (60-79 y):* High OR=0.78 (0.37; 1.62), p>.05	

									Males + unemployed: High OR=1.01 (0.44; 2.30), p>.05 *Females + employed (60-79 y):* High OR=0.92 (0.35; 2.40), p>.05 *Females + unemployed:* High OR=0.92 (0.35; 2.40), p>.05 (Greenery and aesthetically pleasing scenery **0*0.244; 0*0.253; 0*0.133; 0*0.370**)	
47	*No study name* de Melo et al., 2010 [453]	N=60 (urban) 65+ years 75% female Response rate not reported Community-dwellers *Midsized city,* Canada	Cross-sectional Cluster: convenience Individuals: convenience Stratification: none Neighbourhood definition: 15-20mins walk from home	Age, income, physical function	*Objective [StepsCount—01 pedometer; reliable]:* Steps/d → Total walking *TotalWalking(steps/d)*	*Perceived [NEWS-A questionnaire; validated]:* 1. Access to services → Destinations/services (overall/unspecific) access/availability 2. Street connectivity → Street connectivity 3. Infrastructure for walking and cycling → Cycle/walk-friendly infrastructure 4. Aesthetics → Greenery and aesthetically pleasing scenery	None	Hierarchical negative binomial regression due to skewed and overdispersion. Pearson correlation	***Main effects with TotalWalking(steps/d):*** 1. Access to services: RR=1.05 (95% CI=0.99; 1.13), p=.07 (Destinations/services (overall/unspecific) access/availability **0**) 2. Street connectivity: r=not reported, p>.05 (Street connectivity **0**) 3. Infrastructure for walking and cycling: r=not reported, p>.05 (Cycling/Walk-friendly infrastructure **0**) 4. Aesthetics: r=not reported, p>.05 (Greenery and aesthetically pleasing scenery **0**)	#1: Table 4. #2-5: Pearson correlations.
48	*No study name* Gallagher et al., 2012 [454]	N=326 (urban) Mean age: 76 years; 67% female 81.5% response rate Community-dwellers Michigan, USA	Cross-sectional Cluster: none Individuals: convenience Stratification: none Neighbourhood definition: 15min/0.5mile walk from home	Age, sex, education, race, outcome expectations, self-efficacy	*Self-report [Neighbourhood Physical Activity Questionnaire (NPAQ); reliable]:* Neighbourhood walking (mins/wk) → Total walking *TotalWalking(mins/wk)*	*Perceived [NEWS questionnaire; validated]:* 1. Neighbourhood density → Residential density 2. Neighbourhood destinations → Destinations/services	Mobility impairment: Mobility limited (n=163), Non-mobility limited (n=163)	Pearson correlation; multiple linear regression	***Main effects with TotalWalking(mins/wk):*** 1. Neighbourhood density: *All participants:* r=0.106, p>.05 (Residential density **0*1**) ***Moderated effects with TotalWalking(mins/wk):*** 2. Neighbourhood	Moderating effects. Table 2 and 4.

						(overall/unspecific) access/availability			destinations: *Mobility-limited participants:* b=0.318, p<.001 (Destinations/services (overall/unspecific) access/availability **+*0.5**) *Non-mobility-limited participants:* b=0.318, p>.05 (Destinations/services (overall/unspecific) access/availability **0*0.5**)	
49	*No study name* Gomez et al., 2010 [455]	N=1966 (urban) Mean age: 71 years 63% females 67.8% response rate Community-dwellers Bogotá, Colombia	Cross-sectional Cluster: purposive Individuals: random Stratification: area-level SES Neighbourhood definition: participant delineation (perceived); 500m buffer (objective)	Age, sex, education, limitation to engage in PA, slope, SES	*Self-report [IPAQ—modified version; unvalidated]:* Total walking (60+ mins/wk; Yes/No) → Total walking *TotalWalking(60+ mins/wk; Yes/No)* Total walking (150+ mins/wk; Yes/No) → Total walking *TotalWalking(150+ mins/wk; Yes/No)*	*Objective [GIS; unvalidated]:* 1. Slope → No physical barriers to walking 2. Connectivity index → Street connectivity 3. Public park density → Parks/public open space access/availability 4. TransMilenio stations → Public transport access/availability *Perceived [unnamed questionnaire; unvalidated]:* 5. Traffic safety → Traffic/pedestrian safety 6. Quality and maintenance of sidewalks → Pavement/footpath quality	*Note. Cross-level interactions were explored but none found.*	Multilevel models with random intercept to adjusting for clustering.	***Main effects with TotalWalking(60+ mins/wk; Yes/No):*** Objective environment: 1. Slope (Ref:<5%)—OR (95% CIs): 5+% OR=0.61 (0.38; 0.97), p=.038 (No physical barriers to walking **+**) 2. Connectivity index (Ref: 1.46-1.74): 1.75-1.80 OR=0.74 (0.50; 1.10), p=0.143 1.81-1.99 OR=0.64 (0.44; 0.93), p=.021 (Street connectivity **-**) 3. Public park density (Ref: 0.01-4.14): 4.53-7.98 OR=1.42 (1.02; 1.98), p=.039 8.11-35.21 OR=1.06 (0.74; 1.53), p=.726 (Parks/public open space access/availability **+**) 4. TransMilenio stations (Ref: 0): 1+ OR=0.75 (0.52; 1.08), p=.127 (Public transport access/availability **0**) Perceived environment:	Table 2.

									5. Traffic safety (Ref: Very unsafe, unsafe, neither): Very safe, safe OR=1.50 (1.11; 2.03), p=.007 (Traffic/pedestrian safety +) 6. Quality and maintenance (Ref: Very dissatisfied, dissatisfied, neither): Satisfied, very satisfied OR=0.82 (0.61; 1.12), p=.225 (Pavement/footpath quality **0**) ***Main effects with TotalWalking(150+ mins/wk; Yes/No):*** Objective environment: 1. Slope (Ref:<5%): 5+% OR=0.80 (0.55; 1.16), p=.254 (No physical barriers to walking **0**) 2. Connectivity index (Ref: 1.46-1.74): 1.75-1.80 OR=0.79 (0.58; 1.09), p=0.163 1.81-1.99 OR=0.90 (0.67; 1.23), p=.540 (Street connectivity **0**) 3. Public park density (Ref: 0.01-4.14): 4.53-7.98 OR=1.08 (0.81; 1.43), p=.574 8.11-35.21 OR=0.95 (0.70; 1.29), p=.757 (Parks/public open space access/availability **0**) 4. TransMilenio stations (Ref: 0): 1+ OR=0.78 (0.59; 1.04), p=.101 (Public transport	

									access/availability **0**) Perceived environment: 5. Traffic safety (Ref: Very unsafe, unsafe, neither): Very safe, safe OR=1.19 (0.97; 1.47), p=.088 (Traffic/pedestrian safety **0**) 6. Quality and maintenance (Ref: Very dissatisfied, dissatisfied, neither): Satisfied, very satisfied OR=0.95 (0.76; 1.19), p=.712 (Pavement/footpath quality **0**)	
50	*No study name* Grant-Savela et al., 2010 [456]	N=197 (rural) Mean age: 72 years 55% female 50.8% response rate Community-dwellers *Midwest,* USA	Cross-sectional Cluster: none Individuals: convenience Stratification: none Neighbourhood definition: Naturally occurring retirement community (NORC) itself (variable/not fixed)	None	*Self-report [adapted version of PASE; unvalidated]:* Total PASE score → Total PA *TotalPA(score)* Walking frequency (d/wk) → Total walking *TotalWalking(d/wk)* Walking duration (hr/d) → Total walking *TotalWalking(hr/d)*	*Perceived [unnamed questionnaire; unvalidated]:* 1. Convenience of destinations from participant's home → Destinations/services (overall/unspecific) access/availability 2. Location of walking → Land-use mix—destination diversity	None	Spearman's Rank-Order Correlation	***Main effects with TotalPA(score):*** 1. Convenience of destinations: r=0.12, p>.05 (Destinations/services (overall/unspecific) access/availability **0**) 2. Location of walking: r=0.09, p>.05 (Land-use mix—destination diversity **0**) *Main effects with TotalWalking(d/wk):* 1. Convenience of destinations: r=0.08, p>.05 (Destinations/services (overall/unspecific) access/availability **0**) 2. Location of walking: r=0.12, p>.05 (Land-use mix—destination diversity **0**) ***Main effects with***	Table 3.

									TotalWalking(hr/d): 1. Convenience of destinations: r=0.18, p<.05 (Destinations/services (overall/unspecific) access/availability **+**) 2. Location of walking: r=0.17, p<.05 (Land-use mix—destination diversity **+**)	
51	*No study name* Inoue et al., 2011 [344]	N=1921 (mixed) 65+ years 49% female 72.8% response rate Community-dwellers Bunkyo ward in Tokyo, Fuchu in Tokyo, and Oyama in Shizuoka prefecture, Japan	Cross-sectional Cluster: purposive Individuals: random Stratification: age, sex, urbanisation and neighbourhood Neighbourhood definition: cho-cho (smallest administrative unit for area in Japan), 10-15mins walk from residence	Age, education, city of residence, employment status, BMI, self-rated health	*Self-report [modified version of a previously unnamed questionnaire; unvalidated]:* Total neighbourhood walking (150+ mins/wk) → Total walking *TotalWalking(150+ min/wk; Yes/No)*	*Perceived [IPAQ Environmental Module—modified version; validated]:* 1. Residential density → Residential density 2. Access to shops → Shops/commercial access/availability 3. Public transport → Public transport access/availability 4. Sidewalks → Walk-friendly infrastructure 5. Bicycle lanes → Cycle-friendly infrastructure 6. Access to exercise facilities → Recreational facilities access/availability 7. Crime safety → Crime/personal safety 8. Traffic safety → Traffic/pedestrian safety 9. Social environment (seeing people being active) → Crime/personal safety 10. Aesthetics → Greenery and aesthetically pleasing	Sex: Male (n=846), Female (n=855)	Multilevel logistic regression accounting for clustering.	***Main and moderated effects with TotalWalking(150+ mins/wk; Yes/No):*** 1. Residential density—OR (95% CIs): *Males:* High (n=210) vs. Low (n=320): OR=0.93 (0.69; 1.26), p=.650 *Females:* High (n=217) vs. Low (n=286): OR=1.09 (0.80; 1.49), p=.578 (Residential density **0*0.5; 0*0.5**) 2. Access to shops: *Males:* Good (n=385) vs. Poor (n=142): OR=1.02 (0.75; 1.39), p=.913 (Shops/commercial access/availability **0*0.5**) *Females:* Good (n=362) vs. Poor (n=139): OR=1.44 (1.07; 1.94), p=.017 (Shops/commercial access/availability **+*0.5**) 3. Public transport: *Males:* Good (n=482) vs. Poor (n=45): OR=0.94 (0.59; 1.49), p=.799 *Females:* Good (n=473)	Moderating effects. Table 2.

						scenery			vs. Poor (n=32): OR=1.08 (0.65; 1.80), p=.776 (Public transport access/availability **0*0.5; 0*0.5**) 4. Sidewalks: *Males:* Good (n=438) vs. Poor (n=89): OR=1.22 (0.87; 1.72), p=.255 *Females:* Good (n=430) vs. Poor (n=74): OR=1.30 (0.91; 1.85), p=.152 (Walk-friendly infrastructure **0*0.5; 0*0.5**) 5. Bicycle lanes: *Males:* Good (n=200) vs. Poor (n=327): OR=0.98 (0.74; 1.31), p=.904 *Females:* Good (n=203) vs. Poor (n=301): OR=1.18 (0.88; 1.57), p=.271 (Cycle-friendly infrastructure **0*0.5; 0*0.5**) 6. Access to exercise facilities: *Males:* Good (n=354) vs. Poor (n=174): OR=1.19 (0.90; 1.59), p=.221 *Females:* Good (n=346) vs. Poor (n=158): OR=1.31 (0.98; 1.76), p=.221 (Recreational facilities access/availability **0*0.5; 0*0.5**) 7. Crime safety: *Males:* Good (n=388) vs. Poor (n=141): OR=0.78 (0.57; 1.05),	

									p=.106 *Females:* Good (n=329) vs. Poor (n=174): OR=1.16 (0.87; 1.53), p=.308 (Crime/personal safety **0*0.5; 0*0.5**) 8. Traffic safety: *Males:* Good (n=372) vs. Poor (n=156): OR=1.08 (0.81; 1.43), p=.606 *Females:* Good (n=343) vs. Poor (n=162): OR=1.24 (0.94; 1.65), p=.130 (Traffic/pedestrian safety **0*0.5; 0*0.5**) 9. Social environment: *Males:* Good (n=395) vs. Poor (n=134): OR=1.57 (1.18; 2.09), p=.002 (Crime/personal safety **+*0.5**) *Females:* Good (n=357) vs. Poor (n=145): OR=1.24 (0.93; 1.66), p=.145 (Crime/personal safety **0*0.5**) 10. Aesthetics: *Males:* Good (n=376) vs. Poor (n=153): OR=1.56 (1.18; 2.07), p=.002 *Females:* Good (n=367) vs. Poor (n=137): OR=1.38 (1.03; 1.85), p=.030 (Greenery and aesthetically pleasing scenery **+*0.5; +*0.5**)	
52	*No study name* King et al., 2003 [457]	N=149 (not reported) Mean age: 74	Cross-sectional Cluster: purposive	None	*Self-report [Paffenbarger Activity Questionnaire;*	*Perceived [unnamed questionnaire; unvalidated]:*	Walkability*no. of destinations within walking	Wilcoxon rank sum test;	*Significant moderating effects for: Walkability*no. of*	Table 4, 5, and 6.

		years 100% female 79-82% response rate Community-dwellers Pennsylvania, USA	Individuals: convenience Stratification: sex Neighbourhood definition: 20mins walk from home		*validated]:* Total PA (kcal/wk) → Total PA *TotalPA(median kcal/wk)* *Objective [Yamax Digiwalker pedometer; validated]:* Steps/d (kcal/wk) → Total walking *TotalWalking(median kcal/wk); TotalSteps/d (median)*	1. Biking or walking trail → Parks/public open space access/availability 2. Bus stop → Public transport access/availability 3. Café or coffee shop → Food outlets access/availability 4. Church, synagogue, or religious institution → Religious institution access/availability 5. Community centre → Social recreational facilities access/availability 6. Convenience, deli, or grocery store → Shops/commercial access/availability 7. Department, discount, or hardware → Shops/commercial access/availability 8. Library → Education facilities access/availability 9. Park → Parks/public open space access/availability 10. Post office → Shops/commercial access/availability 11. Restaurant, bar, or pub → Food outlets access/availability 12. No. of destinations → Destinations/services (overall/unspecific) access/availability 13. Walkability → Walkability	distance Walkability: Poor (n=16), Fair (n=24), Good (n=62), Excellent (n=46)	Jonckheere-Terpstra trend test	*destinations within walking distance, p=.0005* ***Main and moderated effects with*** ***TotalPA(median kcal/wk; 25th; 75th %tile):*** 1. Biking or walking trail: Yes (n=38)=1517 (785; 2285) vs. no (n=103)=1246 (554; 2354), p=.2636 (Parks/public open space access/availability **0**) 2. Bus stop: Yes (n=116)=1246 (640; 2389) vs. no (n=27)=1344 (646; 2492), p>.05 (Public transport access/availability **0**) 3. Café or coffee shop: Yes (n=82)=1281 (554; 2492) vs. no (n=59)=1246 (658; 2215), p>.05 (Food outlets access/availability **0**) 4. Church, synagogue, or religious institution: Yes (n=68)=1240 (692; 2279) vs. no (n=74)=1341 (623; 2469), p>.05 (Religious institution access/availability **0**) 5. Community centre: Yes (n=46)=1454 (692; 2492) vs. no (n=93)=1235 (623; 2327), p>.05 (Social recreational facilities access/availability **0**)	

									6. Convenience, deli, grocery store: Yes (n=89)=1442 (692; 2354) vs. no (n=54)=1050 (623; 2469), p>.05 (Shops/commercial access/availability **0**) 7. Department, discount, or hardware store: Yes (n=30)=1794 (739; 3000) vs. no (n=111)=1168 (623; 2215), p>.05 (Shops/commercial access/availability **0**) 8. Library: Yes (n=45)=1339 (785; 2539) vs. no (n=97)=1062 (623; 2273), p>.05 (Education facilities access/availability **0**) 9. Park: Yes (n=69)=1344 (692; 2539) vs. no (n=75)=1235 (531; 2273), p>.05 (Parks/public open space access/availability **0**) 10. Post office: Yes (n=50)=1292 (692; 2723) vs. no (n=92)=1246 (635; 2244), p>.05 (Shops/commercial access/availability **0**) 11. Restaurant, bar, or pub: Yes (n=78)=1390 (623; 2469) vs. no (n=64)=1246 (652; 2215), p>.05 (Food outlets access/availability **0**) 12. No. of destinations:	

										0 (n=14) 52 (0; 415) vs. 1 (n=15) 139 (0; 831) vs. 2-11 (n=120) 623 (196; 315), p=.0005 (Destinations/services (overall/unspecific) access/availability **+*0.73; 0*0.27**) 13. Walkability: Poor (n=16) 612 (65; 1015) vs. fair (n=24) 1396 (640; 2308) vs. good (n=62) 1246 (415; 2327) vs. excellent (n=46) 1399 (854; 2908), p=.0016 (Walkability **+**) ***Main effects with TotalWalking(median kcal/wk; 25th; 75th %tile):*** 1. Biking or walking trail: Yes (n=38)=692 (215; 1246) vs. no (n=103)=519 (104; 1246), p>.05 (Parks/public open space access/availability **0**) 2. Bus stop: Yes (n=116)=623 (139; 1240) vs. no (n=27)=623 (138; 1246), p>.05 (Public transport access/availability **0**) 3. Café or coffee shop: Yes (n=82)=623 (116; 1246) vs. no (n=59)=519 (138; 1246), p>.05 (Food outlets access/availability **0**) 4. Church, synagogue, or religious institution: Yes (n=68)=669 (199; 1240) vs. no (n=74)=512 (138; 1246), p>.05	

									(Religious institution access/availability **0**) 5. Community centre: Yes (n=46)=623 (138; 1168) vs. no (n=93)=554 (138; 2356), p>.05 (Social recreational facilities access/availability **0**) 6. Convenience, deli, grocery store: Yes (n=89)=692 (215; 1246) vs. no (n=54)=467 (69; 865), p>.05 (Shops/commercial access/availability **0**) 7. Department, discount, or hardware store: Yes (n=30)=658 (277; 1454) vs. no (n=111)=623 (138; 1246), p>.05 (Shops/commercial access/availability **0**) 8. Library: Yes (n=45)=880 (277; 1246) vs. no (n=97)=623 (138; 1246), p>.05 (Education facilities access/availability **0**) 9. Park: Yes (n=69)=692 (173; 1454) vs. no (n=75)=519 (139; 1235), p>.05 (Parks/public open space access/availability **0**) 10. Post office: Yes (n=50)=623 (242; 1246) vs. no (n=92)=614 (138; 1246), p>.05 (Shops/commercial access/availability **0**) 11. Restaurant, bar, or pub: Yes (n=78)=623 (92; 1050) vs. no (n=64)=623	

									(179; 1246), p>.05 (Food outlets access/availability **0**) 12. No. of destinations: 0 (n=14) 52 (0; 415) vs. 1 (n=15) 139 (0; 831) vs. 2-11 (n=120) 623 (196; 315), p=.0005 (Destinations/services (overall/unspecific) access/availability **+*0.73; 0*0.27**) 13. Walkability: Poor (n=16) 139 (0; 519) vs. fair (n=24) 364 (0; 1000) vs. good (n=62) 623 (176; 1246) vs. excellent (n=46) 692 (415; 1454), p=.0077 (Walkability **+**) ***Main effects with TotalSteps/d(median; 25th; 75th %tile):*** 1. Biking or walking trail: Yes (n=38)=6797 (515; 8331) vs. no (n=103)=4908 (3060; 6728), p=.0018 (Parks/public open space access/availability **+*0.270; 0*0.730**) 2. Bus stop: Yes (n=116)=5494 (3436; 7265) vs. no (n=27)=5105 (3610; 7786), p>.05 (Public transport access/availability **0**) 3. Café or coffee shop: Yes (n=82)=5657 (4021; 7588) vs. no (n=59)=5105 (2858; 7319), p>.05 (Food outlets access/availability **0**)	

										4. Church, synagogue, or religious institution: Yes (n=68)=5134 (3724; 6921) vs. no (n=74)=5695 (3244; 7747), p>.05 (Religious institution access/availability **0**) 5. Community centre: Yes (n=46)=5148 (3449; 7660) vs. no (n=93)=5694 (3677, 7319), p>.05 (Social recreational facilities access/availability **0**) 6. Convenience, deli, grocery store: Yes (n=89)=5732 (3859; 7212) vs. no (n=54)=5084 (2865; 7576), p>.05 (Shops/commercial access/availability **0**) 7. Department, discount, or hardware store: Yes (n=30)=6808 (5871; 8420) vs. no (n=111)=5015 (3060; 7021), p=.0022 (Shops/commercial access/availability **+*0.213; 0*0.787**) 8. Library: Yes (n=45)=5908 (4230; 8150) vs. no (n=97)=5116 (3281; 6889), p>.05 (Education facilities access/availability **0**) 9. Park: Yes (n=69)=6075 (4594; 8150) vs. no (n=75)=4802 (2908; 6305), p=.0044 (Parks/public open space	

									access/availability **+*0.479; 0*0.521**) 10. Post office: Yes (n=50)=5899 (3755; 8034) vs. no (n=92)=5132 (3225; 7051), p>.05 (Shops/commercial access/availability **0**) 11. Restaurant, bar, or pub: Yes (n=78)=5287 (3616; 7114) vs. no (n=64)=5580 (3243; 7592), p>.05 (Food outlets access/availability **0**) 12. No. of destinations: 0 (n=14) 2745 (1038; 4382) vs. 1 (n=15) 3281 (2449; 6801) vs. 2-11 (n=120) 5714 (3940; 7703), p<.0001 (Destinations/services (overall/unspecific) access/availability **+*0.73; 0*0.27**) 13. Walkability: Poor (n=16) 3376 (2449; 4961) vs. fair (n=24) 4258 (2532; 6812) vs. good (n=62) 5377 (3449; 6801) vs. excellent (n=46) 6349 (4877; 8749), p=.0008 (Walkability +)	
53	*No study name* Koh et al., 2015 [345]	N=168 (urban) 60-85+ years % female not reported Response rate not reported Community-dwellers Singapore	Cross-sectional Cluster: purposive Individuals: convenience Stratification: % of older adults/population density	Age, gender, cycling status, exercise duration, medical conditions, assistance from caregiver, working status, fall incidences	*Self-report [unnamed questionnaire; unvalidated]:* Neighbourhood walking (mins/wk) → Total walking *TotalWalking(mins/wk)*	*Perceived [unnamed questionnaire; unvalidated]:* 1. SecurityAM → Crime/personal safety 2. SecurityPM → Crime/personal safety 3. Detour (reach destinations without	None	General linear model	***Main effects with TotalWalking(mins/wk):*** 1. Daytime security: b=not reported, p>.05 (Crime/personal safety **0**) 2. Night-time security: b=not reported, p>.05 (Crime/personal safety **0**)	Table 5.

			Neighbourhood definition: region			barriers) → No physical barriers to walking 4. Road crossing delay → Street connectivity 5. Directional sign (adequate amount of street signage) → Traffic/pedestrian safety 6. Comfort1 (good walkway condition) → Pavement/footpath quality 7. Comfort3 (no obstacles along the walkway) → No physical barriers to walking 8. Stairs/slope → No physical barriers to walking 9. Traffic accident risk → Traffic/pedestrian safety 10. Shops1 (shops within walking distance) → Shops/commercial access/availability 11. Shops2 (eateries within walking distance) → Food outlets access/availability 12. Scenery1 (many trees) → Greenery and aesthetically pleasing scenery 13. Scenery2 (e.g., reservoir, park, lake etc.) → Parks/public open space access/availability 14. Recreational facilities 1 (activity centre) → Social			3. Detour: b=not reported, p>.05 (No physical barriers to walking **0**) 4. Road crossing delay: b=-409.60 (SE=187.52), p=.0307 (Street connectivity **+**) 5. Adequate amount of street signage: b=not reported, p>.05 (Traffic/pedestrian safety **0**) 6. Comfort1 (good walkway condition): b=not reported, p>.05 (Pavement/footpath quality **0**) 7. Comfort3 (no obstacles in the way): b=not reported, p>.05 (No physical barriers to walking **0**) 8. Stairs/slope: b=not reported, p>.05 (No physical barriers to walking **0**) 9. Traffic accident risk: b=not reported, p>.05 (Traffic/pedestrian safety **0**) 10. Shops1: b=1036.49 (SE=354.43), p=.0040 (Shops/commercial access/availability **+**) 11. Shops2 (eateries): b=-1143.06 (SE=406.81), p=.0057 (Food outlets access/availability -) 12. Scenery1: b=not reported, p>.05 (Greenery and aesthetically pleasing scenery **0**)	

						recreational facilities access/availability 15. Recreational facilities 2 (fitness corner) → Recreational facilities access/availability 16. Recreational facilities 3 (sheltered social spaces) → Social recreational facilities access/availability 17. Weather protection (e.g., covered walkways) → Walk-friendly infrastructure			13. Scenery2: b=not reported, p>.05 (Parks/public open space access/availability **0**) 14. Recreational facilities 1 (activity centre): b=not reported, p>.05 (Social recreational facilities access/availability **0**) 15. Recreational facilities 2 (fitness corner): b=not reported, p>.05 (Recreational facilities access/availability **0**) 16. Recreational facilities 3 (sheltered social space): b=331.53 (SE=179.85), p=.0675 (Social recreational facilities access/availability **0**) 17. Weather protection: b=not reported, p>.05 (Walk-friendly infrastructure **0**)	
54	None Kolbe-Alexander et al., 2015 [458]	N=44 (urban) Mean age: 65 years 78% female Response rate not reported Community-dwellers Cape Town, South Africa	Cross-sectional Cluster: purposive Individuals: convenience Stratification: area-level SES Neighbourhood definition: participant delineation	None	*Self-report [Global Physical Activity Questionnaire; validated]:* Total MVPA (150+ mins/wk; Yes/No) → Total MVPA *TotalMVPA(150+ mins/wk; Yes/No)* *Objective [ActiGraph accelerometer; validated; Matthews MVPA cutoff point≥2020 cpm; validated]:* Total MVPA (150+	*Perceived [NEWS questionnaire; validated]:* 1. Residential density → Residential density 2. Land-use mix: diversity → Land-use mix—destination diversity 3. Land-use mix: access → Destinations/services (overall/unspecific) access/availability 4. Street connectivity → Street connectivity 5. Walk/cycle infrastructure →	Area-level SES: Low SES (n=24), High SES (n=20)	Spearman's correlation coefficient. No testing of interaction terms. No adjustment for suburb cluster	***Main effects with self-reported*** ***TotalMVPA(150+ mins/wk; Yes/No):*** 1. Residential density: *Low SES: R^2*=not reported, p>.05 *High SES: R^2*=not reported, p>.05 (Residential density **0*0.55; 0*0.45**) 2. Land-use mix: diversity: *Low SES: R^2*=not reported, p>.05 *High SES: R^2*=not reported, p>.05 (Land-use mix—destination diversity	SES effects. Table 5.

					mins/wk; Yes/No) → Total MVPA *TotalMVPAMatthews(150+ mins/wk; Yes/No)*	Cycle/walk-friendly infrastructure 6. Aesthetics → Greenery and aesthetically pleasing scenery 7. Safety from traffic → Traffic/pedestrian safety 8. Safety from crime → Crime/personal safety			**0*0.55; 0*0.45**) 3. Land-use mix: access: *Low SES: R^2*=not reported, p>.05 *High SES: R^2*=not reported, p>.05 (Destinations/services (overall/unspecific) access/availability **0*0.55; 0*0.45**) 4. Street connectivity: *Low SES: R^2*=not reported, p>.05 *High SES: R^2*=not reported, p>.05 (Street connectivity **0*0.55; 0*0.45**) 5. Walk/cycle infrastructure: *Low SES: R^2*=not reported, p>.05 *High SES: R^2*=not reported, p>.05 (Cycle/Walk-friendly infrastructure **0*0.55; 0*0.45**) 6. Aesthetics: *Low SES: R^2*=not reported, p>.05 *High SES: R^2*=not reported, p>.05 (Greenery and aesthetically pleasing scenery **0*0.55; 0*0.45**) 7. Safety from traffic: *Low SES: R^2*=not reported, p>.05 *High SES: R^2*=not reported, p>.05 (Traffic/pedestrian safety **0*0.55; 0*0.45**) 8. Safety from crime: *Low SES: R^2*=0.41, p=.04 (Crime/personal safety **+*0.55**) *High SES: R^2*=not	

									reported, p>.05 (Crime/personal safety **0*0.45**) ***Main effects with objectively measured TotalMVPAMatthews(150+ mins/wk; Yes/No):*** 1. Residential density: *Low SES: R^2*=not reported, p>.05 *High SES: R^2*=not reported, p>.05 (Residential density **0*0.55; 0*0.45**) 2. Land-use mix: diversity: *Low SES: R^2*=not reported, p>.05 *High SES: R^2*=not reported, p>.05 (Land-use mix—destination diversity **0*0.55; 0*0.45**) 3. Land-use mix: access: *Low SES: R^2*=not reported, p>.05 *High SES: R^2*=not reported, p>.05 (Destinations/services (unspecified) **0*0.55; 0*0.45**) 4. Street connectivity: *Low SES: R^2*=not reported, p>.05 *High SES: R^2*=not reported, p>.05 (Street connectivity **0*0.55; 0*0.45**) 5. Walk/cycle infrastructure: *Low SES: R^2*=not reported, p>.05 *High SES: R^2*=not reported, p>.05 (Cycle/Walk-friendly	

									infrastructure **0*0.55; 0*0.45**) 6. Aesthetics: *Low SES: R^2*=not reported, p>.05 *High SES: R^2*=not reported, p>.05 (Greenery and aesthetically pleasing scenery **0*0.55; 0*0.45**) 7. Safety from traffic: *Low SES: R^2*=not reported, p>.05 *High SES: R^2*=not reported, p>.05 (Traffic/pedestrian safety **0*0.55; 0*0.45**) 8. Safety from crime: *Low SES: R^2*=not reported, p>.05 *High SES: R^2*=not reported, p>.05 (Crime/personal safety **0*0.55; 0*0.45**)	
55	*No study name* Lee & Park, 2015 [346]	N=437 (mixed) 65+ years 100% female Response rate not reported Dwelling not reported Seongnam City and South Chungnam Province, South Korea	Cross-sectional Cluster: purposive Individuals: convenience Stratification: population size, population density (urbanisation) and importance for primary industry Neighbourhood definition: 15-20mins walk from home	Age, income, education, social support, attitude, intention, self-efficacy	*Self-report [unnamed questionnaire; unvalidated]:* Total walking (mins/wk) → Total walking *TotalWalking(150+ mins; Yes/No)*	*Perceived: [NEWS questionnaire; validated]:* 1. Proximity to parks → Parks/public open space access/availability 2. Proximity to stores → Shops/commercial access/availability 3. Street trees → Greenery and aesthetically pleasing scenery 4. Traffic safety → Traffic/pedestrian safety 5. Street lights → Street lighting 6. Crime safety → Crime/personal safety	Urbanisation: Rural (n=221), Urban (n=216)	Logistic regression	***Main effects with TotalWalking(150+ mins/wk; Yes/No):*** 1. Proximity to parks—OR (95% CIs): *Urban:* OR=0.68 (0.24; 1.94) p=.47 (Parks/public open space access/availability **0*0.49**) *Rural:* OR=3.02 (1.07; 8.56) p=.04 (Parks/public open space access/availability **+*0.51**) 2. Proximity to stores: *Urban:* OR=1.69 (0.63; 4.59) p=.30 *Rural:* OR=0.43 (0.12; 1.54) p=.20 (Shops/commercial access/availability	Urbanisation effects. Table 4.

									0*0.49; 0*0.51) 3. Street trees: *Urban:* OR=2.07 (0.76; 5.68) p=.16 (Greenery and aesthetically pleasing scenery **0*0.49**) *Rural:* OR=2.73 (1.02; 7.34) p=.04 (Greenery and aesthetically pleasing scenery **+*0.51**) 4. Traffic safety: *Urban:* OR=1.05 (0.49; 2.24) p=.90 *Rural:* OR=1.00 (0.40; 2.47) p=1.0 (Traffic/pedestrian safety **0*0.49; 0*0.51**) 5. Street lights: *Urban:* OR=0.61 (0.25; 1.51) p=.28 *Rural:* OR=1.73 (0.63; 4.79) p=.29 (Street lighting **0*0.49; 0*0.51**) 6. Crime safety: *Urban:* OR=2.68 (1.06; 6.77) p=.04 (Crime/personal safety **+*0.49**) *Rural:* OR=1.15 (0.51; 2.56) p=.74 (Crime/personal safety **0*0.51**)	
56	*No study name* Lotfi & Koohsari, 2011 [459]	N=238 (urban) 65+ years % female not reported Response rate not reported Dwelling not reported Tehran, Iran	Cross-sectional Cluster: purposive Individuals: random Stratification: walkability and social vulnerability (proxy for SES) Neighbourhood	None	*Self-report [unnamed questionnaire; unvalidated]:* Total walking (10+ mins/occurrence) → Total walking *TotalWalking(10+ mins/occurrence; Yes/No)*	*Objective [Tehran Traffic Control Centre; Statistical Centre of Iran; unvalidated]:* 1. Walkability → Walkability	Walkability*SES: High + Low (n=48), Low + Low (n=40), High + High (n=65), Low + High (n=85)	*No formal analysis conducted—percentages reported*	***Association with TotalWalking(10+ min/occurrence; Yes/No):*** 1. Walkability: High walkability + low social vulnerability: Less than 2 times/wk: 10% 2-5 times/wk: 30% 6-10 times/wk: 36%	Moderating effects. Table 4.

			definition: administrative boundary						≥10 times/wk: 24% High walkability + high social vulnerability: Less than 2 times/wk: 12% 2-5 times/wk: 24% 6-10 times/wk: 42% ≥10 times/wk: 22% Low walkability + low social vulnerability: Less than 2 times/wk: 21% 2-5 times/wk: 47% 6-10 times/wk: 28% ≥10 times/wk: 4% Low walkability + high social vulnerability: Less than 2 times/wk: 23% 2-5 times/wk: 54% 6-10 times/wk: 17% ≥10 times/wk: 6% (Walkability **+*0.37; 0*0.63**)	
57	*No study name* Maisel et al., 2016 [460]	N=121 (mixed) 65+ years 74% female Response rate not reported Community-dwellers Erie County NY, USA	Cross-sectional Cluster: purposive Individuals: convenience Stratification: area-level SES and urbanisation Neighbourhood definition: participant delineation	Age, sex, household income	*Self-report [IPAQ; validated]:* Total neighbourhood walking (>0 mins/wk; Yes/No) → Total walking *TotalWalking(>0 mins/wk; Yes/No)*	*Perceived [NEWS questionnaire; validated]:* 1. Residential density → Residential density 2. Street connectivity → Street connectivity 3. Land-use mix: access → Destinations/services (overall/unspecific) access/availability 4. Land-use mix: diversity → Land-use mix—destination diversity 5. Aesthetics → Greenery and aesthetically pleasing scenery 6. Walking/cycling	Urbanisation: Rural (n=39), Suburban (n=50), Urban (n=32)	Logistic regression. No testing of interaction terms. No adjustment for senior centre cluster. Continuous environmental exposure variables categorised.	***Main and moderated effects with TotalWalking(>0 mins/wk; Yes/No):*** 1. Residential density—OR (95% CIs): *Overall participants:* OR=not reported, p>.05 (Residential density **0*1**) 2. Street connectivity: *Overall participants:* OR=2.34 (1.07; 5.10), p<.05 (Street connectivity **+*1**) 3. Land-use mix: access: *Rural participants:* OR=not reported, p>.05 *Suburban participants:* OR=not reported, p=.009 *Urban participants:* OR=not reported, p>.05 (Destinations/services	Moderating effects.

						facilities → Cycle/walk-friendly infrastructure 7. Crime safety → Crime/personal safety 8. Traffic safety → Traffic/pedestrian safety			(unspecified access/availability **0*0.32; 0*0.41; 0*0.27**) 4. Land-use mix: diversity: *Overall participants:* OR=not reported, p>.05 (Land-use mix—destination diversity **0*1**) 5. Aesthetics: *Overall participants:* OR=not reported, p>.05 (Greenery and aesthetically pleasing scenery **0*1**) 6. Walking/cycling facilities: *Overall participants:* OR=not reported, p>.05 (Cycling/Walk-friendly infrastructure **0*1**) 7. Crime safety: *Rural participants:* OR=11.23 (1.67; 77.56), p<.05 (Crime/personal safety **+*0.32**) *Suburban participants:* OR=not reported, p>.05 (Crime/personal safety **0*0.41**) *Urban participants:* OR=not reported, p>.05 (Crime/personal safety **0*0.27**) 8. Traffic safety: *Overall participants:* OR=not reported, p>.05 (Traffic/pedestrian safety **0*1**)	
58	*No study name* Mowen et al., 2007 [461]	N=1515 (not reported) Mean age: 67 years 66% female	Cross-sectional Cluster: purposive Individuals: random	None	*Self-report [unnamed questionnaire; unvalidated]:* Total PA (ordinal	*Perceived [unnamed questionnaire; unvalidated]:* 1. Park within walking	None	Univariate linear regression	***Main effects with TotalPA(score):*** Perceived environment: 1. Park within walking distance:	Table 1.

		45% response rate Community-dwellers Ohio, USA	Stratification: SES and sociodemographics (unspecified) Neighbourhood definition: participant delineation – “walking distance from home” (perceived), nearest park (objective)		score) → Total PA *TotalPA(score)*	distance → Parks/public open space access/availability *Objective [GIS; unvalidated]:* 2. Distance to closest park → Parks/public open space access/availability			b=0.025, p=.581 (Parks/public open space access/availability **0**) Objective environment: 2. Distance to closest park: b=-0.042, p=.354 (Parks/public open space access/availability **0**)	
59	*No study name* Pelclova et al.,2012 [462]	N=456 (not reported) Mean age: ≈65 years 88% female Response rate not reported Community-dwellers Zlin, Olomouc, Usit, Labem and Brno, Czech Republic; Katowice, Poland; Presov, Slovakia	Cross-sectional Cluster: none Individuals: all eligible participants enrolled in University of Third Age invited Stratification: none Neighbourhood definition: participant delineation	None (no socio-demographics). Perceived environmental variables were entered as covariates	*Self-report [IPAQ—Polish and Slovakian translation; validated]:* Total walking (30+ mins/d*5 d/wk) → Total walking *TotalWalking(30+ mins/d*5d/wk; Yes/No)*	*Perceived [NEWS questionnaire—modified version; unvalidated]:* 1. Residential density → Residential density 2. Land-use mix: proximity → Destinations/services (overall/unspecific) access/availability 3. Accessibility → Destinations/services (overall/unspecific) access/availability 4. Street connectivity → Street connectivity 5. Infrastructure for walking/cycling → Cycle/walk-friendly infrastructure 6. Neighbourhood aesthetics → Greenery and aesthetically pleasing scenery	None	Multivariate logistic regression (study site not accounted for).	***Main effects with TotalWalking(30+ mins/d*5 d/wk; Yes/No):*** 1. Residential density—OR (95% CIs): OR=1.81 (1.13; 2.89), p<.05 (Residential density **+**) 2. Land-use mix: proximity: OR=0.92 (0.60; 1.42), p>.05 (Destinations/services (overall/unspecific) access/availability **0**) 3. Accessibility: OR=1.16 (0.46; 2.94), p>.05 (Destinations/services (overall/unspecific) access/availability **0**) 4. Street connectivity: OR=0.75 (0.20; 2.80), p>.05 (Street connectivity **0**) 5. Infrastructure for walking/cycling: OR=1.17 (0.54; 2.54), p>.05 (Cycling/Walk-friendly infrastructure **0**)	Table 2.

									6. Neighbourhood aesthetics: OR=1.61 (0.92; 2.81), p>.05 (Greenery and aesthetically pleasing scenery **0**)	
60	*No study name* Persson et al., 2011 [463]	N=225 (urban) Mean age: 75 years 77% female 88.6% response rate Community-dwellers London, United Kingdom	Cross-sectional Cluster: purposive Individuals: convenience Stratification: Boroughs with high percentage of older adults and health inequalities Neighbourhood definition: not defined	Age, sex, education, borough lived in, living with someone, social class, ethnicity, health status, health problems, smoking status, BMI	*Self-report [unnamed questionnaire; unvalidated]:* Sufficient PA (30+ mins/d*5 d/wk) → Total MVPA *TotalMVPA(30+ mins/d*5d/wk; Yes/No)*	*Perceived [unnamed questionnaire; unvalidated]:* 1. Good facilities for exercising → Recreational facilities access/availability 2. Access to public transport → Public transport access/availability 3. Feel safe walking outside when dark → Crime/personal safety 4. Good leisure and social facilities in general → Social recreational facilities access/availability 5. Good facilities for people aged 60+ years → Social recreational facilities access/availability 6. Graffiti and vandalism → Greenery and aesthetically pleasing scenery 7. Access to public outdoor areas → Parks/public open space access/availability 8. Proximity to shops → Shops/commercial access/availability 9. Proximity to health services → Health and	None	Forward stepwise logistic regression	***Main effects with TotalMVPA(30+ mins/d*5d/wk; Yes/No):*** 1. Good facilities for exercising—OR (95% CIs): OR=not reported, p=.047 (Recreational facilities access/availability **+**) 2. Access to public transport: OR=2.04 (not reported), p>.05 (Public transport access/availability **0**) 3. Feel safe walking outside when dark: OR=1.33 (not reported), p>.05 (Crime/personal safety **0**) 4. Good leisure and social facilities: OR=1.88 (0.42; 8.53), p>.05 (Social recreational facilities access/availability **0**) 5. Good facilities for people aged 60+ years: OR=1.26 (0.39; 4.07), p>.05 (Social recreational facilities access/availability **0**) 6. Graffiti and vandalism: OR=0.57 (0.22; 1.45), p>.05 (Greenery and	In-text.

						aged care access/availability 10. Litter and rubbish collection → Greenery and aesthetically pleasing scenery 11. Speed and volume of traffic → Traffic/pedestrian safety 12. Crime → Crime/personal safety 13. Air pollution → Pollution			aesthetically pleasing scenery **0**) 7. Access to public outdoor areas: OR=not reported, p>.05 (Parks/public open space access/availability **0**) 8. Proximity to shops: OR=not reported, p>.05 (Shops/commercial access/availability **0**) 9. Proximity to health services: OR=not reported, p>.05 (Health and aged care access/availability **0**) 10. Litter and rubbish collection: OR=not reported, p>.05 (Greenery and aesthetically pleasing scenery **0**) 11. Speed and volume of traffic: OR=not reported, p>.05 (Traffic/pedestrian safety **0**) 12. Crime: OR=not reported, p>.05 (Crime/personal safety **0**) 13. Air pollution: OR=not reported, p>.05 (Pollution **0**)	
61	*No study name* Salvador et al., 2010 [356]	N=385 (urban) 60-74 years 61% female 72.6% response rate Community-dwellers Sao Paulo, Brazil	Cross-sectional Cluster: purposive Individuals: random Stratification: census tracts (SES) Neighbourhood definition: 15-20mins walk from home	Age, education	*Self-report [IPAQ; validated]:* Walking (150+ mins/wk; Yes/No) → Total walking *TotalWalking(150+ mins/wk; Yes/No)*	*Perceived [NEWS questionnaire—Brazilian version; unvalidated]:* 1. Presence of [meeting] square → Parks/public open space access/availability 2. Presence of social places (bars) → Social	Sex: Male (n=152), Female (n=233)	Multivariate logistic regression	***Main effects*** ***TotalWalking(150+ mins/wk; Yes/No):*** 1. Presence of [meeting] square—OR (95% CIs): *Males:* OR=not reported, p>.05 (Parks/public open space access/availability **0*0.39**) *Females:* OR=4.70 (95% CI=1.43; 15.43), p=.012	Sex effects. Tables 3 and 4.

					Recreational facilities access/availability 3. Walking time to parks → Parks/public open space access/availability 4. Walking time to public squares → Parks/public open space access/availability 5. Walking time to places to walk → Destinations/services (overall/unspecific) access/availability 6. Walking time to gyms → Recreational facilities access/availability 7. Walking time to clubs → Recreational facilities access/availability 8. Walking time to sport courts → Recreational facilities access/availability 9. Walking time to soccer fields → Recreational facilities access/availability 10. Walking time to bus stops → Public transport access/availability 11. Walking time to train stations → Public transport access/availability 12. Walking time to health clinics → Health and aged care access/availability 13. Walking time to pharmacies → Health			(Parks/public open space access/availability **+*0.61**) 2. Presence of social places (bar): *Males:* OR=not reported, p>.05 *Females:* OR=2.28 (0.13; 41.25), p=.566 (Social recreational facilities access/availability **0*0.39; 0*0.61**) 3. Walking time to parks: *Males:* OR=not reported, p>.05 *Females:* OR=not reported, p>.05 (Parks/public open space access/availability **0*0.39; 0*0.61**) 4. Walking time to public squares: *Males:* OR=not reported, p>.05 *Females:* OR=not reported, p>.05 (Parks/public open space access/availability **0*0.39; 0*0.61**) 5. Walking time to places to walk: *Males:* OR=2.23 (0.67; 7.40), p=.181 *Females:* OR=2.23 (0.67; 7.40), p=.181 (Destinations/services (overall/unspecific) access/availability **0*0.39; 0*0.61**) 6. Walking time to gyms: *Males:* OR=not reported, p>.05 *Females:* OR=not reported, p>.05 (Recreational facilities	

						and aged care access/availability 14. Walking time to churches or religious temples → Religious institution access/availability 15. Walking time to bakeries → Food outlets access/availability 16. Walking time to bank branches → Government/finance access/availability 17. Walking time to bars → Social recreational facilities access/availability 18. Walking time to street fairs → Social recreational facilities access/availability 19. Walking time to stores → Shops/commercial access/availability 20. Walking time to markets → Shops/commercial access/availability 21. Walking time to supermarkets → Shops/commercial access/availability 22. Presence and quality of pavements/sidewalks → Pavement/footpath quality 23. Presence and quality of green areas → Parks/public open space 24. Streets steepness → No physical barriers			access/availability **0*0.39; 0*0.61**) 7. Walking time to clubs: *Males:* OR=not reported, p>.05 *Females:* OR=not reported, p>.05 (Recreational facilities access/availability **0*0.39; 0*0.61**) 8. Walking time to sports courts: *Males:* OR=not reported, p>.05 *Females:* OR=not reported, p>.05 (Recreational facilities access/availability **0*0.39; 0*0.61**) 9. Walking time to soccer fields: *Males:* OR=3.43 (1.46; 8.10), p=.006 (Recreational facilities access/availability **+*0.39**) *Females:* OR=1.58 (0.64; 3.90), p=.307 (Recreational facilities access/availability **0*0.61**) 10. Walking time to bus stops: *Males:* OR=not reported, p>.05 *Females:* OR=not reported, p>.05 (Public transport access/availability **0*0.39; 0*0.61**) 11. Walking time to train stations: *Males:* OR=not reported, p>.05 *Females:* OR=not reported, p>.05	

						to walking 25. Presence of litter → Greenery and aesthetically pleasing scenery 26. Absence of open-air sewers → Pollution 27. Heavy traffic → Traffic/pedestrian safety 28. Pedestrian crossing close to home → Street connectivity 29. Drivers usually respect pedestrians on crossing → Traffic/pedestrian safety 30. Street lights close to home, well lit at night → Street lighting 31. Safe to walk during day → Crime/personal safety 32. Safe to walk during night → Crime/personal safety 33. Presence of soccer fields → Recreational facilities access/availability 34. Presence of places to walk in the district → Destinations/services (overall/unspecific) access/availability 35. Smoke pollution close to home → Pollution			(Public transport access/availability **0*0.39; 0*0.61**) 12. Walking time to health clinics: *Males:* OR=not reported, p>.05 (Health and aged care access/availability **0*0.39**) *Females:* OR=3.71 (1.19; 11.54), p=.025 (Health and aged care access/availability **+*0.61**) 13. Walking time to pharmacies: *Males:* OR=not reported, p>.05 *Females:* OR=2.45 (0.88; 6.81), p=.084 (Health and aged care access/availability **0*0.39; 0*0.61**) 14. Walking time to churches or religious temples: *Males:* OR=not reported, p>.05 *Females:* OR=not reported, p>.05 (Religious institution access/availability **0*0.39; 0*0.61**) 15. Walking time to bakeries: *Males:* OR=not reported, p>.05 *Females:* OR=not reported, p>.05 (Food outlets access/availability **0*0.39; 0*0.61**) 16. Walking time to bank branches: *Males:* OR=not reported,	

									p>.05 *Females:* OR=not reported, p>.05 (Government/finance services access/availability **0*0.39; 0*0.61**) 17. Walking time to bars: *Males:* OR=not reported, p>.05 *Females:* OR=not reported, p>.05 (Social recreational facilities access/availability **0*0.39; 0*0.61**) 18. Walking time to street fairs: *Males:* OR=not reported, p>.05 *Females:* OR=not reported, p>.05 (Social recreational facilities access/availability **0*0.39; 0*0.61**) 19. Walking time to stores: *Males:* OR=not reported, p>.05 *Females:* OR=not reported, p>.05 (Shops/commercial access/availability **0*0.39; 0*0.61**) 20. Walking time to markets: *Males:* OR=not reported, p>.05 *Females:* OR=not reported, p>.05 (Shops/commercial access/availability **0*0.39; 0*0.61**) 21. Walking time to supermarkets:	

									Males: OR=not reported, p>.05 *Females:* OR=not reported, p>.05 (Shops/commercial access/availability **0*0.39; 0*0.61**) 22. Presence and quality of pavements/sidewalks: *Males:* OR=not reported, p>.05 *Females:* OR=not reported, p>.05 (Pavement/footpath quality **0*0.39; 0*0.61**) 23. Presence and quality of green areas: *Males:* OR=not reported, p>.05 *Females:* OR=not reported, p>.05 (Parks/public open space access/availability **0*0.39; 0*0.61**) 24. Streets steepness: *Males:* OR=not reported, p>.05 *Females:* OR=not reported, p>.05 (No physical barriers to walking **0*0.39; 0*0.61**) 25. Presence of litter: *Males:* OR=not reported, p>.05 *Females:* OR=not reported, p>.05 (Greenery and aesthetically pleasing scenery **0*0.39; 0*0.61**) 26. Absence of open-air sewers: *Males:* OR=2.18 (0.56; 8.52), p=.253 *Females:* OR=not reported, p>.05 (Pollution **0*0.39;**	

									0*0.61) 27. Heavy traffic: *Males:* OR=not reported, p>.05 *Females:* OR=2.88 (0.99; 8.41), p=.052 (Traffic/pedestrian safety **0*0.39; 0*0.61**) 28. Pedestrian crossing close to home: *Males:* OR=not reported, p>.05 *Females:* OR=not reported, p>.05 (Street connectivity **0*0.39; 0*0.61**) 29. Drivers usually respect pedestrians on crossing: *Males:* OR=not reported, p>.05 *Females:* OR=5.29 (0.90; 31.10), p=.064 (Traffic/pedestrian safety **0*0.39; 0*0.61**) 30. Street lights close to home, well lit at night: *Males:* OR=2.00 (0.45; 8.90), p=.353 *Females:* OR=not reported, p>.05 (Street lighting **0*0.39; 0*0.61**) 31. Safe to walk during the day: *Males:* OR=not reported, p>.05 *Females:* OR=not reported, p>.05 (Crime/personal safety **0*0.39; 0*0.61**) 32. Safe to walk during the night: *Males:* OR=1.53 (0.41; 5.61) p=.514 *Females:* OR=not	

									reported, p>.05 (Crime/personal safety **0*0.39; 0*0.61**) 33. Presence of soccer fields: *Males:* OR=4.12 (1.41; 12.02), p=.011 (Recreational facilities access/availability **+*0.39**) *Females:* OR=not reported, p>.05 (Recreational facilities access/availability **0*0.61**) 34. Presence of places to walk in the district: *Males:* OR=2.23 (0.67; 7.40), p=.181 *Females:* OR=not reported, p>.05 (Destinations/services (overall/unspecific) access/availability **0*0.39; 0*0.61**) 35. Smoke pollution close to home: *Males:* OR=2.23 (0.67; 7.40), p=.181 *Females:* OR=not reported, p>.05 (Pollution **0*0.39; 0*0.61**)	
62	*No study name* Sewo Sampaio et al., 2013 [464]	N=465 (mixed) Mean age: 69.0 years 48.7% female 56% response rate Community-dwellers *Multiple locations,* Japan	Cross-sectional Cluster: purposive Individuals: convenience Stratification: urbanisation Neighbourhood definition: urban and rural	None	*Self-report [unnamed questionnaire; unvalidated]:* Physical activity times/wk (e.g., walking, sports etc.) → Total PA *TotalPA(median times/wk)*	*Objective [census data; unvalidated]:* 1. Urbanisation → Urbanisation	Urbanisation: Rural (n=178) Urban (n=287)	Chi-square test	***Main effects with TotalPA(median times/wk):*** 1. Urbanisation: Rural vs. Urban: 3 vs. 4, p<.01 (Urbanisation +)	Table 3.

63	*No study name* Shin et al., 2011 [465]	N=80 (urban) Mean age: 66.8 years 100% female 33.9% response rate Community-dwellers Texas, USA	Cross-sectional Cluster: purposive Individuals: purposive and convenient (2 distinct stages) Stratification: sex and ethnicity (≥80% African-American/census block) Neighbourhood definition: 0.5mile, and 1mile buffer	Age, employment status, household members, self-rated health	*Self-report [CHAMPS questionnaire—modified version; unvalidated]:* Total PA (caloric expenditure/wk/kg → TotalPA *TotalPA(cal/wk/kg)*	*Objective [GIS, ENVI, FRAGSTATS; unvalidated]:* 1. Density of green spaces → Parks/public open space access/availability 2. Number of accessible green spaces → Parks/public open space access/availability 3. Greenery density → Greenery and aesthetically pleasing scenery 4. Street greenery density → Aesthetics and greenspace 5. Land-use mix → Land-use mix—destination diversity 6. Intersection density → Street connectivity 7. Cul-de-sac density → Street connectivity 8. Street density → Street connectivity 9. Commercial density → Shops/commercial access/availability 10. Sidewalk connectivity → Walk-friendly infrastructure 11. Distance to closest green space → Parks/public open space access/availability 12. Distance to closest commercial area → Shops/commercial access/availability 13. Distance to closest school → Education	None	Path analyses	***Main effects with TotalPA(cal/wk/kg):*** 1. Density of green spaces: *0.5 mile:* b=not reported, p>.05 *1 mile:* b=not reported, p>.05 (Parks/public open space access/availability **0*0.5; 0*0.5**) 2. Number of accessible green spaces: *0.5 mile:* b=not reported, p>.05 *1 mile:* b=not reported, p>.05 (Parks/public open space access/availability **0*0.5; 0*0.5**) 3. Greenery density: *0.5 mile:* b=4.99, p=.07) *1 mile:* b=not reported, p>.05 (Greenery and aesthetically pleasing scenery 0***0.5; 0*0.5**) 4. Street greenery density: *0.5 mile:* b=not reported, p>.05 *1 mile:* b=not reported, p>.05 (Greenery and aesthetically pleasing scenery **0*0.5; 0*0.5**) 5. Land-use mix: *0.5 mile:* b=not reported, p>.05 *1 mile:* b=not reported, p>.05 (Land-use mix—destination diversity **0*0.5; 0*0.5**) 6. Intersection density: *0.5 mile:* b=not reported,	Table 6.

						facilities access/availability 14. Distance to closest church → Religious institution access/availability			p>.05 *1 mile:* b=0.24, p=.10 (Street connectivity **0*0.5; 0*0.5**) 7. Cul-de-sac density: *0.5 mile:* b=not reported, p>.05 *1 mile:* b=not reported, p>.05 (Street connectivity **0*0.5; 0*0.5**) 8. Street density: *0.5 mile:* b=not reported, p>.05 *1 mile:* b=not reported, p>.05 (Street connectivity **0*0.5; 0*0.5**) 9. Commercial density: *0.5 mile:* b=not reported, p>.05 *1 mile:* b=not reported, p>.05 (Shops/commercial access/availability **0*0.5; 0*0.5**) 10. Sidewalk connectivity: *0.5 mile:* b=not reported, p>.05 *1 mile:* b=not reported, p>.05 (Walk-friendly infrastructure **0*0.5; 0*0.5**) 11. Distance to closest green space: *0.5 mile:* b=not reported, p>.05 *1 mile:* b=not reported, p>.05 (Parks/public open space access/availability **0*0.5; 0*0.5**) 12. Distance to closest commercial area:	

									0.5 mile: b=not reported, p>.05 *1 mile:* b=not reported, p>.05 (Shops/commercial access/availability **0*0.5; 0*0.5**) 13. Distance to closest school: *0.5 mile:* b=not reported, p>.05 *1 mile:* b=not reported, p>.05 (Education facilities access/availability **0*0.5; 0*0.5**) 14. Distance to closest church: *0.5 mile:* b=not reported, p>.05 *1 mile:* b=not reported, p>.05 (Religious institution access/availability **0*0.5; 0*0.5**)	
64	*No study name* Shores et al., 2009 [466]	N=449 (rural) 65+ years 46.8% female 38% response rate Community-dwellers Western North Carolina, USA	Cross-sectional Cluster: purposive Individuals: random Stratification: population density (urbanisation) Neighbourhood definition: county level	Age, sex, BMI, income	*Self-report [unnamed questionnaire; unvalidated]:* Achievers (MPA/VPA: 20+ mins/d*5 d/wk) → Total MVPA *TotalMVPA(20+ mins/d*5 d/wk; Yes/No)*	*Perceived [unnamed questionnaire; unvalidated]:* 1. Concerned about safety in recreation areas → Crime/personal safety 2. Walking distance to a park → Parks/public open space access/availability 3. Recreational facilities close to home → Recreational facilities access/availability 4. Access to recreational facilities via [public] transport → Public transport	None	ANCOVA	***Main effects with TotalMVPA(20+ mins/d*5+ d/wk; Yes/No):*** 1. Concerned about safety in recreation areas: f=12.6, p=.001 (Crime/personal safety **+**) 2. Walking distance to a park: f=3.94, p=.049 (Parks/public open space access/availability **+**) 3. Recreational facilities close to home: f=7.05, p=.009 (Recreational facilities access/availability **+**) 4. Access to recreational	Table 2.

						access/availability *Perceived [NEWS questionnaire; validated]:* 5. "Walkability": Sidewalk quality, presence of a sidewalk, separation from traffic → Walk-friendly infrastructure			facilities via [public] transport: f=1.55, p=.215 (Public transport **0**) 5."Walkability": f=2.09, p=.063 (Walk-friendly infrastructure **0**)	
65	*No study name* Tanaka et al., 2016 [467]	N=108 (urban) 65+ years 100% female Response rate not reported Community-dwellers Nagasaki City, Japan	Cross-sectional Cluster: purposive Individuals: convenience Stratification: land slope Neighbourhood definition: a place where the ground rises 20m above sea level or ≥5° angle	Comorbidities, pulmonary function, muscle force, depressive symptoms	*Objective [Lifecorder accelerometer; validated]:* Total PA (mean counts/d) → Total PA *TotalPA(counts/d)* Total PA (activity times/d) → Total PA *TotalPA(activity times/d)*	*Objective [Public Health Nursing Care Insurance index; unvalidated]:* 1. Slope → No physical barriers to walking	None	Multivariate logistic regression	***Main effects with TotalPA(counts/d):*** 1. Slope—b; OR (95% CIs): b=-2.001; OR=0.779 (0.715; 0.841), p=.002 (No physical barriers to walking **+**) ***Main effects with TotalPA(activity times/d):*** 1. Slope: b=-.189; OR=0.821 (0.801; 0.913), p=.004 (No physical barriers to walking **+**)	Table 3.
66	*No study name* Towne Jr., 2016 [468]	N=394 (urban) Mean age: 65 years 54% female 6.8% response rate Community-dwelling Texas, USA	Cross-sectional Cluster: convenience Individuals: convenience Stratification: none Neighbourhood definition: ≤30mins from home	Age, sex, race, household income, someone to walk with, marital status, physical function (difficulty with walking), median income (census level)	*Self-report [unnamed questionnaire; unvalidated]:* Total walking (any purpose-- 150+ mins/wk; Yes/No) → Total walking *TotalWalking(150+ mins/wk; Yes/No)*	*Objective [Walk Score™; unvalidated]:* 1. Walk Score™ → Walkability *Perceived [unnamed questionnaire; unvalidated]:* 2. *Aggregated variable:* Perceived neighbourhood environment → Crime/personal safety	None	Multivariate logistic regression	***Main effects with TotalWalking(150+ mins/wk; Yes/No):*** 1. Walk Score™ (Ref:<50)—OR (90% CIs): 50+: OR =3.171 (1.480; 6.797), p=.0128 (Walkability **+**) 2. Perceived neighbourhood environment (Ref: Low): Medium: OR =1.862 (1.059; 3.275) High: OR=2.671 (1.404; 5.082), p=.0406 (Crime/personal safety **+**)	Table 3.

67	*No study name* Wang & Lee 2010 [469]	N=114 and n=61 (urban) Mean age: 84 years 81.6% female 20-45% response rates Assisted-living facility residents Texas, USA	Cross-sectional Cluster: convenience Individuals: convenience Stratification: none Neighbourhood definition: not defined	None	*Self-report [unnamed questionnaire; unvalidated]:* Neighbourhood walking at previous address (when community-dwelling) (1+ walks/d) → Total walking *TotalWalking(1+ walks/d; Yes/No)* Neighbourhood walking at previous address (when community-dwelling) (10+ mins/walking occurrence) → Total walking *TotalWalking(10+ mins/occurrence; Yes/No)*	*Perceived [unnamed questionnaire; unvalidated]:* Neighbourhood environment: 1. Number of walking destinations → Destinations/services (overall/unspecific) access/availability 2. Walking route choices → Street connectivity 3. Safety from crime → Crime/personal safety 4. Lighting conditions → Street lighting 5. Safety from traffic → Traffic/pedestrian safety 6. Visual interest → Greenery and aesthetically pleasing scenery 7. Usable sidewalks (sidewalks present) → Walk-friendly infrastructure *Objective [GIS; unvalidated]:* Neighbourhood environment: 8. Distance to nearest drug store → Health and aged care access/availability 9. Distance to nearest general life facilities → Destinations/services (overall/unspecific) access/availability 10. Distance to nearest health care facilities →	None	Chi-square test	***Main effects with TotalWalking(1+ walks/d):*** Perceived environment: 1. Number of walking destinations: X^2=13.81, p<.001 (Destinations/services (overall/unspecific) access/availability **+**) 2. Walking route choices: X^2=28.47, p<.001 (Street connectivity **+**) 3. Safety from crime: X^2=6.98, p=.008 (Crime/personal safety **+**) 4. Lighting conditions: X^2=9.23, p=.002 (Street lighting **+**) 5. Safety from traffic: X^2=4.04, p=.044 (Traffic/pedestrian safety **+**) 6. Visual interest: X^2=12.62, p=.002 (Greenery and aesthetically pleasing scenery **+**) 7. Usable sidewalks: X^2=11.30, p=.004 (Walk-friendly infrastructure **+**) Objective environment: 8. Distance to nearest drug store: X^2=11.89, p=.036 (Health and aged care access/availability **+**) 9. Distance to nearest general life facility: X^2=not reported, p>.05 (Destinations/services (overall/unspecific) access/availability **0**)	Buffer effects. Table 1. *Note.* *Perceived environment data (n=114); objectively assessed environmental data (n=61).*

						Health and aged care access/availability 11. Number of general daily life facilities within ¼ mile → Destinations/services (overall/unspecific) access/availability 12. Number of general life facilities within ½ mile → Destinations/services (overall/unspecific) access/availability 13. Number of general daily life facilities within 1 mile → Destinations/services (overall/unspecific) access/availability 14. Number of general daily life facilities within 2 miles → Destinations/services (overall/unspecific) access/availability 15. Distance to nearest park → Parks/public open space access/availability 16. Distance to bank → Government/finance access/availability 17. Distance to post office → Shops/commercial access/availability 18. Distance to food facility/establishments → Food outlets access/availability 19. Total amount of paved roads in the area within ¼ mile → Street connectivity 20. Total amount of			10. Distance to nearest healthcare facility: X^2=not reported, p>.05 (Health and aged care access/availability **0**) 11. Number of general life facilities within ¼ mile: X^2=not reported, p>.05 (Destinations/services (overall/unspecific) access/availability **0*0.25**) 12. Number of general life facilities within ½ mile: X^2=not reported, p>.05 (Destinations/services (overall/unspecific) access/availability **0*0.25**) 13. Number of general life facilities within 1 mile: X^2=not reported, p>.05 (Destinations/services (overall/unspecific) access/availability **0*0.25**) 14. Number of general life facilities within 2 miles: X^2=not reported, p>.05 (Destinations/services (overall/unspecific) access/availability **0*0.25**) 15. Distance to nearest park: X^2=not reported, p>.05 (Parks/public open space access/availability **0**) 16. Distance to bank: X^2=not reported, p>.05 (Government/finance services	

						paved roads in the area within ½ mile → Street connectivity 21. Total amount of paved roads in the area within 1 mile → Street connectivity 22. Total amount of paved roads in the area within 2 miles → Street connectivity			access/availability **0**) 17. Distance to post-office: X^2=not reported, p>.05 (Shops/commercial access/availability **0**) 18. Distance to food facility/establishment: X^2=not reported, p>.05 (Food outlets access/availability **0**) 19. Total paved roads within ¼ mile: X^2=not reported, p>.05 (Street connectivity **0*0.25**) 20. Total paved roads within ½ mile: X^2=not reported, p>.05 (Street connectivity **0*0.25**) 21. Total paved roads within 1 mile: X^2=not reported, p>.05 (Street connectivity **0*0.25**) 22. Total paved roads within 2 miles: X^2=not reported, p>.05 (Street connectivity **0*0.25**) ***Main effects with TotalWalking(10+ mins/occurrence):*** Perceived environment: 1. Number of walking destinations: X^2=11.97, p=.001 (Destinations/services (overall/unspecific) access/availability **+**) 2. Walking route choices: X^2=21.78, p<.001 (Street connectivity **+**) 3. Safety from crime:	

									X^2=15.55, p<.001 (Crime/personal safety **+**) 4. Lighting conditions: X^2=8.54, p=.003 (Street lighting **+**) 5. Safety from traffic: X^2=6.72, p=.010 (Traffic/pedestrian safety **+**) 6. Visual interest: X^2=7.07, p=.029 (Greenery and aesthetically pleasing scenery **+**) 7. Usable sidewalks: X^2=not reported, p>.05 (Walk-friendly facilities/infrastructure **0**) Objective environment: 8. Distance to drugstore: X^2=not reported, p>.05 (Health and aged care access/availability **0**) 9. Distance to general life facility: X^2=not reported, p>.05 (Destinations/services (overall/unspecific) access/availability **0**) 10. Distance to healthcare facility: X^2=not reported, p>.05 (Health and aged care access/availability **0**) 11. Number of general life facilities within ¼ mile: X^2=not reported, p>.05 (Destinations/services (overall/unspecific) access/availability **0*0.25**) 12. Number of general	

									life facilities within ½ mile: X^2=not reported, p>.05 (Destinations/services (overall/unspecific) access/availability **0*0.25**) 13. Number of general life facilities within 1 mile: X^2=not reported, p>.05 (Destinations/services (overall/unspecific) access/availability **0*0.25**) 14. Number of general life facilities within 2 miles: X^2=not reported, p>.05 (Destinations/services (overall/unspecific) access/availability **0*0.25**) 15. Distance to park: X^2=not reported, p>.05 (Parks/public open space access/availability **0**) 16. Distance to bank: X^2=not reported, p>.05 (Government/finance access/availability **0**) 17. Distance to post-office: X^2=not reported, p>.05 (Shops/commercial access/availability **0**) 18. Distance to food facility/establishment: X^2=not reported, p>.05 (Food outlets access/availability **0**) 19. Total paved roads within ¼ mile: X^2=not reported, p>.05 (Street connectivity **0*0.25**)	

									20. Total paved roads within ½ mile: X^2=13.75, p=.017 (Street connectivity **+*0.25**) 21. Total paved roads within 1 mile: X^2=not reported, p>.05 (Street connectivity **0*0.25**) 22. Total paved roads within 2 miles: X^2=not reported, p>.05 (Street connectivity **0*0.25**)	
68	*No study name* Wilcox et al., 2003 [470]	N=102 (rural) Mean age: 70.6 years (African-Americans), 71 years (White) 100% female Response rate not reported Dwelling not reported South Carolina, USA	Cross-sectional Cluster: purposive Individuals: convenience Stratification: ethnicity (African-American, White) Neighbourhood definition: participant delineation	Age, education, race, marital status, self-efficacy, decisional balance, depression, stress, social support, healthcare provider	*Self-report [PASE questionnaire; validated]:* Total PA (score) → Total PA *TotalPA(score)*	*Perceived [unnamed questionnaire; unvalidated]:* 1. Perceived neighbourhood safety → Crime/personal safety 2. Traffic volume → Traffic/pedestrian safety 3. Street lighting → Street lighting 4. Unattended dogs → Crime/personal safety 5. Walking distance to a park → Parks/public open space access/availability 6. Absence of sidewalks → Walk-friendly infrastructure	Race: African-American (n≈42), White (n≈60)	Hierarchical linear regression (trimmed model)	*Significant moderating effects for race*nearby park: r=<.01* *No moderating effect for race*all other environmental exposure variables.* ***Main effects with TotalPA(score):*** 1. Perceived neighbourhood safety: b=0.20, p=.03 (Crime/personal safety **+**) 2. Traffic volume: b=not reported, p>.05 (Traffic/pedestrian safety **0**) 3. Street lighting: b=not reported, p>.05 (Street lighting **0**) 4. Unattended dogs: b=not reported, p>.05 (Crime/personal safety **0**) 5. Walking distance to park: b=not reported, p>.05 (Parks/public open space	In-text, below Table 3.

									access/availability **0*0.40; 0*0.60**) 6. Absence of sidewalks: b=-0.21, p=.02 (Walk-friendly infrastructure **+**)	
69	NSW Falls Prevention Baseline Survey 2009 Macniven et al., 2014 [471]	N=1822 (not reported) 65+ years 58% female 60.8% response rate Community-dwellers New South Wales, Australia	Cross-sectional Cluster: purposive Individuals: random Stratification: health service area (none) Neighbourhood definition: not defined	Age, sex, education, BMI, SES (Socio-Economic Indexes for Areas (SEIFA))	*Self-report [NSW Falls Prevention Survey questionnaire; unvalidated]:* Total MVPA (150+ mins/wk; Yes/No) → Total MVPA *TotalMVPA(150+ mins/wk; Yes/No)*	*Perceived [unnamed questionnaire; unvalidated]:* 1. Availability of sports or gym facilities → Recreational facilities access/availability	Health status: Good (n=1260), Bad (n=552)	Binary logistic regression	*No significant moderating effects.* ***Main effects with TotalMVPA(150+ mins/wk; Yes/No):*** 1. Availability of sports or gym facilities—OR (95% CIs): *Good health:* Yes (n=99) vs. No (n=1161) (Ref): OR=1.04 (0.69; 1.57), p>.05 *Poor health:* Yes (n=40) vs. No (n=512) (Ref): OR=1.56 (0.79; 3.06), p>.05 (Recreational facilities access/availability **0*0.696; 0*0.304**)	Table 2.
70	NSW OPHS Lim & Taylor 2005 [472]	N=4419 (mixed) 65+ years 47% female 70.7% response rate Community-dwelling New South Wales, Australia	Cross-sectional Cluster: purposive Individuals: random Stratification: health area (500 residents/area) (none) Neighbourhood definition: health area (administrative)	Age, sex, education (age left school), physical functioning, diabetes, eyesight, fruit and vegetables intake, caregiving, language spoken, living arrangements, employment, fear of falling, can travel independently	*Self-report [NSW OPHS questionnaire; unvalidated]:* Adequate PA (30+ mins/d, 5 d/wk; Yes/No) → Total PA *TotalPA(30+ mins/d, 5 d/wk; Yes/No)*	*Perceived [OPHS questionnaire; unvalidated]:* 1. Area of residence → Urbanisation 2. Feel safe in neighbourhood → Crime/personal safety	None	Cox's proportional hazards model	***Main effects with TotalPA(30+ mins/d, 5 d/wk; Yes/No):*** 1. Area of residence (Ref: rural)—RR (95% CIs): Urban: RR=0.911 (0.871; 0.954), p<.001 (Urbanisation -) 2. Feel safe in the neighbourhood (Ref: some/none of the time): All/most of the time: RR=0.941 (0.854; 1.038), p>.05 (Crime/personal safety **0**)	Table 2—adjusted model.
71	Nurses' Health Study James et al., 2013 [473]	N=34,952 (likely mixed/not reported)	Cross-sectional Cluster: purposive Individuals:	Age, smoking, race, husband's education	*Self-report [Nurses' Health study questionnaire; validated]:*	*Objective [county sprawl index developed by Smart Growth America; unvalidated]:*	Age: 66.2-72.5 y (n=17,633),	Multilevel logistic regression accounting	***Main effects with TotalPA(500+ MET mins/wk; Yes/No):*** 1. Urban sprawl—b (95%	Table 3.

		66+ years 100% female 90% response rate Community-dwellers *48 states,* USA	convenience Stratification: sex and occupation Neighbourhood definition: postal code		Total PA (500+ MET mins/wk) → Total PA *TotalPA(500+ MET mins/wk; Yes/No)* Total walking (>3 METs; 500+ MET mins/wk) → Total walking *TotalWalking(500+ MET mins/wk; Yes/No)*	1. Urban sprawl → Urbanisation	72.6-81.3 y (n=17,319)	for clustering	CIs): *66.2-72.5 years:* b=-0.12 (-0.54; 0.30), p>.05 72.6-81.3 years: b=-0.23 (-0.57; 0.11), p>.05 (Urbanisation **0*0.5; 0*0.5**) ***Main effects with TotalWalking(500+ MET mins/wk; Yes/No):*** 1. Urban sprawl: *66.2-72.5 years:* b=0.23 (-0.07; 0.39), p<.05 *72.6-81.3 years:* b=0.17 (0.02; 0.31), p<.05 (Urbanisation **+*0.5; +*0.5**)	
72	Nurses' Health Study Troped et al., 2014 [474]	N=23,434 (likely mixed/not reported) Mean age: 70 years 100% female 90% response rate Community-dwellers California, Massachusetts, and Pennsylvania, USA	Cross-sectional Cluster: purposive Individuals: convenience Stratification: population density (urbanisation) and state (highest populations) Neighbourhood definition: 94.5% street number level; 800m, and 1200m buffers	Age, number of years at address, race, ethnicity, husband's and nurse's education, BMI, walking limitations, more relaxed indoors, smoking status	*Self-report [Nurses' Health study questionnaire; validated]:* Total walking (500+ MET mins/wk) → Total walking *TotalWalking(500+ MET mins/wk; Yes/No)*	*Objective [GIS, LandScan; unvalidated]:* 1. Population density → Residential density 2. Intersection density → Street connectivity 3. Total facilities → Destinations/services (overall/unspecific) access/availability 4. Retail/stores → Shops/commercial access/availability 5. Services → Destinations/services (overall/unspecific) access/availability 6. Cultural/Education → Education facilities access/availability 7. Physical activity → Recreational facilities access/availability 8. Restaurants → Food outlets access/availability	Population density*facilities (n=cases): 0-20.0th (n=1053), 20.1-40.0th (n=1102), 40.1-60.0th (n=1072), 60.1-80.0th (n=1064), 80.1-90.0th (n=511), 90.1-95.1th (n=272), 95.1-100th (n=292)	Multivariate logistic regression	***Main and moderated effects with TotalWalking(500+ MET mins/wk; Yes/No):*** 1. Population density—OR (95% CIs): OR=1.04 (1.02; 1.07), p<.05 (Residential density +) 2. Intersection density (Ref: <2.00 ≥3-way intersections/km): 2.00-3.99: OR=1.18 (1.05; 1.34), p<.05 4.00-5.99: OR=1.28 (1.13; 1.44), p<.05 6.00-11.00: OR=1.23 (1.03; 1.48), p<.05 (Street connectivity **+*0.092; +*0.384; +*0.470; +*0.054**) 3. Total facilities: OR=1.04 (1.02; 1.07), p<.05 (Destinations/services (overall/unspecific) access/availability **+*0.29; 0*0.71**)	Moderating effects. Table 2.

						9. Fast food restaurants → Food outlets access/availability 10. Grocery stores → Shops/commercial access/availability 11. Convenience stores → Shops/commercial access/availability			4. Retail/stores: OR=1.10 (1.05; 1.15), p<.05 (Shops/commercial access/availability **+*0.29; 0*0.71**) 5. Services: OR=1.53 (1.20; 1.95), p<.05 (Destinations/services (overall/unspecific) access/availability **+*0.14; 0*0.86**) 6. Cultural/Education: OR=1.15 (1.03; 1.28), p<.05 (Education facilities access/availability **+*0.14; 0*0.86**) 7. Physical activity facilities: OR=1.45 (0.98; 2.15), p>.05 (Recreational facilities access/availability **+*0.29; 0*0.71**) 8. Restaurants: OR=1.04 (1.01; 1.06), p<.05 (Food outlets access/availability **+*0.29; 0*0.86**) 9. Fast food restaurants: OR=1.01 (1.01; 1.02), p<.05 (Food outlets access/availability **+*0.43; 0*0.57**) 10. Grocery stores: OR=1.06 (1.00; 1.12), p<.05 (Shops/commercial access/availability **+*1**) 11. Convenience stores: OR=1.09 (1.04; 1.15), p<.05	

									(Shops/commercial access/availability **+*0.29; 0*0.71**)	
73	Oslo Health Study Piro et al., 2006 [475]	N=3499 (urban) 74/75 years 57% female 53.2% response rate Community-dwellers (apart from n=35, whom resided in an institution) Oslo, Norway	Cross-sectional Clusters: purposive Individuals: convenience Stratification: none Neighbourhood definition: administrative borough	Education, medical conditions, marital status, income, fortune, time in current residence	*Self-report [Oslo Health Study questionnaire; unvalidated]:* Total PA (1+ hr/wk; Yes/No) → Total PA *TotalPA(1+ hr/wk; Yes/No)*	*Perceived [Oslo Health Study questionnaire; unvalidated]:* 1. Feeling safe walking alone in the evening → Crime/personal safety *Objective [Oslo City Council data; unvalidated]:* 2. Neighbourhood violence (violent cases/1000 inhabitants) → Crime/personal safety	Sex: Male (n=1409), Female (n=1864)	Multilevel logistic regression accounting for clustering	***Moderated effects with TotalPA(1+ hr/wk; Yes/No):*** 1. Feeling safe walking alone at night (Ref: high)—OR (95% CIs): *Males:* Low: OR=0.68 (0.45; 1.02), p>.05 (Crime/personal safety **0*0.5**) *Females:* Low: OR=0.64 (0.47; 0.87), p<.05 (Crime/personal safety **-*0.5**) 2. Neighbourhood violence (Ref: low): *Males:* High: OR=0.54 (0.36; 0.81), p<.05 (Crime/personal safety **-*0.5**) *Females:* High: OR=1.08 (0.82; 1.42), p>.05 (Crime/personal safety **0*0.5**)	Moderating effects. Table 3 (male); Table 4 (female).
74	Physical Activity Monitor 2002 Pan et al., 2009 [476]	N=637 (not reported) Subsample: 60-79 years % female not reported 51% response rate Community-dwellers *All provinces,* Canada	Cross-sectional Cluster: none Individuals: random Stratification: population density (urbanisation) Neighbourhood definition: "local community" (variable/not fixed)	Age, education, self-rated health, family income, intention, self-efficacy, perceived barriers, perceived health benefits, social support, facility availability	*Self-report [IPAQ; validated]:* Sufficient PA (Yes/No) → Total MVPA *TotalMVPA(MPA: 30+ mins/d*7 d/wk; VPA: 20+ mins/d*3 d/wk; 840 MET mins/wk; Yes/No)*	*Perceived [Physical Activity Monitor questionnaire; unvalidated]:* 1. Availability of PA facilities – aggregated measure of number of: places to walk safely (inc., walking trails), places to ride a bike safely, publicly-owned multi-purpose recreation trails, facilities, places, recreation facilities, and other places (e.g., school gyms, skate	None. *Notes:* Age: 15-24 y (n=645), 25-39 y (n=1589), 40-64 y (n=2296), 65-79 y (n=637)	Multivariate logistic regression	***Main effects with TotalMVPA(30+mins/d*7 d/wk; 20+mins/d*3 d/wk; 840 MET mins/wk; Yes/No):*** 1. Facility availability—OR (95% CIs): OR=0.94 (0.61; 1.44) (Recreational facilities access/availability **0**)	Table 3.

						parks) → Recreational facilities access/availability				
75	PACS (Physical Activity Cohort Scotland) McMurdo et al., 2012 [477]	N=547 (mixed) 65+ years 54% female 17% response rate Community-dwellers Scotland, United Kingdom	Cross-sectional Cluster: purposive Individuals: random Stratification: age, SES (index of deprivation) and urbanisation Neighbourhood definition: postal code	Age, perceived behavioural control, physical functioning, social cohesion (number of people can turn to nearby)	*Objective [RT3 accelerometer; validated]:* Counts/min → Total PA *TotalPA(cpm)*	*Objective [GIS; yell.com ltd.; unvalidated]:* 1. Urbanisation → Urbanisation 2. % greenspace in the residential ward → Aesthetics and greenspace 3. Road distance to grocery shop or supermarket → Shops/commercial access/availability *Perceived [Project OPAL questionnaire; unvalidated]:* *Notes:* Local area surroundings, streets in your area, and personal safety not extracted as reported in Sniehotta et al. (2013).	None	Stepwise multiple linear regression	***Main effects with TotalPA(cpm):*** 1. Urbanisation: b=not reported, p>.05 (Urbanisation **0**) 2. % greenspace in the residential ward: b=not reported, p>.05 (Greenery and aesthetically pleasing scenery **0**) 3. Road distance to grocery shop or supermarket: b=not reported, p>.05 (Shops/commercial access/availability **0**)	Table 2. Perceived environmental variables reported in Sniehotta et al. 2013 accounting for self-selection.
76	PACS Sniehotta et al., 2013 [478]	N=547 (mixed) 65+ years 54% female 17.5% response rate Community-dwellers Scotland, United Kingdom	Cross-sectional Cluster: purposive Individuals: random Stratification: age, SES (index of deprivation) and urbanisation Neighbourhood definition: 15-20mins walk from home	Age, sex, deprivation, intention, self-efficacy, physical functioning, bodily pain, general health, vitality, mental health, psychosocial health, depression, anxiety, need for support, received support, loneliness, neighbourhoodliness, sun, minimum temperature, maximum	*Objective [RT3 accelerometer; validated]:* Counts/min → Total PA *TotalPA(cpm)*	*Perceived [Project OPAL questionnaire; unvalidated];* 1. Local area surroundings → Greenery and aesthetically pleasing scenery 2. Streets in your area → Street connectivity 3. Traffic → Traffic/pedestrian safety 4. Pedestrian safety → Traffic/pedestrian safety	Social cognitions: Intention, Self-efficacy	Stepwise multiple linear regression	*No significant moderating effects.* ***Main effects with TotalPA(cpm):*** 1. Local area surroundings: b=0.02, p>.05 (Greenery and aesthetically pleasing scenery **0**) 2. Streets in your local area: b=-0.02, p>.05 (Street connectivity **0**) 3. Traffic: b=-0.05, p>.05 (Traffic/pedestrian	Table 4.

				temperature, rainfall		5. Personal safety → Crime/personal safety			safety **0**) 4. Pedestrian safety: b=-0.06, p>.05 (Traffic/pedestrian safety **0**) 5. Personal safety: b=0.20, p<.001 (Crime/personal safety +)	
77	Project OPAL Davis et al., 2011 [115]	N=214 (urban) Mean age: 78.1 years 49% female 20.8% response rate Dwelling not reported Bristol, United Kingdom	Cross-sectional Cluster: purposive Individuals: random Stratification: amenity access and SES (Index of Multiple Deprivation) Neighbourhood definition: 5min walk from home	None	*Self-report [daily trip log; unvalidated]:* Total trips/wk → Total PA *TotalPA(trips/wk)*	*Perceived [OPAL questionnaire; unvalidated]:* 1. Amenities → Destinations/services (overall/unspecific) access/availability	None	One-way ANOVA	***Main effects with TotalPA(trips/wk):*** 1. Amenities: None (n=18): 5.8±4.0, 1 (n=26): 8.7±4.3, 2-3 (n=56): 9.7±4.6, 4-7 (n=59): 9.8±5.1, 8+ (n=55): 11.1±4.9, F=4.5, p=.002 (Destinations/services (overall/unspecific) access/availability **+**)	Table 1.
78	Project OPAL Fox et al., 2011 [269]	N=240 (urban) 70+ years 48% female 20.4% response rate Dwelling not reported Bristol, United Kingdom	Cross-sectional Cluster: purposive Individuals: random Stratification: amenity access and SES (Index of Multiple Deprivation) Neighbourhood definition: distance to nearest shop	None	*Objective[ActiGraph accelerometer; validated; Freedson MVPA cutoff point (>1952 cpm); validated]:* Counts/min → Total PA *TotalPA(cpm—logged)* Steps/d → Total walking *TotalWalking(steps/d)* MVPA → Total MVPA *TotalMVPA(mins/d—logged)*	*Perceived [OPAL questionnaire; unvalidated]:* 1. Distance to nearest shop → Shops/commercial access/availability	None	One-way ANOVA *Note.* MVPA mins/d and cpm were log-transformed)	***Main effect with TotalPA(cpm—logged):*** 1. Distance to nearest shop: 0.27-0.63km: 4.9±0.8, 0.64-1.07km: 5.0±0.5, 1.08-6.52km: 5.1±0.7, p=.35 (Shops/commercial access/availability **0**) ***Main effect with TotalMVPAFreedson(mins/d—logged):*** 1. Distance to nearest shop: 0.27-0.63km: 2.2±1.3, 0.64-1.07km: 2.4±1.0, 1.08-6.52km: 2.4±1.3, p=.53 (Shops/commercial access/availability **0**) ***Main effect with***	Table 3.

									TotalWalking(steps/d): 1. Distance to nearest shop: 0.27-0.63km: 4286±2899, 0.64-1.07km: 4472±2010, 1.08-6.52km: 4616±2472, p=.72 (Shops/commercial access/availability **0**)	
79	Project OPAL Thompson et al., 2011 [479]	N=240 (urban) Mean age: 78.1 years 48% female 20.4% response rate Dwelling not reported Bristol, United Kingdom	Cross-sectional Cluster: purposive Individuals: random Stratification: amenity access and SES (Index of Multiple Deprivation) Neighbourhood definition: distance to nearest shop	None	*Objective[ActiGraph accelerometer; validated]:* Steps/d → Total walking *TotalWalking(steps/d)*	*Perceived [Project OPAL questionnaire; unvalidated]:* 1. Minutes taken to reach the main food shopping venue → Shops/commercial access/availability	None	Spearman's rank order correlations	***Main effects with TotalWalking(steps/d)***: 1. Minutes to reach main food shopping venue: r=-0.100, p>.05 (Shops/commercial access/availability **0**)	Table 4.
80	Project RICE pilot Han et al., 2016 [480]	n=106 (sub-sample) (urban) 65+ years 56% female Response rate not reported New York City, USA	Cross-sectional Cluster: none Individuals: convenient Stratification: ethnicity (Korean) Neighbourhood definition: participant delineation	Age, sex, years lived in USA, marital status, health insurance, BMI	*Self-report [Behavioral Risk Factor Surveillance System—Korean version; unvalidated]:* MVPA (min/d) → Total MVPA *TotalMVPA(150+ min/wk; Yes/No)*	*Perceived [Exercise Benefits and Barriers Scale—Korean version; unvalidated]:* 1. No safe place to exercise → Crime/personal safety	None	Multiple logistic regression analysis	***Main effects with TotalMVPA(150+ min/wk; Yes/No)***: 1. No safe place to exercise—OR (95% CIs): OR=1.7 (0.5; 6.2), p=.410 (Crime/personal safety **0**)	Table 2.
81	SHAPE Li et al., 2005a [481]	N=577 (urban) 65+ years 64% female 31% response rate Community-dwellers Portland, USA	Cross-sectional Cluster: purposive Individuals: random Stratification: population density, residential density, commercial	None	*Self-report [SHAPE questionnaire; reliable]:* Total neighbourhood walking (score) → Total walking *TotalWalking(score)*	*Objective [ArcGIS, Regional Land Information System data; unvalidated]:* Neighbourhood level: 1. Employment density → Urbanisation 2. Household density → Residential density 3. Area of green and	Area of green and open space*access to recreational facilities Number of street intersections*safe from traffic	Multilevel linear regression accounting for clustering	*No significant moderating effects between* area of green and open space for recreation*access to recreational facilities: b=-0.022 (95% CI=-0.060; 0.016) (SE=0.019), p=.13 Significant moderating effects for number of	*Resident and neighbourhood like a buffer, as resident level findings were 'aggregated up' to determine neighbourhood level*

			density (urbanisation) and income Neighbourhood definition: street level (objective); 0.5mile buffer (objective); not defined (perceived)			open space for recreation → Parks/public open space access/availability Resident level: 4. Area of green and open space for recreation → Parks/public open space access/availability *Perceived [unnamed questionnaire; reliable]:* 5. Number of Recreational facilities → Recreational facilities access/availability 6. Safe from traffic → Traffic/pedestrian safety *Notes:* Number of street intersections not reported because they were reported in Li et al. (2005b). In addition, access/proximity to recreational facilities access/availability, and safe to walk not reported because they were reported in Nagel et al. (2008).			street intersections*safe from traffic: b=0.019 (95% CI=0.007; 0.016) (SE=0.032), p=.05 ***Main effects with TotalWalking(score):*** Objective environment: Neighbourhood level: 1. Employment density—b (unstandardised) (95% CIs): b=0.187 (0.061; 0.313) (SE=0.06), p=.05 (Urbanisation +) 2. Household density: b=0.047 (0.001; 0.094) (SE=0.024), p=.05 (Residential density +) 3. Area of green and open space for recreation: b=0.074 (0.009; 0.140) (SE=0.033), p=.05 (Parks/public open space access/availability +) Resident level: 4. Area of green and open space for recreation: b=-0.056 (-0.103; -0.009) (SE=0.024), p=.05 (Parks/public open space access/availability **0**) Perceived environment: 5. Number of Recreational facilities: b=0.077 (0.052; 0.103) (SE=0.013), p=.001 (Recreational facilities access/availability +) 6. Safe from traffic: b=0.152 (-0.016; 0.321) (SE=0.086), p=.06	*findings.* Table 2. Findings regarding 'Access/proximity to Recreational facilities access/availability' and 'Safe to walk' were not reported because they are reported in Li et al. (2005b) adjusted for some covariates (e.g., education). Findings regarding 'Number of street intersections' was not reported because they are reported in Nagel et al. (2008) adjusted for age, sex, education etc. In addition, the outcome variable was assessed using a validated measure.	

									(Traffic/pedestrian safety **0**)	
82	SHAPE Li et al., 2005b [482]	N=303 (urban) 65+ years 64% female 31% response rate Community-dwellers Portland, USA	Cross-sectional and longitudinal Cluster: purposive Individuals: random Stratification: population density, residential density, commercial density (urbanisation) and income Neighbourhood definition: street level (objective); 0.5mile buffer (objective); not defined (perceived)	Education, health status, household income, walking self-efficacy	*Self-report [SHAPE questionnaire; reliable]:* Total neighbourhood walking (score) → Total walking *TotalWalking(score)* Total neighbourhood walking—rate of change (score) → Total walking *TotalWalking(score—rate of change)*	*Perceived [unnamed questionnaire; reliable]:* Initial status: 1. Safe to walk → Crime/personal safety 2. Access to Recreational facilities → Recreational facilities access/availability Rate of change: 1. Safe to walk → Crime/personal safety 2. Access/proximity to Recreational facilities access/availability → Recreational facilities access/availability	None	Multilevel growth model	***Main effects with TotalWalking(score):*** Cross-sectional: 1. Safe to walk: b (unstandardised)=0.25 (SE=0.56), t=0.45, p>.05 (Crime/personal safety **0**) 2. Access to Recreational facilities: b (unstandardised)=-0.16 (SE=0.35), t=-0.46 p>.05 (Recreational facilities access/availability **0**) ***Main effects with TotalWalking(score—rate of change):*** Longitudinal: 1. Safe to walk: b (unstandardised)=0.44 (SE=0.15), t=2.92, p<.05 (Crime/personal safety **+**) 2. Access/proximity to Recreational facilities access/availability : b (unstandardised)=0.30 (SE=0.10), t=2.96, p<.05 (Recreational facilities access/availability **+**)	Table 2.
83	SHAPE Michael et al., 2006 [483]	N=105 (urban) 65+ years 67% female 31% response rate Community-dwellers Portland, USA	Cross-sectional Cluster: purposive Individuals: random Stratification: walkability Neighbourhood definition: street level (objective); "near home" (perceived)	Age, sex, education, race, income	*Self-report [SHAPE questionnaire; reliable]:* Total neighbourhood walking (low walkers: not at all, a little bit, moderate amount; high walkers: quite a bit, a great deal; Yes/No) → Total walking	*Objective [ArcGIS, Regional Land Information System data; unvalidated];* 1. Graffiti and vandalism → Greenery and aesthetically pleasing scenery 2. Sidewalk obstruction → No physical barriers to walking 3. Presence of parks →	None	Multivariate logistic regression *Note. Several [unnamed] variables transformed* .	***Main effects with TotalWalking(High walker; Yes/No):*** Objective environment: 1. Graffiti and vandalism: OR=0.57, p=.28 (Greenery and aesthetically pleasing scenery **0**) 2. Sidewalk obstruction: OR=not reported, p>.05 (No physical barriers to walking **0**)	In-text, below Table 2.

					TotalWalking(High walker; Yes/No)	Parks/public open space access/availability 4. Presence of malls → Shops/commercial access/availability 5. Presence of trails → Parks/public open space access/availability *Perceived [unnamed questionnaire; reliable]:* 6. Graffiti and vandalism → Greenery and aesthetically pleasing scenery 7. Sidewalk obstruction → No physical barriers to walking 8. Presence of parks → Parks/public open space access/availability 9. Presence of malls → Shops/commercial access/availability 10. Presence of trails → Parks/public open space access/availability			3. Presence of parks: OR=not reported, p>.05 (Parks/public open space access/availability **0**) 4. Presence of malls: OR=4.12, p=.147 (Shops/commercial access/availability **0**) 5. Presence of trails: OR=not reported, p>.05 (Parks/public open space access/availability **0**) Perceived environment: 6. Graffiti and vandalism: OR=not reported, p>.05 (Greenery and aesthetically pleasing scenery **0**) 7. Sidewalk obstruction: OR=not reported, p>.05 (No physical barriers to walking **0**) 8. Presence of parks: OR=not reported, p>.05 (Parks/public open space access/availability **0**) 9. Presence of malls: OR=2.10, p=.108 (Shops/commercial access/availability **0**) 10. Presence of trails: OR=not reported, p>.05 (Parks/public open space access/availability **0**)	
84	SHAPE Nagel et al., 2008 [484]	N=426 (urban) 65+ years 70% female Response rate not reported Community-dwellers Portland, USA	Cross-sectional Cluster: purposive Individuals: random Stratification: none Neighbourhood definition: 0.25mile and 0.5mile buffers	Age, sex, education, race, income, health status, walking self-efficacy	*Self-report [Yale Physical Activity Scale questionnaire; validated]:* Total walking (mins/wk) → Total walking *TotalWalking(mins/wk)*	*Objective [ArcGIS, Regional Land Information System database; unvalidated]:* 1. % of high volume streets → Traffic/pedestrian safety 2. % of medium-volume streets →	None	Multilevel linear and logistic regression models accounting for clustering.	***Main effects with TotalWalking(mins/wk):*** 1. High volume [traffic] streets: *0.25 mile:* b=1.27 (SE=0.5), p<.05 *0.5 mile:* b=1.83 (SE=0.61), p<.001 (Traffic/pedestrian safety **-*0.5; -*0.5**) 2. Medium volume	Buffer effects. Table 4—Model 2. *Note. Total walking (n=426), brisk walking (n=275)*

					Likelihood of walking (0 mins/wk vs.>0 mins/wk; Yes/No) → Total walking *TotalWalking(likelihood>0 mins/wk; Yes/No)* Brisk walking time (mins/wk) → Total walking *BriskTotalWalking(mins/wk)*	Traffic/pedestrian safety 3. % of low-volume streets → Traffic/pedestrian safety 4. Sidewalk coverage → Walk-friendly infrastructure 5. Number of intersections → Street connectivity 6. Number of bus lines → Public transport access/availability 7. Number of commercial establishments → Shops/commercial access/availability 8. Number of select establishments → Destinations/services (overall/unspecific) access/availability 9. Distance to nearest park → Parks/public open space access/availability 10. Neighbourhood-level problems → Crime/personal safety 11. Neighbourhood-level walking safety → Crime/personal safety			[traffic] streets: *0.25 mile:* b=0.73 (SE=0.6), p>.05 *0.5 mile:* b=1.15 (SE=0.89), p>.05 (Traffic/pedestrian safety **0*0.5; 0*0.5**) 3. Low volume [traffic] streets: *0.25 mile:* b=-1.36 (SE=0.4), p<.001 *0.5 mile:* b=-1.93 (SE=0.48), p<.001 (Traffic/pedestrian safety **-*0.5; -*0.5**) 4. Sidewalk coverage: *0.25 mile:* b=0.16 (SE=0.17), p>.05 *0.5 mile:* b=0.32 (SE=0.21), p>.05 (Walk-friendly infrastructure **0*0.5; 0*0.5**) 5. Number of intersections: *0.25 mile:* b=0.36 (SE=0.27), p>.05 (Street connectivity **0*0.5**) *0.5 mile:* b=0.20 (SE=0.08), p<.05 (Street connectivity **+*0.5**) 6. Number of bus lines: *0.25 mile:* b=2.22 (SE=1.21), p>.05 (Public transport access/availability **0*0.5**) *0.5 mile:* b=1.86 (SE=0.70), p<.05 (Public transport access/availability **+*0.5**) 7. Number of commercial establishments: *0.25 mile:* b=0.25	

									(SE=0.06), p<.001 *0.5 mile:* b=0.07 (SE=0.02), p<.001 (Shops/commercial access/availability **+*0.5; +*0.5**) 8. Number of select establishments: *0.25 mile:* b=0.68 (SE=0.26), p<.05 (Destinations/services (overall/unspecific) access/availability **+*0.5**) *0.5 mile:* b=0.34 (SE=0.09), p<.001 (Destinations/services (overall/unspecific) access/availability **0*0.5**) 9. Distance to nearest park: b=-0.01 (SE=0.01), p<.05 (Parks/public open space access/availability **+**) 10. Neighbourhood-level problems: b=-4.11, p=.050 (Crime/personal safety **+**) 11. Neighbourhood-level walking safety: b=not reported, p>.05 (Crime/personal safety **0**) ***Main effects with TotalWalking(likelihood >0 mins/wk; Yes/No):*** 1. High volume streets: *0.25 mile:* OR=not reported, p>.05 *0.5 mile:* OR=not reported, p>.05 (Traffic/pedestrian safety **0*0.5; 0*0.5**) 2. Medium volume streets:	

									0.25 mile: OR=not reported, p>.05 *0.5 mile:* OR=not reported, p>.05 (Traffic/pedestrian safety **0*0.5; 0*0.5**) 3. Low volume streets: *0.25 mile:* OR=not reported, p>.05 *0.5 mile:* OR=not reported, p>.05 (Traffic/pedestrian safety **0*0.5; 0*0.5**) 4. Sidewalk coverage: *0.25 mile:* OR=not reported, p>.05 *0.5 mile:* OR=not reported, p>.05 (Walk-friendly infrastructure **0*0.5; 0*0.5**) 5. Number of intersections: *0.25 mile:* OR=not reported), p>.05 *0.5 mile:* OR=not reported, p>.05 (Street connectivity **0*0.5; 0*0.5**) 6. Number of bus lines: *0.25 mile:* OR=not reported, p>.05 *0.5 mile:* OR=not reported, p>.05 (Public transport access/availability **0*0.5; 0*0.5**) 7. Number of commercial establishments: *0.25 mile:* OR=not reported, p>.05 *0.5 mile:* OR=not reported, p>.05 (Shops/commercial access/availability **0*0.5;**	

									0*0.5) 8. Number of select establishments: *0.25 mile:* OR=not reported, p>.05 *0.5 mile:* OR=not reported, p>.05 (Destinations/services (overall/unspecific) access/availability **0*0.5; 0*0.5**) 9. Distance to nearest park: OR=not reported, p>.05 (Parks/public space access/availability **0**) 10. Neighbourhood-level problems: b=not reported, p>.05 (Crime/personal safety **0**) 11. Neighbourhood-level walking safety: b=not reported, p>.05 (Crime/personal safety **0**) ***Main effects with BriskTotalWalking(mins /wk):*** 1. High volume [traffic] streets: *0.25 mile:* b=1.11, p=.028 (Traffic/pedestrian safety **-*0.5**) *0.5 mile:* b=not reported, p>.05 (Traffic/pedestrian safety **0*0.5**) 2. Medium volume [traffic] streets: *0.25 mile:* b=not reported, p>.05 *0.5 mile:* b=not reported, p>.05	

								(Traffic/pedestrian safety **0*0.5; 0*0.5**) 3. Low volume [traffic] streets: *0.25 mile:* b=-0.85, p=0.42 (Traffic/pedestrian safety **-*0.5**) *0.5 mile:* b=not reported, p>.05 (Traffic/pedestrian safety **0*0.5**) 4. Sidewalk coverage: *0.25 mile:* b=not reported, p>.05 *0.5 mile:* b=not reported, p>.05 (Walk-friendly infrastructure **0*0.5; 0*0.5**) 5. Number of intersections: *0.25 mile:* b=not reported, p>.05 *0.5 mile:* b=not reported, p>.05 (Street connectivity **0*0.5; 0*0.5**) 6. Number of bus lines: *0.25 mile:* b=not reported, p>.05 *0.5 mile:* b=not reported, p>.05 (Public transport access/availability **0*0.5; 0*0.5**) 7. Number of commercial establishments: *0.25 mile:* b=not reported, p>.05 (Shops/commercial access/availability **0*0.5**) *0.5 mile:* b=0.04, p=.016 (Shops/commercial access/availability **+*0.5**)	

									8. Number of select establishments: *0.25 mile:* b=not reported, p>.05 (Destinations/services (overall/unspecific) access/availability **0*0.5**) *0.5 mile:* b=0.20, p=.033 (Destinations/services (overall/unspecific) access/availability **+*0.5**) 9. Distance to nearest park: b=-0.02, p=.032 (Parks/public open space access/availability **+**) 10. Neighbourhood-level problems: b=not reported, p>.05 (Crime/personal safety **0**) 11. Neighbourhood-level walking safety: b=not reported, p>.05 (Crime/personal safety **0**)	
85	SMARTRAQ Frank et al., 2010 [253]	N=1970 (urban) 65+ years 56% female 30.4% response rate Community-dwellers Atlanta, USA	Cross-sectional Cluster: purposive Individuals: purposive Stratification: residential density (urbanisation), household size and income Neighbourhood definition: 1km buffer	Age, sex, education, living with others, income, car ownership, ethnicity	*Self-report [travel survey; unvalidated]:* MVPA (150+ mins/wk; Yes/No) → Total MVPA *TotalMVPA(150+ mins/wk; Yes/No)* Walked at least once in 2 days → Total walking *TotalWalking(Once/2d ; Yes/No)*	*Objective [County Level Tax Assessor's data, regional land use data, street network data, census data; unvalidated]:* 1. Walkability – categorised as: low, medium and high walkability	None	Multilevel logistic regression	***Main effect with TotalMVPA(150+ mins/wk; Yes/No):*** 1. Walkability (Ref: Low)—OR (95% CIs): Medium OR=1.13 (0.82; 1.54), High OR=1.08 (0.78; 1.48) (Walkability **0**) ***Main effect with TotalWalking(Once/2d; Yes/No):*** 1. Walkability (Ref: Low)—OR (95% CIs): Medium OR=1.10 (0.59; 2.07), High OR=2.02 (1.13; 3.64) (Walkability **+**)	Table 3.

86	SNQLS Kerr et al., 2011 [270]	N=147 (urban) Mean age: 80 years 71% female Response rate not reported Retirement village dwellers Baltimore, Palo Alto, San Diego, & Seattle USA	Validation study Cluster: purposive Individuals: convenience Stratification: participants/site (≤n=30) (none) Neighbourhood definition: retirement village	Clustering	*Objective [ActiGraph—validated; Freedson MVPA cutoff point—validated]:* MVPA → Total MVPA *TotalMVPAFreedson (mins/d)*	*Objective [Audit of Physical Activity Resources for Seniors; validated]:* 1. Grassy area → Parks/public open space access/availability 2. Path intersections → Street connectivity 3. Path with moderate slope → No physical barriers to walking 4. Water features → Greenery and aesthetically pleasing scenery 5. Art/sculptures → Greenery and aesthetically pleasing scenery 6. Pleasant views → Greenery and aesthetically pleasing scenery 7. Hazardous path sections → No physical barriers to walking 8. Obstructions on path and lighting → No physical barriers to walking 9. ≤1 exterior light → Crime/personal safety 10. Putting green → Recreational facilities access/availability 11. Lawn bowling → Recreational facilities access/availability 12. Basketball hoop → Recreational facilities access/availability 13. Exercise stations → Recreational facilities	None	Bivariate and Spearman correlations; mixed effects regression models adjusted for clustering.	***Main effects with TotalMVPAFreedson(mins/d):*** 1. Grassy area: r=not reported, p>.05 (Parks/public open space access/availability **0**) 2. Path intersections: r=.165, p<.05 (Street connectivity **+**) 3. Path with moderate slope: r=.193, p<.05 (No physical barriers to walking **+**) 4. Water features: r=not reported, p>.05 (Greenery and aesthetically pleasing scenery **0**) 5. Art/sculptures: r=not reported, p>.05 (Greenery and aesthetically pleasing scenery **0**) 6. Pleasant views: r=not reported, p>.05 (Greenery and aesthetically pleasing scenery **0**) 7. Hazardous path sections: r=not reported, p>.05 (No physical barriers to walking **0**) 8. Obstructions on path: r=.165, p<.05 (No physical barriers to walking -) 9. ≤1 exterior light: r=.165, p<.05 (Crime/personal safety **+**) 10. Putting green: r=.138, p>.05 (Recreational facilities	Table 4.

						access/availability 14. Tennis court → Recreational facilities access/availability 15. Swimming pool → Recreational facilities access/availability 16. Combined fitness aerobic classroom → Recreational facilities access/availability 17. Indoor pool → Recreational facilities access/availability 18. Exercise equipment not in designated room → Recreational facilities access/availability 19. Open lounges → Social recreational facilities access/availability 20. Dining room → Social recreational facilities access/availability 21. Kitchen → Social recreational facilities access/availability 22. Open areas/courtyards/patios → Parks/public open space access/availability 23. Bank → Government/finance services access/availability 24. Pharmacy → Shops/commercial access/availability 25. Hairdresser/beautician → Other service/institution			access/availability **0**) 11. Lawn bowling: r=.138, p>.05 (Recreational facilities access/availability **0**) 12. Basketball hoop: r=.138, p>.05 (Recreational facilities access/availability **0**) 13. Exercise stations: r=.206, p<.05 (Recreational facilities access/availability **+**) 14. Tennis court: r=not reported, p>.05 (Recreational facilities access/availability **+**) 15. Swimming pool: r=.138 p>.05 (Recreational facilities access/availability **0**) 16. Combined fitness aerobic classroom: r=.234 p<.01 (Recreational facilities access/availability **+**) 17. Indoor pool: r=not reported, p>.05 (Recreational facilities access/availability **0**) 18. Exercise equipment not in designated room: r=not reported, p>.05 (Recreational facilities access/availability **0**) 19. Open lounges: r=not reported, p>.05 (Social Recreational facilities access/availability **0**) 20. Dining room: r=-.103, p>.05 (Social recreational facilities access/availability **0**) 21. Kitchen:	

						access/availability 26. Chapel/religious services → Religious institution access/availability 27. Mail room → Other service/institution access/availability 28. Café/cafeteria → Food outlets access/availability 29. Gift shop → Shops/commercial access/availability 30. Snack shop → Shops/commercial access/availability 31. Laundry → Other service/institution access/availability 32. Medical/dental clinic → Health and aged care access/availability 33. Length of longest walking path → Walk-friendly infrastructure			r=.228, p<.01 (Social recreational facilities access/availability **+**) 22. Open areas/courtyards/patios: r=not reported, p>.05 (Parks/public open space access/availability **0**) 23. Bank: r=not reported, p>.05 (Government/finance access/availability **0**) 24. Pharmacy: r=not reported, p>.05 (Shops/commercial access/availability **0**) 25. Hairdresser/beautician: r=-.086, p>.05 (Other service/institution access/availability **0**) 26. Chapel/religious services: r=not reported, p>.05 (Religious institution access/availability **0**) 27. Mail room: r=not reported, p>.05 (Other service/institution access/availability **0**) 28. Café/cafeteria: r=not reported, p>.05 (Food outlets access/availability **0**) 29. Gift shop: r=.008, p>.05 (Shops/commercial access/availability **0**) 30. Snack shop: r=not reported, p>.05 (Shops/commercial access/availability **0**) 31. Laundry:	

									r=-.138, p>.05 (Other service/institution access/availability **0**) 32. Medical/dental clinic: r=not reported, p>.05 (Health and aged care access/availability **0**) 33. Length of longest walking path: r=.176, p<.05 (Walk-friendly infrastructure **+**)	
87	SNQLS Carlson et al., 2012 [271]	N=687 (urban) 66+ years; 53% women 21.4% response rate Community dwellers Seattle and Baltimore, USA	Cross-sectional Cluster: purposive Individuals: random Stratification: walkability and SES Neighbourhood definition: 500m street-network buffer (objective) and 15-20mins walk from home (perceived)	Age, sex, education, marital status, moths at address, number of people in the household, number of vehicles per adult	*Objective [ActiGraph accelerometer; validated; Freedson cutoff point; validated]:* Total MVPA (mins/wk) → Total MVPA *TotalMVPAFreedson(mins/wk)*	*Objective [data from county-level tax assessor; GIS walkability index; unvalidated]:* 1. Parks and recreation → Parks/open space access/availability *Perceived [NEWS questionnaire; validated]:* 2. Aesthetics → Greenery and aesthetically pleasing scenery 3. Walking facilities → Walk-friendly infrastructure *Note:* Walkability not extracted as included in Bracy et al. with more appropriate statistical analyses and moderating effects yielding same-direction associations across values of moderator.	Social support, Self-efficacy, Barriers n average (mean)=488 n high (+1SD)=115 n low (-1SD)=115	General mixed models accounting for clustering	*Moderating effects:* Walkability*social support p=.003 Stronger positive effects in those with higher social support Walkability*self-efficacy p=.512 Nil effects in those with higher self-efficacy Walkability*barriers p>.376 Nil effects in those with lower levels of barriers ***Main and moderated effects with TotalMVPAFreedson(mins/wk):*** *Objective:* 1. Parks and recreation—b (95% CIs): b=7.6 (-10.9; 26.0), p>.05 (Parks/public open space access/availability **0**) *Perceived:* 2. Aesthetics: b=3.0 (-5.3; 11.3), p>.05 (Greenery and aesthetically pleasing scenery **+*0.5; -*0.5**—interaction with barriers)	Moderating effects. Walkability not reported here as it is included in Bracy et al. with more appropriate statistical analyses and moderating effects yielding same-direction associations across values of moderators.

									3. Walking facilities: b=-3.5 (-11.9; 4.8), p>.05 (Walk-friendly infrastructure **0**)	
88	SNQLS Bracy et al., 2014 [272]	N=718 (urban) 66+ years; 53% women 21.4% response rate Community dwellers Seattle and Baltimore, USA	Cross-sectional Cluster: purposive Individuals: random Stratification: walkability and SES Neighbourhood definition: 500m street-network buffer (objective) and 15-20mins walk from home (perceived)	Age, sex, education, marital status, moths at address, number of people in the household, number of vehicles per adult	*Objective [ActiGraph accelerometer; validated; Freedson MVPA cutoff point; validated]:* Total MVPA (mins/d) → Total MVPA *TotalMVPAFreedson(mins/wk)*	*Objective [Walkability index; validated]:* 1. Walkability → Walkability *Perceived [NEWS questionnaire; validated]:* 2. Parks → Parks/public open space access/availability 3. Recreational facilities → Recreational facilities access/availability *Notes:* Traffic safety, pedestrian safety, and crime safety not reported as included in Carlson et al. (2014).	Traffic safety, Pedestrian safety, Crime safety n average (mean)=488 n high (+1SD)=115 n low (-1SD)=115	General mixed models accounting for clustering; log transformed transport walking	*No significant moderating effects.* ***Main and moderated effects with TotalMVPAFreedson(mins/wk):*** Objective environment: 1. Walkability—b (95% CIs): b=6.03 (2.71; 9.34), p<.05 (Walkability +) Perceived environment: 2. Parks: b=33.01 (15.76; 50.26), p<.05 (Parks/public open space access/availability +) 3. Recreational facilities: b=10.20 (-7.57; 27.98), p>.05 (Recreational facilities access/availability **0**)	There are multiple measures per environmental construct that need to be summed. Traffic, pedestrian and crime safety not reported as reported in Carlson et al. (2014).
89	SNQLS Cain et al., 2014 [273]	N=367 (urban) Mean age: 75.0 years 51% female 21.4% response rate Community dwellers Seattle and Baltimore, USA	Cross-sectional Cluster: purposive Individuals: random Stratification: walkability and SES Neighbourhood definition: 0.25mile buffer	Age, sex, education, race, physical functioning, clustering of participants within block groups	*Objective [ActiGraph accelerometer—validated; Freedson MVPA cutoff point—validated]:* Total MVPA → Total MVPAFreedson (mins/d) *TotalMVPAFreedson(mins/d)*	*Objective [Microscale Audit of Pedestrian Streetscapes; unvalidated]:* 1. Residential mix → Residential density 2. Shops → Shops/commercial access/availability 3. Restaurant → Food outlets access/availability 4. Institutional-service → Government/finance services	None	Mixed linear regression	***Main effects with TotalMVPAFreedson(mins/d):*** 1. Residential mix: t=2.269, p≤.05 (Residential density +) 2. Shops: t=1.312, p>.05 (Shops/commercial access/availability **0**) 3. Restaurant-entertainment: t=1.039, p>.05 (Food outlets access/availability **0**) 4. Institutional-service: t=0.421, p>.05	Table 5–Unadjusted.

						access/availability 5. Government-service → Government/finance services access/availability 6. Public recreation → Recreational facilities access/availability 7. Private recreation → Recreational facilities access/availability 8. Transit stops → Public transport access/availability 9. Aesthetics and social characteristics → Greenery and aesthetically pleasing scenery 10. Curb quality → Pavement/footpath quality 11. Crossings/intersections / Impediments → No physical barriers to walking 12. Street segments / Buffer → Traffic/pedestrian safety 13. Bike infrastructure → Cycle-friendly infrastructure 14. Trees → Greenery and aesthetically pleasing scenery 15. Building aesthetics/design → Greenery and aesthetically pleasing scenery 16. Sidewalk → Walk-friendly infrastructure 17. Sidewalk			(Government/finance access/availability **0**) 5. Government-service: t=-0.875, p>.05 (Government/finance access/availability **0**) 6. Public recreation: t=-0.278, p>.05 (Recreational facilities access/availability **0**) 7. Private recreation: t=-1.216, p>.05 (Recreational facilities access/availability **0**) 8. Transit stops: t=0.969, p>.05 (Public transport access/availability **0**) 9. Aesthetics and social characteristics: t=0.057, p>.05 (Greenery and aesthetically pleasing scenery **0**) 10. Curb quality: t=2.662, p≤.01 (Pavement/footpath quality **+**) 11. Crossings/intersections / Impediments: t=-2.016, p ≤ .05 (No physical barriers to walking **+**) 12. Street segments / Buffer: t=1.007, p>.05 (Traffic/pedestrian safety **0**) 13. Bike infrastructure: t=0.292, p>.05 (Cycle-friendly infrastructure **0**) 14. Trees: t=1.450, p>.05 (Greenery and	

						obstructions/hazards → No physical barriers to walking 18. Slope → No physical barriers to walking 19. Intersection control → Traffic/pedestrian safety			aesthetically pleasing scenery **0**) 15. Building aesthetics/design: t=0.400, p>.05 (Greenery and aesthetically pleasing scenery **0**) 16. Sidewalk: t=1.816, p>.05 (Walk-friendly infrastructure **0**) 17. Sidewalk obstruction/hazards: t=-1.814, p>.05 (No physical barriers to walking **0**) 18. Slope: t=-1.442, p>.05 (No physical barriers to walking **0**) 19. Intersection control: t=3.581, p≤.001 (Traffic/pedestrian safety **+**)	
90	SNQLS Carlson et al., 2014 [274]	N=718 (urban) 66+ years; 53% women 21.4% response rate Community dwellers Seattle and Baltimore, USA	Cross-sectional Cluster: purposive Individuals: random Stratification: walkability and SES Neighbourhood definition: 15-20mins walk from home	Age, sex, education, marital status, moths at address, number of people in the household, number of vehicles per adult, walkability	*Objective [ActiGraph accelerometer; validated; Freedson cutoff point; validated]:* Total MVPA (mins/wk) → Total MVPA *TotalMVPA(mins/wk)*	*Perceived [NEWS questionnaire; validated]:* 1. Crime safety → Crime/personal safety 2. Pedestrian safety → Traffic/pedestrian safety 3. Traffic safety → Traffic/pedestrian safety	Gender; race/ethnicity; education; neighbourhood income n average (mean)=488 n high (+1SD)=115 n low (-1SD)=115	General mixed models accounting for clustering.	*Significant moderating effects for:* Crime safety*gender, p>.05 Crime safety*race/ethnicity, p>.05 Crime safety*education, p>.05 Crime safety*neighbourhood income, p>.05 Pedestrian safety*gender, p>.05 Pedestrian safety*race/ethnicity, p>.05 Pedestrian safety*education, p>.05 Pedestrian safety*neighbourhood	Table 4.

									income, p<.10 Traffic safety*gender, p>.05 Traffic safety*race/ethnicity, p>.05 Traffic safety*education, p<.10 Traffic safety*neighbourhood income, p>.05 ***Main effects with TotalMVPA(mins/wk):*** 1. Crime safety—b (95% CIs): b=0.4 (-9.4; 10.2), p>.05 (Crime/personal safety **0**) 2. Pedestrian safety: b=5.0 (-4.6; 14.7), p>.05 (Traffic/pedestrian safety **0**) 3. Traffic safety: b=2.0 (-7.3; 11.3), p>.05 (Traffic/pedestrian safety **0**)	
91	SNQLS Ding et al., 2013 [275]	N=861 (urban) 66+ years; 56% women 21.4% response rate Community and retirement village dwellers Seattle and Baltimore, USA	Cross-sectional with two assessments Cluster: purposive Individuals: random Stratification: walkability and SES Neighbourhood definition: 500m street-network buffer (objective) and 15-20mins walk from home (perceived)	Age, sex, education, ethnicity, study site, marital status, number of people in household, living situation, length of time in current address, medical conditions, mobility impairment	*Objective [ActiGraph accelerometer; validated; Freedson MVPA cutoff point: validated]:* Counts/min → Total PA *TotalPA(cpm)* MVPA (mins/d) → Total MVPA *TotalMVPAFreedson(mins/d)*	*Objective [GIS index; validated]:* 1. Walkability → Walkability 2. Parks and Recreational facilities access/availability (categorized) → Parks/public open space access/availability *Perceived [NEWS questionnaire; validated]:* 3. Residential density → Residential density	Driving status: Driving (n=712), Non-driving (n=149)	Mixed linear regression models	*No significant moderating effects.* ***Main effects with TotalPA(cpm):*** Objective environment: 1. Walkability—b (95% CIs): *Drivers:* b=3.23 (0.61; 5.82), p<.05 *Non-drivers:* b=1.09 (-1.92; 4.10), p>.05 (Walkability **+*1**) 2. Parks and Recreational facilities access/availability : *Drivers:* 1 vs. 0 (Ref): b=10.80 (-6.66; 28.28), p>.05; 2+ vs. 0 (Ref):	Moderating effects. *Note. Multiple measures per environmental construct need to be summed.* Table 3.

						4. Land use mix—access → Destinations/services (overall/unspecific) access/availability 5. Land use mix—diversity → Land-use mix—destination diversity 6. Street connectivity → Street connectivity 7. Walking or cycling infrastructures → Cycle/walk-friendly infrastructure 8. Neighbourhood aesthetics → Greenery and aesthetically pleasing scenery 9. Traffic safety → Traffic/pedestrian safety 10. Pedestrian safety structures → Traffic/pedestrian safety 11. Transit access → Public transport access/availability 12. Personal safety → Crime/personal safety			b=11.98 (-3.79; 27.20), p>.05 *Non-drivers:* 1 vs. 0 (Ref): b=14.76 (-22.84; 52.37), p>.05; 2+ vs. 0 (Ref): b=27.84 (-7.11; 62.79), p>.05 (Parks/public open space access/availability **0*1**) Perceived environment: 3. Residential density: *Drivers:* b=1.49 (-7.10; 10.07), p>.05 *Non-drivers:* b=0.28 (-8.08; 8.64), p>.05 (Residential density **0*1**) 4. Land-use mix—access: *Drivers:* b=9.67 (-1.42; 20.76), p<.10 *Non-drivers:* b=9.15 (-8.02; 26.32), p>.05 (Destinations/services (overall/unspecific) access/availability **0*1**) 5. Land-use mix–diversity: *Drivers:* b=11.24 (2.88; 19.59), p<.01 *Non-drivers:* b=9.20 (-3.31; 21.72), p>.05 (Land-use mix—destination diversity **+*1**) 6. Street connectivity: *Drivers:* b=2.58 (-6.84; 12.00), p>.05 *Non-drivers:* b=-9.77 (-25.62; 6.07), p>.05 (Street connectivity **0*1**) 7. Walking or cycling infrastructures: *Drivers:* b=0.85 (-6.87; 8.58), p>.05 *Non-drivers:* b=0.68 (-13.36; 14.71), p>.05	

									(Cycle/Walk-friendly infrastructure **0*1**) 8. Neighbourhood aesthetics: *Drivers:* b=5.14 (-4.92; 15.21), p>.05 *Non-drivers:* b=-5.58 (-20.29; 9.12), p>.05 (Greenery and aesthetically pleasing scenery **0*1**) 9. Traffic safety: *Drivers:* b=-0.01 (-0.48; 0.50), p>.05 *Non-drivers:* b=-13.72 (-29.29; 1.72), p>.05 (Traffic/pedestrian safety **0*1**) 10. Pedestrian safety structures: *Drivers:* b=-3.01 (-17.34; 11.33), p>.05 *Non-drivers:* b=0.94 (-20.94; 22.82), p>.05 (Traffic/pedestrian safety **0*1**) 11. Transit access: *Drivers:* b=3.04 (-3.53; 9.60), p>.05 *Non-drivers:* b=2.26 (-9.08; 13.60), p>.05 (Public transport **0*1**) 12. Personal safety: *Drivers:* b=2.03 (-9.48; 13.22), p>.05 *Non-drivers:* b=-10.84 (-27.78; 6.10), p>.05 (Crime/personal safety **0*1**) ***Main effects with TotalMVPAFreedson(mins/d):*** Objective environment: 1. Walkability: *Drivers:* b=0.72 (0.27;	

									1.16), p<.01 *Non-drivers:* b=0.06 (-0.37; 0.49), p>.05 (Walkability **+*1**) 2. Parks and Recreational facilities access/availability : *Drivers:* 1 vs. 0 (Ref): b=1.09 (-1.92; 4.10), p>.05; 2+ vs. 0 (Ref): b=2.36 (-0.31; 5.03), p>.05 *Non-drivers:* 1 vs. 0 (Ref): b=-0.90 (-6.26; 4.46), p>.05; 2+ vs. 0 (Ref): b=2.52 (-2.74; 7.22), p>.05 (Parks/public open space access/availability **0*1**) Perceived environment: 3. Residential density: *Drivers:* b=0.77 (-0.71; 1.69), p>.05 *Non-drivers:* b=0.46 (-0.76; 1.68), p>.05 (Residential density **0*1**) 4. Land-use mix—access: *Drivers:* b=1.98 (0.07; 3.89), p<.05 *Non-drivers:* b=1.60 (-0.84; 4.05), p>.05 (Destinations/services (overall/unspecific) access/availability **+*1**) 5. Land-use mix—diversity: *Drivers:* b=2.53 (1.09; 3.96), p<.01 *Non-drivers:* b=1.87 (0.12; 3.61), p<.05 (Land-use mix—destination diversity **+*1**) 6. Street connectivity: *Drivers:* b=-0.66 (-2.28;	

									0.96), p>.05 (Street connectivity **0*0.86**) *Non-drivers:* b=-2.45 (-4.68; -0.21), p<.05 (Street connectivity **-*0.14**) 7. Walking or cycling infrastructures: *Drivers:* b=0.39 (-0.94; 1.72), p>.05 *Non-drivers:* b=0.77 (-1.23; 2.76), p>.05 (Cycle/Walk-friendly infrastructure **0*1**) 8. Neighbourhood aesthetics: *Drivers:* b=0.27 (-1.46; 2.01), p>.05 *Non-drivers:* b=-0.31 (-2.41; 1.79), p>.05 (Greenery and aesthetically pleasing scenery **0*1**) 9. Traffic safety: *Drivers:* b=-0.01 (-1.63; 1.62), p>.05 *Non-drivers:* b=-1.24 (-3.45; 0.98), p>.05 (Traffic/pedestrian safety **0*1**) 10. Pedestrian safety structures: *Drivers:* b=0.78 (-1.68; 3.25), p>.05 *Non-drivers:* b=0.13 (-3.00; 3.24), p>.05 (Traffic/pedestrian safety **0*1**) 11. Transit access: *Drivers:* b=1.05 (-0.08; 2.17), p<.10 *Non-drivers:* b=0.92 (-0.69; 2.53), p>.05 (Public transport **0*1**) 12. Personal safety:	

									Drivers: b=-0.20 (-2.16; 1.75), p>.05 *Non-drivers:* b=0.49 (-1.94; 2.91), p>.05 (Crime/personal safety **0*1**)	
92	TILDA McKee et al., 2015 [485]	N=596 (mixed) 65+ years 53% female Response rate not reported Community-dwellers *Dublin City or County and other locations,* Ireland	Cross-sectional Cluster: purposive Individuals: random Stratification: age, SES and geography (urbanisation) Neighbourhood definition: townland cluster (≈500-1180 addresses) (other participant delineation)	Age, sex, education, employment status, loneliness, membership of a non-church club, type of house, disability, time spent sitting, grip test, often troubled with pain, BMI, long-term illness, self-rated vision, self-rated hearing, number of regular medications, fallen last year, anxiety, quality of life, depression, mini-mental state examination, self-rated memory	*Self-report [IPAQ; validated]:* METs/wk → Total PA *TotalPA(METs/wk)*	*Perceived [unnamed questionnaire; unvalidated]:* 1. Location of home → Urbanisation 2. Physical state of buildings in area → Greenery and aesthetically pleasing scenery 3. Vandalism in area Aesthetics and greenery 4. Litter in area → Greenery and aesthetically pleasing scenery	None	Multivariate linear regression	***Main effects with TotalPA(METs/wk):*** 1. Location of home—b (95% CIs): b=not reported, p>.001 (Urbanisation **0**) 2. Physical state of buildings in the area: b=-0.024 (-0.060; 0.015), p =.246 (Greenery and aesthetically pleasing scenery **0**) 3. Vandalism in area: b=not reported, p>.001 (Greenery and aesthetically pleasing scenery **0**) 4. Litter in area: b=not reported, p>.001 (Greenery and aesthetically pleasing scenery **0**)	*Note. Bonferroni adjustment (α=.001).* Table 2.
93	TILDA Murtagh et al., 2015 [486]	N=4892 (mixed) 60-75+ years 53% female Response rate not reported Community-dwellers *Dublin City or County and other locations,* Ireland	Cross-sectional Cluster: purposive Individuals: random Stratification: age, SES and geography (urbanisation) Neighbourhood definition: townland cluster (≈500-1180 addresses) (other participant delineation)	Age, education, SES, living status, having children, employment status, car ownership, perceived overall health, perceived emotional health, falls in last year, fear of falling, activity limited by illness, caring for grandchildren, attendance to an Education course	*Self-report [IPAQ; validated]:* Total MVPA (<150 mins/wk; Yes/No) → Total MVPA *TotalMVPA(<150 mins/wk; Yes/No)*	*Perceived [unnamed questionnaire; unvalidated]:* 1. Location → Urbanisation	Sex: Males(n≈2280), Females (n≈2612)	Multivariate logistic regression	***Moderated effects with TotalMVPA(<150 mins/wk; Yes/No):*** 1. Location—OR (95% CIs): *Females:* OR=0.87 (0.84; 0.89), p<.05 (Urbanisation **+*0.53**) *Males:* OR=1.24 (1.20; 1.28), p<.05 (Urbanisation **-*0.47**)	Moderating effects. Table 3.

94	UAB Study of Aging Hannon et al., 2012 [487]	N=433 (mixed) 65+ years 50% female 45.7% response rate (original study) Community-dwellers Jefferson, Tuscaloosa, Hale, Pickens, and Bibb, USA	Cross-sectional Cluster: purposive Individuals: random Stratification: ethnicity/race (African-Americans) and urbanisation Neighbourhood definition: county level (objective); not reported (perceived)	Age, sex, education, homeownership, occupancy, median home value, length of residency, income, marital status, comorbidities	*Self-report [unnamed questionnaire; unvalidated]:* Neighbourhood walking (blocks/d) → Total walking *TotalWalking(blocks/d)*	*Objective [Alabama Rural Health Association data; unvalidated]:* 1. Residence → Urbanisation *Perceived [unnamed questionnaire; unvalidated]:* 2. Fear of being robbed or attacked → Crime/personal safety	None	Hierarchical linear regression	***Main effects with TotalWalking(blocks/d):*** Objective environment: 1. Residence: b=-0.193, p<.01 (Urbanisation -) Perceived environment: 2. Fear of being robbed or attacked: b=0.064, p>.05 (Crime/personal safety **0**)	Table 3—model 4.
95	VoisiNuAge Gauvin et al., 2012 [488]	N=521 (urban) 67+ years 53% female Response rate not reported Community-dwellers Montreal and Laval, Canada	Longitudinal Cluster: none Individuals: random Stratification: age and sex Neighbourhood definition: participant delineation (perceived); not defined (objective)	Age, sex, education, country of birth, marital status, family income, housing ownership	*Self-report [1 question from PASE questionnaire; validated]:* Frequency of walking change over time? (days) → Total walking *TotalWalking(d/wk)*	*Objective [MEGAPHONE database; validated]:* 1. Accessibility to 16 services and amenities → Destinations/services (overall/unspecific) access/availability *Perceived [unnamed questionnaire; validated]:* 2. Quality of walking environment and transportation services → Walk-friendly infrastructure 3. Neighbourhood amenities and services—key resources for older adults → Destinations/services (overall/unspecific) access/availability 4. Neighbourhood amenities and services	None	Ordinal growth curve analysis. Spatial autocorrelation examined to account for clustering.	***Main effects with TotalWalking(d/wk):*** Objective: 1. Accessibility to 16 services and amenities (Ref: Furthest)—OR (95% CIs): *Closest:* OR=2.52 (1.42; 4.49), p<.001 *Close:* OR=1.86 (1.09; 3.18), p<.05 *Far:* OR=1.15 (0.69; 1.94), p>.05 (Destinations/services (overall/unspecific) access/availability +) Perceived: 2. Quality of walking environment (Ref: Very easy): *Very/somewhat difficult:* OR=0.34 (0.14; 0.86), p<.05 *Somewhat easy:* OR=0.71 (0.42; 1.21), p>.05 (Walk-friendly infrastructure +) 3. Neighbourhood	Table 3 – apart from #5 public transport that was not presented in Table 3 but measured, evidenced in Table 2.

						within 5 min → Destinations/services (overall/unspecific) access/availability 5. Availability of a bus stop or subway within 5 min walk → Public transport access/availability			amenities and services (Ref: Higher): *Lower:* OR=0.96 (0.61; 1.53), p>.05 *Average:* OR=1.12 (0.69; 1.78), p>.05 (Destinations/services (overall/unspecific) access/availability **0**) 4. Neighbourhood amenities and services within 5 min walk (Ref: Most): *Fewest:* OR=1.05 (0.52; 2.13), p>.05 *Few:* OR=1.22 (0.67; 2.23), p>.05 *Average:* OR=0.86 (0.42; 1.64), p>.05 *Many:* OR=0.88 (0.50; 1.55), p>.05 (Destinations/services (overall/unspecific) access/availability **0**) 5. Availability of a bus stop or subway within 5 min walk: OR=not reported, p>.05 (Public transport access/availability **0**)	
96	VoisiNuAge Julien et al., 2015 [489]	N=519 (urban) 68+ years 53% female 58.6% response rate Community-dwellers Montreal and Laval, Canada	Cross-sectional Cluster: purposive Individuals: random Stratification: age and sex Neighbourhood definition: postal code	Age, sex, education, income, owning a car, transit stop	*Self-report [1 question from PASE questionnaire; unvalidated]:* Frequency of walking (days) → Total walking *TotalWalking(d/wk)*	*Objective [MEGAPHONE database; validated]:* 1. Accessibility to services and amenities conducive to social participation → Social recreational facilities access/availability	None	Multiple mediation analyses	***Direct effects with TotalWalking(d/wk):*** 1. Access to/availability of amenities/services: b=0.43 (SE=0.14), p<.05 (Social recreational facilities access/availability **+**)	Fig. 1.
97	Walk the Talk Hirsch et al., 2016 [276]	N=77 (urban) 65+ years 66% female 8% response rate Community-	Cross-sectional Cluster: purposive Individuals: random Stratification:	Age, sex, education, vehicle access	*Objective [ActiGraph accelerometer—validated; using Freedson cutoff points for LPA and MVPA—validated]:*	*Objective [Environics Analytics business data, North American Industry Classification System, ArcGIS; unvalidated]:*	None	Multiple linear and logistic regression models, no adjustment	***Main effects with TotalPA(mins/d):*** 1. Diversity (1 additional destination type)—b (95% CIs): *400m:* b=-0.97 (5.47;	

		dwellers Vancouver, Canada	income and walkability Neighbourhood definition: variable (6 different types of buffers)		Total PA (min/d) → Total PA *TotalPA(mins/d)* Steps/d → Total walking *TotalWalking(steps/d)* Meeting recommended daily steps → Total walking *Total Walking(10,000+ steps/d; Yes/No)*	1. Destination diversity (number of different destinations; 1 additional destination type) → Land-use mix—destination diversity 2. Ambulatory health care services destination density (10% difference)→ Health and aged care access/availability 3. Banks/credit unions destination density (10% difference)→ Government/finance access/availability 4. Community centre/neighbourhood house destination density (10% difference)→ Social recreational access/availability 5. Convenience stores destination density (10% difference)→ Shops/commercial access/availability 6. Entertainment destination density (10% difference)→ Social recreational facilities access/availability 7. Food stores destination density (10% difference)→ Shops/commercial access/availability 8. Gym and fitness centres destination density (10% difference)→		for clustering.	3.53), p>.05 *800m:* b=3.03 (1.79; 7.86), p>.05 *All-mode activity space:* b=-7.24 (-18.76; 4.28), p>.05 *Pedestrian and bicycling activity space:* b=3.97 (-1.17; 9.12), p>.05 *SD ellipse:* b=-2.80 (-8.90; 3.29), p>.05 *Min. convex polygon:* b=-1.12 (-8.80; 6.55), p>.05 (Land-use mix—destination diversity **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) 2. Ambulatory health care services: *400m:* b=0.02 (-0.04; 0.07), p>.05 *800m:* b=0.02 (-0.06; 0.09), p>.05 *SD ellipse:* b=-0.05 (-0.21; 0.11), p>.05 *Min. convex polygon:* b=-0.02 (-0.24; 0.20), p>.05 *Daily path area:* b=0.06 (-0.83; 0.96), p>.05 *Daily path area (pedestrian/bike):* b=0.05 (-0.05; 0.15), p>.05 (Health and aged care access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) 3. Banks/credit unions: *400m:* b=0.01 (-0.07; 0.05), p>.05 *800m:* b=0.02 (-0.04; 0.08), p>.05 *SD ellipse:* b=-0.05 (-0.16; 0.07), p>.05 *Min. convex polygon:*	

						Recreational facilities access/availability 9. Library destination density (10% difference)→ Education facilities access/availability 10. Malls destination density (10% difference)→ Shops/commercial access/availability 11. Museum destination density (10% difference)→ Education facilities access/availability 12. Nature/parks/botanical gardens destination density (10% difference)→ Parks/public open space access/availability 13. Pharmacies/drug stores/personal care destination density (10% difference)→ Health and aged care access/availability 14. Religious organisations destination density (10% difference)→ Religious institution access/availability 15. Restaurants destination density (10% difference)→ Food outlets access/availability 16. Retail shopping destination density (10% difference)→ Shops/commercial			b=0.05 (-0.09; 0.20), p>.05 *Daily path area:* b=0.21 (-0.82; 1.24), p>.05 (Government/finance services access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) *Daily path area (pedestrian/bike):* b=0.08 (0.01; 0.14), p<.05 (Government/finance services access/availability **+*0.166**) 4. Community centre/neighbourhood house: *400m:* b=-0.01 (-0.07; 0.04), p>.05 *800m:* b=0.01 (-0.06; 0.07), p>.05 *SD ellipse:* b=0.00 (-0.15; 0.14), p>.05 *Min. convex polygon:* b=0.04 (-0.13; 0.21), p>.05 *Daily path area:* b=-0.02 (-0.26; 0.21), p>.05 *Daily path area (pedestrian/bike):* b=0.03 (-0.05; 0.11), p>.05 (Social recreational facilities access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) 5. Convenience stores: *400m:* b=0.00 (-0.07; 0.07), p>.05 *800m:* b=0.04 (-0.02; 0.10), p>.05 *SD ellipse:* b=-0.03 (-	

						access/availability 17. Services destination density (10% difference)→ Destinations/services (overall/unspecific) access/availability 18. Total densities (10% difference) → Destinations/services (unspecified)access/availability			0.11; 0.04), p>.05 *Min. convex polygon:* b=-0.02 (-0.11; 0.08), p>.05 *Daily path area:* b=-0.02 (-0.10; 0.07), p>.05 *Daily path area (pedestrian/bike):* b=0.06 (0.00; 0.12), p<.10 (Shops/commercial access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) 6. Entertainment: *400m:* b=-0.01 (-0.09; 0.07), p>.05 *800m:* b=0.02 (-0.04; 0.07), p>.05 *SD ellipse:* b=-0.02 (-0.10; 0.07), p>.05 *Min. convex polygon:* b=0.00 (-0.11; 0.11), p>.05 *Daily path area:* b=0.04 (-0.10; 0.17), p>.05 *Daily path area (pedestrian/bike):* b=0.05 (-0.01; 0.11), p>.05 (Social recreational facilities access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) 7. Food stores: *400m:* b=-0.02 (-0.08; 0.04), p>.05 *800m:* b=0.08 (-0.01; 0.17), p>.05 *SD ellipse:* b=-0.06 (-0.20; 0.08), p>.05 *Min. convex polygon:* b=0.00 (-0.23; 0.23), p>.05 *Daily path area:* b=0.29 (-0.66; 1.24), p>.05	

									Daily path area (pedestrian/bike): b=0.04 (-0.04; 0.12), p>.05 (Shops/commercial access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) 8. Gym and fitness facilities: *400m:* b=-0.02 (-0.08; 0.03), p>.05 *800m:* b=0.01 (-0.06; 0.08), p>.05 *SD ellipse:* b=-0.06 (-0.18; 0.07), p>.05 *Min. convex polygon:* b=-0.05 (-0.23; 0.12), p>.05 *Daily path area:* b=-0.09 (-0.34; 0.15), p>.05 *Daily path area (pedestrian/bike):* b=0.02 (-0.04; 0.09), p>.05 (Recreational facilities access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) 9. Library: *400m:* b=0.01 (-0.07; 0.08), p>.05 *800m:* b=0.04 (-0.02; 0.10), p>.05 *SD ellipse:* b=0.03 (-0.04; 0.10), p>.05 *Min. convex polygon:* b=0.04 (-0.05; 0.12), p>.05 *Daily path area:* b=-0.02 (-0.12; 0.07), p>.05 (Education facilities access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) *Daily path area*	

									(pedestrian/bike): b=0.06 (0.00; 0.12), p<.05 (Education facilities access/availability **+*0.166**) 10. Malls: *400m:* b=0.05 (-0.14; 0.05), p>.05 *800m:* b=0.04 (-0.02; 0.10), p>.05 *SD ellipse:* b=-0.02 (-0.09; 0.04), p>.05 *Min. convex polygon:* b=-0.02 (-0.09; 0.06), p>.05 *Daily path area:* b=-0.02 (-0.10; 0.06), p>.05 *Daily path area (pedestrian/bike):* b=0.01 (-0.05; 0.07), p>.05 (Shops/commercial access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) 11. Museum: *400m:* b=-0.05 (-0.17; 0.06), p>.05 *800m:* b=-0.02 (-0.09; 0.06), p>.05 *SD ellipse:* b=-0.02 (-0.08; 0.05), p>.05 *Min. convex polygon:* b=-0.02 (-0.08; 0.05), p>.05 *Daily path area:* b=-0.03 (-0.10; 0.03), p>.05 *Daily path area (pedestrian/bike):* b=-0.02 (-0.09; 0.05), p>.05 (Education facilities access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) 12. Nature/parks/botanical gardens:	

									400m: b=-0.03 (-0.12; 0.06), p>.05 *800m:* b=0.01 (-0.07; 0.09), p>.05 *SD ellipse:* b=-0.03 (-0.10; 0.03), p>.05 *Min. convex polygon:* b=-0.03 (-0.10; 0.04), p>.05 *Daily path area:* b=-0.06 (-0.12; 0.00), p<.10 *Daily path area (pedestrian/bike):* b=-0.04 (-0.12; 0.03), p>.05 (Parks/public open space access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) 13. Pharmacies/drug stores/personal care: *400m:* b=-0.04 (-0.09; 0.02), p>.05 *800m:* b=0.02 (-0.04; 0.09), p>.05 *SD ellipse:* b=-0.06 (-0.20; 0.08), p>.05 *Min. convex polygon:* b=-0.01 (-0.23; 0.22), p>.05 *Daily path area:* b=0.14 (-0.84; 1.11), p>.05 *Daily path area (pedestrian/bike):* b=0.02 (-0.07; 0.10), p>.05 (Health care and aged access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) 14. Religious organisations: *400m:* b=0.04 (-0.02; 0.10), p>.05 *800m:* b=0.00 (-0.09; 0.10), p>.05 *SD ellipse:* b=-0.02 (-0.13; 0.08), p>.05	

									Min. convex polygon: b=0.05 (-0.10; 0.19), p>.05 *Daily path area:* b=0.30 (-0.89; 1.50), p>.05 *Daily path area (pedestrian/bike):* b=-0.01 (-0.08; 0.07), p>.05 (Religious institution access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) 15. Restaurants: *400m:* b=0.00 (-0.06; 0.06), p>.05 *800m:* b=0.08 (-0.01; 0.18), p>.05 *SD ellipse:* b=-0.05 (-0.21; 0.11), p>.05 *Min. convex polygon:* b=0.01 (-0.21; 0.22), p>.05 *Daily path area:* b=0.16 (-0.68; 0.99), p>.05 *Daily path area (pedestrian/bike):* b=0.06 (-0.04; 0.16), p>.05 (Food outlets access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) 16. Retail shopping: *400m:* b=0.00 (-0.06; 0.06), p>.05 *800m:* b=0.00 (-0.12; 0.11), p>.05 *SD ellipse:* b=-0.06 (-0.22; 0.10), p>.05 *Min. convex polygon:* b=-0.01 (-0.23; 0.21), p>.05 *Daily path area:* b=-0.03 (-0.79; 0.73), p>.05 *Daily path area (pedestrian/bike):* b=0.01	

									(-0.08; 0.11), p>.05 (Shops/commercial access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) 17. Services: *400m:* b=-0.01 (-0.08; 0.05), p>.05 *800m:* b=0.11 (0.01; 0.21), p<.05 (Destinations/services (overall/unspecific) access/availability **+*0.166**) *SD ellipse:* b=-0.06 (-0.23; 0.10), p>.05 *Min. convex polygon:* b=-0.01 (-0.23; 0.22), p>.05 *Daily path area:* b=0.10 (-0.85; 1.05), p>.05 *Daily path area (pedestrian/bike):* b=0.03 (-0.08; 0.14), p>.05 (Destinations/services (overall/unspecific) access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) ***Main effects with TotalWalking(steps/d):*** 1. Diversity (1 additional destination type): *400m:* b=39.32 (-138.51; 217.15), p>.05 *800m:* b=127.07 (-63.17; 317.30), p>.05 *All-mode activity space:* b=-45.68 (-505.59; 414.23), p>.05 *Pedestrian and bicycling activity space:* b=243.34 (35.97; 450.70), p<.05 (Land-use mix—	

									destination diversity **+*0.166**) *SD ellipse:* b=-56.58 (-298.42; 185.26), p>.05 *Min. convex polygon:* b=23.80 (-279.45; 327.06), p>.05 (Land-use mix—destination diversity **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) 2. Ambulatory health care services: *400m:* b=1.19 (-1.10; 3.49), p>.05 *800m:* b=1.21 (-1.81; 4.24), p>.05 *SD ellipse:* b=0.18 (-6.13; 6.49), p>.05 *Min. convex polygon:* b=2.05 (-6.57; 10.68), p>.05 *Daily path area:* b=26.43 (-8.35; 61.22), p>.05 *Daily path area (pedestrian/bike):* b=3.72 (-0.35; 7.80), p<.10 (Health and aged care access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) 3. Banks/credit unions: *400m:* b=0.06 (-2.23; 2.34), p>.05 *800m:* b=0.81 (-1.57; 3.19), p>.05 *SD ellipse:* b=0.53 (-4.13; 5.19), p>.05 *Min. convex polygon:* b=1.41 (-4.34; 7.17), p>.05 *Daily path area:* b=37.16 (-2.66; 76.99), p<.10 (Government/finance	

									services access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) *Daily path area (pedestrian/bike):* b=3.10 (0.44; 5.75), p<.05 (Government/finance services access/availability **+*0.166**) 4. Community centre/neighbourhood house: *400m:* b=-0.06 (-2.29; 2.16), p>.05 *800m:* b=0.12 (-2.45; 2.69), p>.05 *SD ellipse:* b=-0.44 (-6.11; 5.24), p>.05 *Min. convex polygon:* b=1.59 (-5.20; 8.37), p>.05 *Daily path area:* b=1.50 (-7.70; 10.71), p>.05 *Daily path area (pedestrian/bike):* b=1.98 (-1.19; 5.15), p>.05 (Social recreational facilities access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) 5. Convenience stores: *400m:* b=0.79 (-2.05; 3.64), p>.05 *800m:* b=2.20 (-0.09; 4.49), p>.05 *SD ellipse:* b=-0.61 (-3.60; 2.38), p>.05 *Min. convex polygon:* b=0.91 (-2.84; 4.66), p>.05 *Daily path area:* b=0.50	

									(-2.87; 3.87), p>.05 (Shops/commercial access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) *Daily path area (pedestrian/bike):* b=3.26 (0.79; 5.74), p<.05 (Shops/commercial access/availability **+*0.166**) 6. Entertainment: *400m:* b=0.68 (-2.47; 3.83), p>.05 *800m:* b=0.78 (-1.56; 3.13), p>.05 *SD ellipse:* b=1.32 (-2.01; 4.64), p>.05 *Min. convex polygon:* b=0.95 (-3.26; 5.17), p>.05 *Daily path area:* b=1.68 (95% CL=-3.59; 6.96), p>.05 *Daily path area (pedestrian/bike):* b=2.10 (95% CL=-0.44; 4.64), p>.05 (Social recreational facilities access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) 7. Food stores: *400m:* b=-0.20 (-2.52; 2.12), p>.05 *800m:* b=3.28 (-.41; 6.98), p<.10 *SD ellipse:* b=-1.69 (-7.26; 3.87), p>.05 *Min. convex polygon:* b=1.97 (-7.04; 10.97), p>.05 *Daily path area:* b=24.89	

									(-12.18; 61.96), p>.05 *Daily path area (pedestrian/bike):* b=2.14 (-1.20; 5.49), p>.05 (Shops/commercial access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) 8. Gym and fitness facilities: *400m:* b=0.56 (-1.60; 2.71), p>.05 *800m:* b=1.37 (-1.29; 4.03), p>.05 *SD ellipse:* b=-1.67 (-6.75; 3.41), p>.05 *Min. convex polygon:* b=-0.02 (-7.01; 6.98), p>.05 *Daily path area:* b=-0.24 (-9.99; 9.51), p>.05 *Daily path area (pedestrian/bike):* b=2.51 (-0.15; 5.16), p>.05 (Recreational facilities access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) 9. Library: *400m:* b=1.23 (-1.59; 4.06), p>.05 *800m:* b=1.56 (-0.81; 3.92), p>.05 *SD ellipse:* b=1.54 (-1.33; 4.41), p>.05 *Min. convex polygon:* b=0.39 (-3.09; 3.86), p>.05 *Daily path area:* b=-1.25 (-4.99; 2.50), p>.05 *Daily path area (pedestrian/bike):* b=2.25 (-0.25; 4.76), p<.10 (Education facilities access/availability	

									0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17) 10. Malls: *400m:* b=-1.40 (-5.22; 2.42), p>.05 *800m:* b=2.35 (-0.09; 4.78), p<.10 *SD ellipse:* b=-0.15 (-2.75; 2.45), p>.05 *Min. convex polygon:* b=1.27 (-1.70; 4.25), p>.05 *Daily path area:* b=1.50 (-1.74; 4.74), p>.05 *Daily path area (pedestrian/bike):* b=0.99 (-1.53; 3.51), p>.05 (Shops/commercial access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) 11. Museum: *400m:* b=-1.37 (-5.83; 3.09), p>.05 *800m:* b=-1.12 (-4.09; 1.86), p>.05 *SD ellipse:* b=-0.70 (-3.17; 1.76), p>.05 *Min. convex polygon:* b=-0.24 (-2.92; 2.45), p>.05 *Daily path area:* b=0.00 (-2.58; 2.57), p>.05 *Daily path area (pedestrian/bike):* b=1.45 (-1.48; 4.38), p>.05 (Education facilities access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) 12. Nature/parks/botanical gardens: *400m:* b=-1.33 (-4.85;	

									2.20), p>.05 *800m:* b=-0.28 (-3.31; 2.75), p>.05 *SD ellipse:* b=-0.76 (-3.45; 1.93), p>.05 *Min. convex polygon:* b=0.09 (-2.61; 2.78), p>.05 *Daily path area:* b=-1.01 (-3.41; 1.39), p>.05 *Daily path area (pedestrian/bike):* b=0.02 (-3.19; 3.23), p>.05 (Parks/public open space access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) 13. Pharmacies/drug stores/personal care: *400m:* b=0.13 (-1.98; 2.25), p>.05 *800m:* b=1.28 (-1.32; 3.88), p>.05 *SD ellipse:* b=-1.25 (-6.83; 4.32), p>.05 *Min. convex polygon:* b=2.27 (-6.71; 11.26), p>.05 *Daily path area:* b=27.94 (-10.01; 65.90), p>.05 *Daily path area (pedestrian/bike):* b=1.76 (-1.71; 5.23), p>.05 (Health and aged care access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) 14. Religious organisations: *400m:* b=0.39 (-1.98; 2.75), p>.05 *800m:* b=-1.33 (-5.23; 2.56), p>.05 *SD ellipse:* b=-1.59 (-	

									5.83; 2.64), p>.05 *Min. convex polygon:* b=0.52 (-5.09; 6.13), p>.05 *Daily path area:* b=9.29 (-38.07; 56.64), p>.05 *Daily path area (pedestrian/bike):* b=-0.78 (-4.02; 2.45), p>.05 (Religious institution access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) 15. Restaurants: *400m:* b=0.74 (-1.63; 3.12), p>.05 *800m:* b=3.53 (-0.18; 7.24), p<.10 *SD ellipse:* b=-0.28 (-6.57; 6.01), p>.05 *Min. convex polygon:* b=2.36 (-6.15; 10.87), p>.05 *Daily path area:* b=22.21 (-10.47; 54.89), p>.05 *Daily path area (pedestrian/bike):* b=3.19 (-0.85; 7.24), p>.05 (Food outlets access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) 16. Retail shopping: *400m:* b=0.01 (-2.45; 2.47), p>.05 *800m:* b=-1.57 (-6.10; 2.96), p>.05 *SD ellipse:* b=-0.34 (95% CL=-6.66; 5.98), p>.05 *Min. convex polygon:* b=2.21 (-6.33; 10.75), p>.05 *Daily path area:* b=18.47 (-11.17; 48.11), p>.05	

									Daily path area (pedestrian/bike): b=0.76 (-3.16; 4.67), p>.05 (Shops/commercial access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) 17. Services: *400m:* b=1.09 (-1.43; 3.61), p>.05 *800m:* b=4.72 (0.78; 8.66), p<.05 (Destinations/services (overall/unspecific) access/availability **+*0.166**) *SD ellipse:* b=-0.40 (-6.90; 6.10), p>.05 *Min. convex polygon:* b=1.97 (-6.87; 10.82), p>.05 *Daily path area:* b=25.32 (-11.72; 62.36), p>.05 *Daily path area (pedestrian/bike):* b=2.41 (-2.04; 6.86), p>.05 (Destinations/services (overall/unspecific) access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) ***Main effects with TotalWalking(10,000+ steps/d; Yes/No):*** 1. Diversity (1 additional destination type): *400m:* OR=1.03 (0.88; 1.20), p>.05 *800m:* OR=1.06 (0.90; 1.26), p>.05 *All-mode activity space:* OR=0.90 (0.62; 1.35), p>.05	

									Pedestrian and bicycling activity space: OR=1.21 (0.97; 1.59), p>.05 *SD ellipse:* OR=0.94 (0.78; 1.17), p>.05 *Min. convex polygon:* OR=1.00 (0.78; 1.39), p>.05 (Land-use mix—destination diversity **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**) 18. Total densities (10% difference): *400m:* OR=1.00 (1.00; 1.02), p>.05 *800m:* OR=1.01 (1.00; 1.03), p>.05 *All-mode activity space:* OR=1.02 (0.99; 1.05), p>.05 *Pedestrian and bicycling activity space:* OR=1.003 (1.00; 1.03), p>.05 *SD ellipse:* OR=1.01 (1.00; 1.03), p>.05 *Min. convex polygon:* OR=1.02 (1.00; 1.04), p>.05 (Destinations/services (overall/unspecific) access/availability **0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.166; 0*0.17**)	
98	WHI Perry et al., 2013 [490]	N=1038 (mixed) Mean age: 66 years 100% female Response rate not reported Community-dwellers	Cross-sectional Cluster: purposive Individuals: convenience Stratification: sex (female), age, menopausal and urbanisation Neighbourhood	Age, education, health status, ethnicity, previous vigorous exercise history, personal income, marital status, energy expenditure (non-walking),	*Self-report [WHI questionnaire; reliable]:* Walking (MET hr/wk) → Total walking *TotalWalking(MET hr/wk)*	*Objective [Walkable and Bikable Communities Index; unvalidated]:* 1. Walkability → Walkability	Interaction terms for: Walkability*age Walkability*ethnicity: White (n≈987), Asian/Pacific Islander (n≈21), African-	Multivariate linear regression	*No significant moderating effects.* ***Main effect with TotalWalking(MET hr/wk):*** 1. Walkability—b (95% CIs): b=0.001 (0.017; 0.019), p=.948 (Walkability **0**)	

		Seattle, USA	definition: 1km buffer	neighbourhood income			American (n≈10), American Indian/Alaskan Native (n≈10), Latina (n≈10) Walkability*marital status: Married (n≈654), previously married/never (n≈384) Walkability*median family income: <$10,000 (n≈21), $10k-$19,999 (n≈145), $20,000-$34,999 (n≈280), $35,000-$49,999 (n≈239), $50,000-$74,999 (n≈197), $75,000-$99,999 (n≈83), $100,000-$149,999 (n≈52), $150,000+ (n≈21) Walkability*education level: Less than high school (n≈31), graduated high school (n≈135), some college (n≈467), graduated college (n≈135), >College (n≈270) Walkability*prio			

							r exercise history: Very hard exercise 3 d/wk at 35 years old (n≈457)			
99	WISER study De Melo 2013 [491]	N=88 (urban) Mean age: 71 years 55% female 82.6% response rate (at follow-up) Community-dwellers Winnipeg, Canada	Longitudinal Cluster: purposive Individuals: convenience Stratification: select neighbourhoods (none) Neighbourhood definition: participant delineation	Sex, physical function, chronic disease, BMI	*Objective [Digiwalker pedometer; validated]:* Total change in step/d (increase; Yes/No) → Total walking *TotalWalking(change; increased steps/d; Yes/No)*	*Perceived [modified version of NEWS questionnaire; unvalidated]:* All factor analysis-derived variables: 1. Traffic safety → Traffic/pedestrian safety 2. Sidewalks → Walk-friendly infrastructure 3. Aesthetics → Greenery and aesthetically pleasing scenery 4. Walkability safety → Crime/personal safety	None	Multivariate logistic regression analysis	***Main effects with TotalWalking(change); increased steps/d; Yes/No):*** 1. Traffic safety—OR (95% CIs): OR=0.46 (0.16; 1.30), p=.14 (Traffic/pedestrian safety **0**) 2. Sidewalks: OR=0.54 (0.18; 1.58), p=.26 (Walk-friendly infrastructure **0**) 3. Aesthetics: OR=1.75 (0.58; 5.32, p=.31 (Greenery and aesthetically pleasing scenery **0**) 4. Walkability safety: OR=7.24 (1.54; 33.92), p=.01 (Crime/personal safety **0**)	Table 9—Model 4.
10 0	ZHTS 2014 Zhang et al., 2014 [492]	N=4308 (urban) 60+ years (no mean) 29-48% female (two groups) 85.4% response rate Community-dwellers Zhongshan, China	Cross-sectional Cluster: purposive Individuals: random Stratification: Traffic analysis zone (urbanisation) Neighbourhood definition: Traffic analysis zone (administrative)	Age, sex, employment status, household size, household income, number of bikes, e-bikes, motorbikes, cars in household	*Self-report [ZHTS questionnaire; unvalidated]:* Likelihood of walking → Total walking *TotalWalking(likelihoo d; Yes/No)* Frequency of walking (trips/d) → Total walking *TotalWalking(trips/d)* Duration of total	*Objective [ArcGIS—Zhongshan Municipal Bureau of Urban Planning; unvalidated]:* 1. Population density → Residential density 2. Access to commercial and service destinations → Shops/commercial access/availability 3. % greenspace → Greenery and aesthetically pleasing	None	Zero-inflated Poisson regression model	***Main effects with TotalWalking(likelihood; Yes/No):*** 1. Population density: (Residential density +) 2. Access to commercial and service destinations: (Shops/commercial access/availability **0**) 3. % greenspace: (Greenery and aesthetically pleasing scenery +) 4. Land-use mix—diversity:	Table 2.

					walking among walkers (mins/d) → Total walking *TotalWalking(mins/d)*	scenery 4. Land-use mix: diversity → Land-use mix—destination diversity 5. Sidewalk density → Walk-friendly infrastructure 6. Bus stop density → Public transport access/availability			(Land-use mix—destination diversity **0**) 5. Sidewalk density: (Walk-friendly infrastructure **+**) 6. Bus stop density: (Public transport access/availability **+**) ***Main effects with TotalWalking(trips/d):*** 1. Population density: Poisson: IRR=-0.008, p<.05 (Residential density -) 2. Access to commercial and service destinations: Poisson: IRR=0.004, p<.05 (Shops/commercial access/availability **+**) 3. % greenspace: Poisson: IRR=0.305, p<.05 (Greenery and aesthetically pleasing scenery **+**) 4. Land-use mix—diversity: Poisson: IRR=-0.360, p<.05 (Land-use mix—destination diversity -) 5. Sidewalk density: Poisson: IRR=0.034, p<.05 (Walk-friendly infrastructure **+**) 6. Bus stop density: Poisson: IRR=0.012, p<.05 (Public transport access/availability **+**) ***Main effects with TotalWalking(mins/d):***	

										1. Population density: Poisson: IRR=-0.005, p<.05 (Residential density -) 2. Access to commercial and service destinations: Poisson: IRR=0.002, p<.05 (Shops/commercial access/availability +) 3. % greenspace: Poisson: IRR=0.224, p<.05 (Greenery and aesthetically pleasing scenery +) 4. Land-use mix—diversity: Poisson: IRR=-0.041, p<.05 (Land-use mix—destination diversity -) 5. Sidewalk density: Poisson: IRR=0.016, p<.05 (Walk-friendly infrastructure +) 6. Bus stop density: Poisson: IRR=0.012, p<.05 (Public transport access/availability +)	

Appendix 6. Reviewed total physical activity articles (N=100) – Quality assessment

#	Study name and authors	Study design [weight: cross-sectional = 0; longitudinal = 1; quasi-experimental = 2]	Stratification of recruitment sites by relevant environmental attributes [weight 1]	Adequate response rate (>60%) or shown to be representative of the population [weight 1]	Outcome measures shown to be reliable and valid [weight 1]	Adjustment for socio-demographic covariates (at least age, gender, and education considered) [weight 1]	Adjustment for self-selection [weight 1]	Appropriate analytical approach – accounting for clustering (if needed) [weight 1/3]	Appropriate analytical approach – accounting for distributional assumptions [weight 1/3]	Appropriate analytical approach – analyses conducted and presented correctly (e.g., formal testing of moderators; presentation of point estimates and *p*-values, 95% CIs) [weight 1/3]	Did not (inappropriately) categorise continuous environmental exposure [weight 1]	Total quality score (maximum of 9)
1	Active Living Study Nathan et al., 2014 [422]	Cross-sectional	Y	N	Y	Y	Y	Y	Y	Y	Y	6
2	Active Living Study Nathan et al., 2014 [265]	Cross-sectional	Y	N	Y	Y	N	Y	Y	Y	Y	5
3	Active Living Study Nathan et al., 2014 [266]	Cross-sectional	Y	N	Y	Y	Y	Y	Y	Y	Y	6
4	AGES Hanibuchi et al., 2011 [354]	Cross-sectional	N	N	Y	Y	N	N	Y	N (significance of interaction effects were not provided)	Y	4.33
5	AIBL study Cerin et al., 2016 [423]	Cross-sectional	N	N	Y	Y	N	Y	Y	Y	Y	4

6	ALECS study Cerin et al., 2016 [242]	Cross-sectional	Y	Y	Y	Y	Y	Y	Y	Y	Y	7
7	Australian Time Use Survey 2006 Espinel et al., 2015 [424]	Cross-sectional	N	Y	N (PA diary; unvalidated)	Y	N	Y (not needed)	Y	Y	Y	4
8	Behavior Change Consortium Initiative – Rhode Island Trail King et al., 2006 [425]	Cross-sectional	N	N	Y	Y	N	Y	N	Y	Y	4.67
9	BEPAS Seniors Van Cauwenberg et al., 2016 [267]	Cross-sectional	Y	N	Y	Y	Y	Y	Y	Y	Y	6
10	BEPAS Seniors Van Holle et al., 2016 [268]	Cross-sectional	Y	N	Y	Y	N	Y	Y	Y	Y	5
11	British Regional Heart Study & British Women's Heart Health Study Jefferis et al., 2014 [357]	Cross-sectional	Y	N	Y	N (education missing)	N	Y (included region in models)	Y	Y	N	3
12	Canada's General Social Survey Time Use Spinney & Millward 2014 [426]	Cross-sectional	Y	Y (across many variables, albeit %female: 65.8, 63.2, 60.2, 58.8)	N	Y (in main logistic regression analysis)	N	Y	Y	Y	Y	5
13	CCHS 2008/2009 Winters et al., 2015 [427]	Cross-sectional	N	Y (albeit ↑% higher educated)	N	Y	N	N	Y	Y	Y	3.67
14	CHIS 2003 data Li et al., 2015 [428]	Cross-sectional	N	Y (albeit Asians oversampled)	N	Y	N	N	Y (observed overdispersion)	N (no formal test of moderation by ethnicity)	N (exposure variables categorised without justification)	2.33
15	CNDS Mendes de Leon et al., 2009 [429]	Cross-sectional	N	Y (61% female)	N	Y	N (years in neighbourhood)	Y	Y	Y	Y	4
16	DIY Streets Thompson et al., 2012 [430]	Quasi-experimental	Y (comparison streets)	N (large discrepancies across some demographics, e.g.,	N	N	N	N	N (initial tests were non-parametric, then same	N (missing b-values for multiple	Y	4

				ethnicity—2008: 24.5% vs. 11.1% not white British)					variables fitted to a regression model without mention of, e.g., transformation)	variables, no 95% CIs)		
17	Easy Steps to Health Merom et al., 2015 [358]	Cross-sectional	N	N (73% female; inactive participants only -- <120 min/wk)	Y	Y	N	Y	Y	Y	N	3
18	EPOSA – Dutch trial Timmermans et al., 2016 [431]	Cross-sectional	Y	Y (although urban (n=176; 71%) participants were oversampled vs. rural (n=53; 22%))	Y	Y	N	N	Y	Y	Y	6.67
19	Great Britain older adults 1 (name assigned) Sugiyama & Ward Thompson 2007 [432]	Cross-sectional	Y	N	N	N	N	N	Y	N (no data reported related to chi-square test)	Y	2.33
20	Great Britain older adults 1 (name assigned) Sugiyama et al., 2009 [433]	Cross-sectional	Y	N	N	Y (sex was not associated with outcome, hence exclusion from final model)	N	N	Y	Y	N (all environmental exposures categorised without justification)	2.67
21	HAN Walking Study Satariano et al., 2010 [359]	Cross-sectional	Y	N (albeit 77% female; ↑% higher educated)	N	Y	N	Y (study site included in models)	Y	N (many missing point estimates and associated CIs and p-values)	N (no justification for categorising exposure variables)	2.67
22	Harvard Alumni Study Lee et al., 2009 [333]	Cross-sectional & longitudinal	Y (conveniently recruited, however, there was	N	Y	Y	N	N	Y	Y	Y	5.67

			variability in urbanisation)									
23	Health and Retirement study Latham et al., 2015 [434]	Cross-sectional	N	Y (albeit 67% female; only those reporting mobility impairment included)	N	Y	N	Y	Y	Y	Y	4
24	Health and Wellbeing Surveillance System Nathan et al., 2012 [355]	Cross-sectional	Y	Y	Y	Y	N	Y (not needed)	Y	Y	Y	6
25	Health and Wellbeing Surveillance System Villanueva et al., 2014 [435]	Cross-sectional	Y	Y	Y	Y	N	Y (not needed)	Y	Y	Y (despite categorising walkability, the authors also reported the continuous variable)	6
26	Hong Kong Elderly Study Cerin et al., 2013 [376]	Cross-sectional	Y	Y	Y	Y	N	Y	Y	Y	Y	6
27	Kasama Study Tsunoda et al., 2012 [347]	Cross-sectional	N	N (excluded those with difficulty walking)	Y	Y	N	Y (not needed)	Y	Y (no moderators considered)	N (categorised all exposure variables without justification)	3
28	KNHANES 2007/2008 Yeom et al., 2011 [436]	Cross-sectional	Y	Y	Y	N	N	Y	Y	Y	Y	5
29	LL-FDI study Morris et al., 2008 [437]	Cross-sectional	N	N	Y	N	N	Y	Y	N	Y	2.67
30	LL-FDI study Hall & McAuley, 2010 [438]	Cross-sectional	N	N	Y	N	N	Y (not needed)	Y	Y	Y	3
31	Malaysian National Health and Morbidity Survey III 2006 data Kaur et al., 2015 [439]	Cross-sectional	Y	Y	Y	Y	N	N	Y	Y	Y	5.67

32	Melbourne older adults study 1 (name assigned) Bird et al., 2009 [440]	Cross-sectional	N	N	Y	N	N	N	Y	Y	Y	2.67
33	Melbourne older adults study 1 (name assigned) Bird et al., 2010 [441]	Cross-sectional	N	N	Y (albeit translated version)	N	N	N	N	N	Y	2
34	MOBILIZE Boston study Procter-Gray et al., 2015 [442]	Cross-sectional	N	Y	N	Y	N	N	Y	Y	Y	3.67
35	Neighbourhoods and Physical Activity in Elderly Men Michael et al., 2010 [443]	Longitudinal	N	N	Y	Y	N	Y	Y	N (many missing values related to RR and 95% CI)	N (environmental exposures categorised without justification)	3.67
36	Netherlands Housing Survey (WoON) data Jongeneel-Grimen et al., 2013 [444]	Cross-sectional	Y	Y	N	Y	N	Y	Y	N (no formal testing of moderation in older adults)	Y	4.67
37	Netherlands Housing Survey (WoON) data Jongeneel-Grimen et al., 2014 [445]	Cross-sectional	Y	Y	N	Y	N	Y	Y	N (no formal testing of moderation in older adults)	Y	4.67
38	*No study name* Aird et al., 2015 [446]	Cross-sectional	Y	N (↑ income in some; ↓income in others)	N	N	N	N	N (no mention of assessing normality; likely skewed based on mean and range reported)	Y	Y	2.33
39	*No study name* Arnadottir et al., 2009 [447]	Cross-sectional	Y	Y	Y	Y	N	N	Y	Y	Y	5.67
40	*No study name* Asawachaisuwikrom 2001 [448]	Cross-sectional	Y	N (↓ education – elementary school completion	Y	N	N	N (no adjustment for village cluster)	Y	Y	Y	3.67

				compulsory until 1978 (Smalley, 1994))								
41	*No study name* Baceviciene & Alisauskas 2013 [449]	Cross-sectional	N	N (61% female; 39% university-educated)	Y	N	N	Y (not needed)	Y	Y	Y	3
42	*No study name* Bocker et al., 2016 [450]	Cross-sectional	Y	N (63% female; underrepresentation of lower-educated)	N	Y	N	Y	Y	Y	Y	4
43	*No study name* Carvalho Sampaio et al., 2012 [451]	Cross-sectional	Y	N	N (questionnaire)	N	N	Y (not needed)	Y	N (no formal testing of moderators)	Y	2.67
44	*No study name* Chad et al., 2005 [353]	Cross-sectional	N	Y	Y	N	N	Y (not needed)	Y	N (no formal testing of moderators)	N (all environmental exposures were categorised without justification)	2.67
45	*No study name* Chaudhury et al., 2016 [452]	Cross-sectional	Y (population density and median household income)	N (6% response rate; 64% female; 44% degree-educated)	N	Y	N	N	Y	Y	N (categorised scale without justification)	2.67
46	*No study name* Chen et al.,2013 [343]	Cross-sectional	N	N	Y	N	N	Y	Y	Y	N	2
47	*No study name* de Melo et al., 2010 [453]	Cross-sectional	N	N (75% female + response rate not reported)	Y	Y	N	N	Y (negative binomial model fitted to skewed data)	Y	Y	3.67
48	*No study name* Gallagher et al., 2012 [454]	Cross-sectional	N	Y	Y	Y	N	Y (not needed)	N	Y	Y	4.67
49	*No study name* Gomez et al., 2010 [455]	Cross-sectional	Y	Y	N (adapted without validation)	Y	N	Y	Y	Y	N (categorisation of exposure variables unjustified)	4
50	*No study name* Grant-Savela et al., 2010 [456]	Cross-sectional	N	N (↑% higher educated)	N (adapted PASE questionnaire	N	N	Y (not needed)	Y	Y	Y	3

				without validation)							
51	*No study name* Inoue et al., 2011 [344]	Cross-sectional	Y	Y	N	Y	N	Y	Y	N (no formal testing of moderation)	N (exposure variable dichotomised without justification)	3.67
52	*No study name* King et al., 2003 [457]	Cross-sectional	N	N	Y	N	N	N	Y	Y	Y	2.67
53	*No study name* Koh et al., 2015 [345]	Cross-sectional	N	N	N	Y	N	N	Y	Y	Y (even though table 1 reports "categorical" exposure variables, table 4 reports them as continuous…)	2.67
54	None Kolbe-Alexander et al., 2015 [458]	Cross-sectional	Y (SES)	N (78% female)	Y	N	N	N	Y	N (no formal testing of moderators)	Y	3.33
55	*No study name* Lee & Park, 2015 [346]	Cross-sectional	Y	Y	Y	Y	Y (attitude toward regular walking; PA self-efficacy; intention to walk regularly)	N	Y	N (no formal testing of moderator)	Y	6.33
56	*No study name* Lotfi & Koohsari, 2011 [459]	Cross-sectional	Y	N (no sociodemographic info reported)	N	N	N	N	N	N	Y	2
57	*No study name* Maisel et al., 2016 [460]	Cross-sectional	Y	N (74% female)	Y	Y	Y (overall neighbourhoo d satisfaction)	N	Y	N (no formal testing of moderators)	N	4.33
58	*No study name* Mowen et al., 2007 [461]	Cross-sectional	Y (SES)	N	N	N	N	Y	N	Y	Y	2.67
59	*No study name* Pelclova et al.,2012 [462]	Cross-sectional	N	N (88% female)	Y (albeit translated version)	N	N	N	Y	Y	N (exposure variables dichotomised without justification)	1.67

60	*No study name* Persson et al., 2011 [463]	Cross-sectional	N	Y (albeit 77% female)	N	Y	N	Y (borough lived included in model)	Y	N (majority of ORs and CIs missing)	N	2.67
61	*No study name* Salvador et al., 2010 [356]	Cross-sectional	Y (large SES inequality in area; probability proportional to size measures)	Y	Y	Y	N	N	Y	Y	Y	5.67
62	*No study name* Sewo Sampaio et al., 2013 [464]	Cross-sectional	Y	N	N	N	N	Y	Y	N (actual p-values not reported)	Y	2.67
63	*No study name* Shin et al., 2011 [465]	Cross-sectional	N	Y	N (modified version of CHAMPS--modifications not reported)	N	N	N	Y	N	Y	2.33
64	*No study name* Shores et al., 2009 [466]	Cross-sectional	N	N	N	N (education not in model)	N	Y	Y	Y	Y	2
65	*No study name* Tanaka et al., 2016 [467]	Cross-sectional	Y	Y	Y	Y	N	N	Y	Y	Y	5.67
66	*No study name* Towne Jr., 2016 [468]	Cross-sectional	N	N	N	N (education not in model)	N	N	Y	Y	N (both environmental exposures were categorised without justification)	0.67
67	*No study name* Wang & Lee 2010 [469]	Cross-sectional	N	N	N	Y	N	Y	Y	Y	Y	3
68	*No study name* Wilcox et al., 2003 [470]	Cross-sectional	N	N	Y	Y	Y (decisional balance of PA: pros vs. cons)	N	Y	Y	Y	4.67
69	NSW Falls Prevention Baseline Survey 2009 Macniven et al., 2014 [471]	Cross-sectional	N	Y (albeit 19% osteoporosis; 58% female; 56% suffering arthritis)	N	Y	Y (make time to be active)	N	Y	N (no formal test of moderation)	Y	4.33
70	NSW OPHS Lim & Taylor 2005 [472]	Cross-sectional	N	Y	N	Y	N	Y	Y	Y	N (categorised feel safe in neighbourhood	3

										variable without justification)	
71	Nurses' Health Study James et al., 2013 [473]	Cross-sectional	N	Y	Y	Y	N	Y	N	Y	Y	4.67
72	Nurses' Health Study Troped et al., 2014 [474]	Cross-sectional	N	Y	Y	Y	N	Y	Y	Y	N (intersection and population density were categorised without justification)	4
73	Oslo Health Study Piro et al., 2006 [475]	Cross-sectional	N	N	N	Y	N	Y	Y	Y	N	2
74	Physical Activity Monitor 2002 Pan et al., 2009 [476]	Cross-sectional	N	N	Y	Y	Y (PA intention)	Y	Y	Y	Y	5
75	PACS (Physical Activity Cohort Scotland) McMurdo et al., 2012 [477]	Cross-sectional	Y	N	Y	N (education not added)	N	N	Y	Y	Y	3.67
76	PACS Sniehotta et al., 2013 [478]	Cross-sectional	Y	N	Y	N (education not added)	Y (intention)	N	Y	Y	Y	4.67
77	Project OPAL Davis et al., 2011 [115]	Cross-sectional	Y (amenity access and SES)	N (↑% higher educated)	Y	N	N	N (clustering at the clinical level not accounted for)	Y	Y	N	2.67
78	Project OPAL Fox et al., 2011 [269]	Cross-sectional	Y	N	Y	N	N	N	Y	Y	N (categorised distance to nearest shop without justification)	2.67
79	Project OPAL Thompson et al., 2011 [479]	Cross-sectional	Y	N (↑% higher educated)	Y	N	N	N	Y	Y	Y	3.67
80	Project RICE pilot Han et al., 2016 [480]	Cross-sectional	N	N	Y (albeit translated version)	Y	N	Y (not needed)	Y	Y	Y	4
81	SHAPE Li et al., 2005a [481]	Cross-sectional	Y	N	Y	N	N	Y	Y	Y	Y	4

82	SHAPE Li et al., 2005b [482]	Longitudinal	Y	N (64% female + inadequate response rate)	Y	N (age and sex not added)	N	Y	Y	Y	Y	5
83	SHAPE Michael et al., 2006 [483]	Cross-sectional	Y	N (67% female + inadequate response rate)	Y	Y	N	N	Y	N (many ORs missing, and all 95% CIs not reported)	N (perceived environmental exposures categorised without justification)	3.33
84	SHAPE Nagel et al., 2008 [484]	Cross-sectional	N	N (70% female + inadequate response rate)	Y	Y	N	Y	Y	Y	Y	4
85	SMARTRAQ Frank et al., 2010 [253]	Cross-sectional	Y	N	Y (travel survey)	Y	N	Y	Y	Y	N (categorisation from continuous walkability index)	4
86	SNQLS Kerr et al., 2011 [270]	Cross-sectional	Y	N (71% female)	Y	N	N	N	N (outcome likely skewed)	Y	Y	3.33
87	SNQLS Carlson et al., 2012 [271]	Cross-sectional	Y	N (↑ % Caucasians; higher education)	Y	Y	N	Y	N (outcome likely skewed)	N	N	3.33
88	SNQLS Bracy et al., 2014 [272]	Cross-sectional	Y	N (↑ % Caucasians; higher education)	Y	Y	N	Y	N (outcome likely skewed)	Y	Y	4.67
89	SNQLS Cain et al., 2014 [273]	Cross-sectional	Y	N (↑% Caucasians; higher educated)	Y	Y	N	Y	N (outcome likely skewed)	N	Y	4.33
90	SNQLS Carlson et al., 2014 [274]	Cross-sectional	Y	N (↑ % Caucasians; higher education)	Y	Y	N	Y	N (outcome likely skewed)	Y	Y	4.67
91	SNQLS Ding et al., 2013 [275]	Cross-sectional	Y	N (↑ % Caucasians; higher education)	Y	Y	N	Y	N (outcome likely skewed)	Y	Y	4.67
92	TILDA McKee et al., 2015 [485]	Cross-sectional	Y	N	Y	Y	N	N	Y	Y	Y	4.67
93	TILDA Murtagh et al., 2015 [486]	Cross-sectional	Y	N	Y	Y	N	Y	Y	Y	Y	5
94	UAB Study of Aging Hannon et al., 2012 [487]	Cross-sectional	Y	N	N	Y	N	N	Y	Y	Y	3.67

95	VoisiNuAge Gauvin et al., 2012 [488]	Longitudinal	N	N (↑% higher educated and non-low income residents)	Y	Y	Y (proximity to friend or relative)	Y (examined spatial autocorrelation)	Y (categorisation of outcome variable justified)	Y	N (categorisation of exposure variables unjustified)	4
96	VoisiNuAge Julien et al., 2015 [489]	Cross-sectional	N	N	Y	N	N	Y	Y	Y	Y	2.67
97	Walk the Talk Hirsch et al., 2016 [276]	Cross-sectional	Y	N (low income older adults only=inadequate response rate)	Y	Y	N	N	Y	Y	Y	4.67
98	WHI Perry et al., 2013 [490]	Cross-sectional	N	N (participants keen to be a part of research + inadequate response rate)	Y (reliable)	Y	N	Y	N	Y	Y	3.67
99	WISER study De Melo 2013 [491]	Longitudinal	N	Y	Y	N	N	N	N (outcome variable poorly defined: increased steps vs. decreased steps—no specified amount reported)	Y	Y	4.33
100	ZHTS 2014 Zhang et al., 2014 [492]	Cross-sectional	N	Y	N	Y	Y (pro-walking)	N	Y (insignificant overdispersion reported, zero-inflated Poisson model adopted)	Y	N	3.67

Appendix 7: The University of Hong Kong ethics memorandum (Project ID: EA270211)

THE UNIVERSITY OF HONG KONG

香 港 大 學

February 22, 2011

Dr. Ester Cerin
Institute of Human Performance

Dear Dr. Cerin,

Reference No. EA270211: Application for Ethical Approval

I refer to your application for ethical approval of your project entitled "Understanding the impact of the neighborhood environment on physical activity, quality of life and depressive symptoms in older adults".

2. I am pleased to inform you that the application has been approved by the Human Research Ethics Committee for Non-Clinical Faculties regarding the ethical aspect of the above-mentioned research project, and the expiration date of the ethical approval is February 21, 2013.

3. Please be reminded that you are required to submit, as appropriate, an annual progress/final completion report on the prescribed report form available at the HRECNCF website. For extension of the ethical approval and/or amendments to the approved project, please also ensure to submit an application, on the same form, prior to the above-specified expiration date.

Yours sincerely,

Professor J. Bacon-Shone
Chairman
Human Research Ethics Committee for Non-Clinical Faculties

THE REGISTRY 教務處

POKFULAM ROAD, HONG KONG. TEL:(852)2859 2111 FAX:(852)2858 2549

Appendix 8: Neighborhood Environment Walkability Scale for Chinese Seniors (NEWS-CS)

We would like to find out about the way that you perceive or think about your neighborhood. Please answer the following questions about your neighborhood and yourself.

A. Types of residences in your neighborhood

Please choose the answer that best applies to you and your neighborhood.

1. How common are <u>detached single-family residences</u> in your immediate neighborhood?

1	2	3	4	5
None	A few	Some	Most	All

2. How common are <u>multi-family houses or apartments or condos of 1-3 stories</u> in your immediate neighborhood?

1	2	3	4	5
None	A few	Some	Most	All

3. How common are <u>apartments or condos of 4-6 stories</u> in your immediate neighborhood?

1	2	3	4	5
None	A few	Some	Most	All

4. How common are <u>apartments or condos of 7-12 stories</u> in your immediate neighborhood?

1	2	3	4	5
None	A few	Some	Most	All

5. How common are <u>apartments or condos of 13-20 stories</u> in your immediate neighborhood?

1	2	3	4	5
None	A few	Some	Most	All

6. How common are <u>apartments or condos of more than 20 stories</u> in your immediate neighborhood?

1	2	3	4	5
None	A few	Some	Most	All

B. Stores, facilities, and other things in your neighborhood

About how long would it take to get from your home to the <u>nearest</u> businesses or facilities listed below if you <u>walked</u> to them? Please put only <u>one</u> check mark (√) for each business or facility.

	1-5 min	6-10 min	11-20 min	20-30 min	30+ min	don't know
example: gas station	1. ____	2. ____	3. √	4. ____	5. ____	8. ____
1. convenience/small grocery store	1. ____	2. ____	3. ____	4. ____	5. ____	8. ____
2. supermarket	1. ____	2. ____	3. ____	4. ____	5. ____	8. ____
3. fresh food market	1. ____	2. ____	3. ____	4. ____	5. ____	8. ____
4. hardware store	1. ____	2. ____	3. ____	4. ____	5. ____	8. ____
5. clothing & shoes store	1. ____	2. ____	3. ____	4. ____	5. ____	8. ____
6. pharmacy/drug store	1. ____	2. ____	3. ____	4. ____	5. ____	8. ____
7. book / stationary store	1. ____	2. ____	3. ____	4. ____	5. ____	8. ____
8. video / audio store	1. ____	2. ____	3. ____	4. ____	5. ____	8. ____
9. library	1. ____	2. ____	3. ____	4. ____	5. ____	8. ____
10. laundry/dry cleaners	1. ____	2. ____	3. ____	4. ____	5. ____	8. ____
11. salon/barber shop	1. ____	2. ____	3. ____	4. ____	5. ____	8. ____
12. bank/credit union	1. ____	2. ____	3. ____	4. ____	5. ____	8. ____
13. post office	1. ____	2. ____	3. ____	4. ____	5. ____	8. ____
14. doctor/clinical service	1. ____	2. ____	3. ____	4. ____	5. ____	8. ____
15. Primary school	1. ____	2. ____	3. ____	4. ____	5. ____	8. ____

16. nursery schools 1. ____ 2. ____ 3. ____ 4. ____ 5. ____
8. ____

17. Chained Western or 1. ____ 2. ____ 3. ____ 4. ____ 5. ____
8. ____
Chinese fast food restaurant
(e.g., MacDonald, Café de Coral, Fairwood,)

18. Chinese coffee shop 1. ____ 2. ____ 3. ____ 4. ____ 5. ____
8. ____
or noodle shop

19. Chinese non-fast 1. ____ 2. ____ 3. ____ 4. ____ 5. ____
8. ____
food restaurant

20. Western non-fast food 1. ____ 2. ____ 3. ____ 4. ____ 5. ____
8. ____
restaurant (e.g., spaghetti house)

21. Coffee shop 1. ____ 2. ____ 3. ____ 4. ____ 5. ____
8. ____
(e.g., Starbucks)

22. park 1. ____ 2. ____ 3. ____ 4. ____ 5. ____
8. ____

23. community center 1. ____ 2. ____ 3. ____ 4. ____ 5. ____
8. ____
or elderly centre

24. gym or fitness facility 1. ____ 2. ____ 3. ____ 4. ____ 5. ____
8. ____

25. swimming pool 1. ____ 2. ____ 3. ____ 4. ____ 5. ____
8. ____

26. Religious places 1. ____ 2. ____ 3. ____ 4. ____ 5. ____
8. ____
(Church, temples)

27. public toilet 1. ____ 2. ____ 3. ____ 4. ____ 5. ____
8. ____

28. bakery / cake shop 1. ____ 2. ____ 3. ____ 4. ____ 5. ____
8. ____

29. public transit 1. ____ 2. ____ 3. ____ 4. ____ 5. ____
8. ____
(bus stops; MTR/KCR stations)

30. Hong Kong Jockey Club betting branch

1. ____ 2. ____ 3. ____ 4. ____ 5. ____ 8. ____

C. Access to services

Please choose the answer that best applies to you and your neighborhood. Both local and within walking distance mean within a 10-15 minute walk from your home.

1. Stores are within easy walking distance of my home.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

2. Shopping areas are easily accessible via public transport.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

3. There are many places to go within easy walking distance of my home.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

4. It is easy to walk to a transit stop (bus, MTR) from my home.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

5. The streets in my neighborhood are hilly, making my neighborhood difficult to walk in.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

6. There are major barriers to walking in my local area that make it hard to get from place to place (for example, freeways, railway lines, rivers, steep staircases, roadwork).

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

7. The streets are so crowded that it is difficult to walk.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

8. I need to walk over a bridge or through a tunnel to access the nearest services.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

9. I can easily access the entrance/exit of the building I in live in (e.g., there is a lift that I can use).

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

D. Streets in my neighborhood

Please choose the answer that best applies to you and your neighborhood.

1. The streets in my neighborhood have many cul-de-sacs (dead-end streets).

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

2. The distance between intersections in my neighborhood is usually short.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

3. There are many alternative routes for getting from place to place in my neighborhood. (I don't have to go the same way every time.)

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

You're making great progress......keep it up!

E. Places for walking

Please choose the answer that best applies to you and your neighborhood.

1. There are sidewalks on most of the streets in my neighborhood.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

2. There are motor vehicles parked on the sidewalks in my neighborhood making it difficult to walk.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

3. There is a fence that separates the streets from the sidewalks in my neighborhood.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

4. My neighborhood streets are well lit at night.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

5. There are ‘hawkers’ and shops on the streets and sidewalks blocking the way.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

6. There are crosswalks and pedestrian signals to help walkers cross busy streets in my neighborhood.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

7. The are many covered sidewalks in my neighborhood.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

8. There are indoor, air-conditioned places (shopping malls) in my neighborhood where people can walk.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

9. The streets and sidewalks in my neighborhood are often slippery.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

10. There are sitting facilities (e.g., benches) where I can rest in my neighborhood

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

F. Neighborhood surroundings

Please choose the answer that best applies to you and your neighborhood.

1. There are trees along the streets in my neighborhood.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

2. There are many interesting things to look at while walking in my neighborhood.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

3. There are many attractive natural sights in my neighborhood (such as landscaping, views).

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

4. There are attractive buildings/homes in my neighborhood.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

5. The level of air pollution in my neighborhood is often high.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

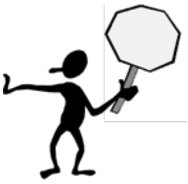
6. There are lots of animal droppings in my neighborhood making walking unpleasant.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

7. It is unsafe to walk in my neighborhood because of objects dropping from high-rise buildings.

1	2	3	4
strongly	somewhat	somewhat	strongly

disagree	disagree	agree	agree



G. Traffic hazards

Please choose the answer that best applies to you and your neighborhood.

1. There is so much traffic along nearby streets that it makes it difficult or unpleasant to walk in my neighborhood.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

2. The speed of traffic on most nearby streets is usually slow (40 km/h or less).

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

3. Most drivers exceed the posted speed limits while driving in my neighborhood.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

4. There are parked vehicles in my neighborhood that block my vision and make it difficult to safely cross the road.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

5. I am afraid to cross the roads in my neighborhood because there are too many passing cars.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

H. Safety from crime

Please choose the answer that best applies to you and your neighborhood.

1. Walkers on the streets in my neighborhood can be easily seen by other people.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

2. There is a high crime rate in my neighborhood.

1	2	3	4

strongly disagree	somewhat disagree	somewhat agree	strongly agree

3. The crime rate in my neighborhood makes it unsafe to go on walks <u>during the day</u>.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

4. The crime rate in my neighborhood makes it unsafe to go on walks <u>at night</u>.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

5. There are many homeless people, drug addicts and/or prostitutes in my neighborhood.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

6. It would be difficult to ask for help in my neighborhood because there are not many people around.

1	2	3	4
strongly disagree	somewhat disagree	somewhat agree	strongly agree

Appendix 9. Deakin University's ethics memorandum (Project ID: HEAG-H 88_2014)

Memo

To:	Professor Ester Cerin School of Exercise and Nutrition Sciences
From:	Secretary – HEAG-H Faculty of Health
CC:	David William Barnett, Dr Anthony Barnett, A/Prof Anna Timperio, Dr Nicola Ridgers, Ms Winsfred Ngan
Date:	3 June, 2014
Re:	**HEAG-H 88_2014: Development of accelerometer cut-points for the assessment of sedentary time and physical activity intensity in Chinese older adults**

Approval has been given for Professor Ester Cerin of the School of Exercise and Nutrition Sciences, to undertake this project for a period of 1 year from 3 June, 2014. The current end date for this project is 3 June, 2015.

The approval given by the Deakin University HEAG - H is given only for the project and for the period as stated in the approval. It is your responsibility to contact the Secretary immediately should any of the following occur:

- Serious or unexpected adverse effects on the participants
- Any proposed changes in the protocol, including extensions of time
- Any events which might affect the continuing ethical acceptability of the project
- The project is discontinued before the expected date of completion
- Modifications that have been requested by other Human Research Ethics Committees

In addition you will be required to report on the progress of your project at least once every year and at the conclusion of the project. Failure to report as required will result in suspension of your approval to proceed with the project.

An Annual Project Report Form can be found at:
http://www.deakin.edu.au/hmnbs/research/ethics/ethicssubmissionprocess.php
This should be completed and returned to the Administrative Officer to the HEAG-H, Pro-Vice Chancellor's office, Faculty of Health, Burwood campus by **Tuesday 18th November, 2014** and when the project is completed. HEAG-H may need to audit this project as part of the requirements for monitoring set out in the National Statement on Ethical Conduct in Human Research (2007).

Good luck with the project!

CRICOS Provid

Human Ethics Advisory Group, Faculty of Health,
Melbourne Burwood Campus, 221 Burwood Highway, Burwood, VIC 3125
Tel 03 9251 7174, email health-ethics@deakin.edu.au www.deakin.edu.au

Appendix 10: Power calculations for accelerometer calibration study (study #1)

In order to determine an appropriate sample size for developing a regression equation, we began by working from previously reported data (N=28) from Yngve, et al. [282]. Specifically, hip-based ActiGraph data collected from a track protocol conferred a standard error of the estimate (SEE) of 1.10. The equation used to determine METs was:

$$METs = 0.0008198 * counts\ per\ min + 0.751$$

We then calculated the sum of squared errors (SSE) – a measure of discrepancy between the observed data and fitted values – which equalled 31.46. One achieved this by:

$$SEE = \sqrt{\frac{Sum\ of\ squared\ errors}{n-2}}$$

$$1.10 = \sqrt{\frac{Sum\ of\ squared\ errors}{26}}$$

$$1.10^2 = \frac{Sum\ of\ squared\ errors}{26}$$

$$Sum\ of\ squared\ errors = 26 \times 1.10^2$$

$$= 31.46$$

In the proposed PhD calibration study:

Observed sample size (N) = 40 * 10 assessments (n) = 400 data-points

Effective sample size (accounting for correlation in the data arising from conducting multiple assessments on the same participants) is:

$$\mathrm{N} = \frac{\mathrm{N} * \mathrm{n}}{1 + (\mathrm{n} - 1) * \rho}$$

ρ = correlation between data from the same person = 0.25 (conservatively equivalent to r = 0.5)

$$\mathrm{N} = \frac{400}{1 + 9 * 0.25}$$

$$\mathrm{N} = \frac{400}{3.25}$$

$$\mathrm{N} = 123$$

$$SEE = \sqrt{\frac{31.46}{123-2}} = 0.51\,METs$$

This tells us that the standard error of the estimate associated with our proposed calibration equation is predicted to be 0.51 METs (i.e., less than half the level of error than that reported by Yngve et al. [282]). Specifically, under/overestimation of METs based on accelerometer counts is predicted to be approximately 15% (see immediately below):

$$\frac{0.51\,METs}{3.5\,METs} = \ 14.6\%\ accuracy$$

Appendix 11: Example advertisement flyer (English version)

CHINESE VOLUNTEERS

Research Study

Deakin University's Centre for Physical Activity and Nutrition Research is looking for English or Cantonese-speaking Chinese older adults to take part in a new study that will investigate sitting and walking behaviour.

You may be **eligible** for the study if you:

- are Chinese
- aged 60 years and older (no upper age limit)
- can walk unaided
- able to attend a one off data collection session of up to 1.5 hours

CONTACT US

If you'd like to find out more or to register for the study, please contact:

Cantonese-speaking:

NGAN Winsfred on 9244 6722
winsfred.ngan@deakin.edu.au

or, English-speaking:

BARNETT David on 9246 8696
dwbarnet@deakin.edu.au

DEAKIN UNIVERSITY AUSTRALIA Worldly

Burwood Campus

Appendix 12: Example newspaper advert (English version)

Deakin University's
Centre for Physical Activity and Nutrition Research

CHINESE VOLUNTEERS REQUIRED

We are conducting a research study in Chinese older adults to look at improving the estimation of energy expenditure during daily walking. This estimation is important when examining the effect of walking on health.

We would like to hear from you if you are:

- ✔ Chinese
- ✔ Aged 60 years or older (no upper age limit)
- ✔ Can walk unaided
- ✔ Able to attend a one off data collection session of up to 1.5 hours

If you'd like to find out more in Cantonese, please contact **Ms. Winnie Ngan** on **9244 6722** or by email at **winsfred.ngan@deakin.edu.au**

If you'd like to find out more in English, please contact **Mr. David Barnett** on **9246 8696** or by email at **dwbarnet@deakin.edu.au**

Appendix 13: Plain language statement and consent form

PLAIN LANGUAGE STATEMENT AND CONSENT FORM

To: Participant

Plain Language Statement

Date:

Full Project Title: Development of accelerometer cut-points for the assessment of sedentary time and physical activity intensity in Chinese older adults

Principal Researcher: Professor Ester Cerin

Student Researcher: Mr David Barnett

Associate Researcher(s): Dr Anthony Barnett, Associate Professor Anna Timperio, Dr Nicola Ridgers and Ms Winsfred Ngan

Reference number: HEAG-H 88_2014

We invite you to participate in our research project investigating energy expenditure during several activities, namely: sedentary activities (laying and sitting) and physical activities at a light (standing and slow walking) and moderate (walking) intensity. To participate in this study, you must be ethnically Chinese, be able to walk without help and not have diabetes.

Background to the study:

Chinese people are at high risk of diabetes. Physical activity is important for reducing the risk of several diseases (e.g., type 2 diabetes and heart disease), and can also help mental and social health. In contrast, sedentary behaviour (sitting for long periods) can have a negative impact on people’s health. However, little is known about how best to measure physical activity and sedentary behaviour. This study will examine how accurately we can measure physical activity and sedentary behaviour in older people of Chinese background using a small activity monitor (called ActiGraph accelerometer). We know that the ActiGraph can accurately measure physical activity and sedentary behaviour in younger adults and in children. However, we are unsure whether this is also the case for older Chinese. In this project we will be looking at accelerometer data during walking (the most common physical activity amongst over-60-year-olds) and sedentary behaviours.

What the study involves:

We first ask participants (you) to sign a consent form stating that they agree to participate in the study and complete two questionnaires: the first asks them to provide their contact details and general information on their health; the second is a questionnaire about their physical activity and sedentary behaviour habits.

We then ask participants to attend a data collection session at the School of Exercise and Nutrition Sciences facilities at Deakin University, Burwood. The session will last less than 1.5 hours.

Before coming to Deakin University, participants are asked to:

- complete the consent form and the two questionnaires mentioned above
- fast for the preceding 5 hours (fasting means not eating or drinking anything except for water)
- not eat or drink any caffeine after 10pm the night before
- not smoke for at least 2 hours beforehand
- not do any moderate intensity exercise for 2 hours beforehand (for example, brisk walking is a moderate intensity activity)
- not undertake vigorous activity for the preceding 14 hours.

When participants arrive at Deakin, they will need to hand in the signed consent form and completed questionnaires to the research staff who will check the health-related questions to see whether the participants are sufficiently healthy to take part in the study. Research staff will then measure the participants' height, weight, waist and hips. Participants will then be asked to perform a short and easy physical test (e.g., to see how fast they walk for 3 metres, how good their balance is).

Research staff will then determine the participants' resting metabolic rate – the energy people use while resting. In a quiet room, participants will lay resting quietly for 30 minutes. Then, they will first quietly sit for 2.5 minutes and then stand motionless for 2.5 minutes. They will be asked to wear three devices during this period, namely: a face mask connected to a small device which will analyse their breath and two small activity monitors (smaller than a matchbox); one will be worn around their right hip on an elastic belt, and the other will be attached with a belt on their right thigh.

After this, research staff will ask participants to do five walking sessions on flat ground. Each walking session will last between 3.8 and 5.5 minutes, and will get a little faster each time. The slowest walking speed will be 1.6 km per hour and the fastest 4 km per hour. The total distance they will walk is 1km. Participants will wear the devices while they are walking (the mask and the activity monitors). They will also be asked to continue to wear the two small activity monitors (but NOT the mask) for three additional days, taking them off only for bathing/showering or swimming (as they are not waterproof). We will give the participants a reply-paid package for them to send the activity monitors back to us after 3 days. However, we can collect the monitors from them in person if they wish.

Demands:

This project requires no demands above those typically experienced during everyday life.

Your rights:

Your participation in this project is voluntary and you may withdraw at any time without prejudice.

Risks and potential benefits to participants:

This project involves rest and walking, normal daily activities. There should be no foreseeable added risk to the risks of everyday living. Some people may feel minor discomfort wearing the mask for analysis of expired air.

Participants will receive feedback on their physical activity and sedentary behaviour based on the information collected using the two monitors for the 3 days of wear. Feedback will be mailed to them (to their residential address) in a sealed envelope.

Expected benefits to the wider community:

The results of this project will allow us to improve our measurement of physical activity and sedentary behaviour in Chinese 60+ year olds. This information will allow us to more accurately study and understand how physical activity and sedentary behaviour habits can be changed and affect health in this population.

Protection of privacy and confidentiality:

Data will be stored on a secured server or in locked storage. Each participant will be given a study Identification Number. Only this number will be written on questionnaires and data collection forms – no names will be attached to these.

Dissemination of research results:

The results of this research will be presented at a relevant conference and may be published in a scientific journal. The results will also be presented in Mr David Barnett’s PhD thesis.

Payments to participants:

Participants will receive a parking voucher to attend the data collection session at Deakin University and be entered into a lottery draw to win a selection of prizes.

Project funding:

School of Exercise & Nutrition Sciences, Deakin University Student Fund.

Complaints and questions

If you have questions about this study please contact Mr David Barnett at 0478 415 835 or 9246 8696 or dwbarnet@deakin.edu.au (in English) or Ms Winnie Ngan at or (03) 9244 6722 winsfred.ngan@deakin.edu.au (in Cantonese)

If you have any complaints about any aspect of the project, the way it is being conducted or any questions about your rights as a research participant, then you may contact:

The Manager, Research Integrity, Deakin University, 221 Burwood Highway, Burwood Victoria 3125, Telephone: 9251 7129, research-ethics@deakin.edu.au

Please quote project number [HEAG-H 88_2014].

Participant ID: ________________ (for office use only)

PLAIN LANGUAGE STATEMENT AND CONSENT FORM

To: Participant

Consent Form

Date:

Full Project Title: Development of accelerometer cut-points for the assessment of sedentary time and physical activity intensity in Chinese older adults

Reference Number:

I have read, or have had read to me in my first language, and I understand the attached Plain Language Statement.

I freely agree to participate in this project according to the conditions in the Plain Language Statement.

I have been given a copy of the Plain Language Statement and Consent Form to keep.

The researcher has agreed not to reveal my identity and personal details, including where information about this project is published, or presented in any public form.

I agree for my contact details to be kept on file at Deakin University so that I may be contacted in the future for other potential projects.

Participant's Name (printed) ……………………………………………………………………

Signature …………………………………………………… Date ………………………..

Please return the forms to:

Mr David Barnett

J3.42
Centre for Physical Activity and Nutrition Research (C-PAN),
School of Exercise and Nutrition Sciences, Deakin University,
221 Burwood Highway, Burwood VIC 3125, Australia
E: dwbarnet@deakin.edu.au
T: +61 (0) 478 415 835

DEMOGRAPHIC AND HEALTH QUESTIONNAIRE

SECTION A. Programme description

1. Project TITLE
Development of accelerometer cut-points for the assessment of sedentary time and physical activity intensity in Chinese older adults

SECTION B. Participant information

2. Please provide as much detail as you can. All of your information will be kept **strictly** confidential.

2.1. How old are you?	

2.2. Ethnicity (x where appropriate)			
Chinese		Hong Kongese	
Japanese		Taiwanese	
Malaysian		Singaporean	
Thai		Vietnamese	
South Korean		Filipino	
Other (please indicate):			

3.3. Gender (x where appropriate)	
Male	
Female	
Intersex	
Prefer not to disclose	

2.4. If Chinese, which province are you from in China? (x where appropriate)

South Central		**Southwest**		**East**		**North & Northeast**		**Northwest**	
Hainan		Chongqing		Anhui		Beijing		Gansu	
Henan		Guizhou		Fujian		Heilongjiang		Ningxia	
Hubei		Sichuang		Jiangsu		Hebei		Shaanxi	
Hunan		Tibet		Jiangxi		Inner Mongolia		Qinghai	
Guangdong				Shandong		Jinlin		Xinjiang	
Guangxi				Shanghai		Liaoning			
				Taiwan		Shanxi			
				Zhejiang		Tianjin			
Other (please state):									

SECTION C. Medical history NOW

3. PARTICIPANT INFORMATION. We ask these questions to get a better picture of your overall health and quality of life. Again, all of your information will be kept **strictly** confidential.		
3.1. Have you been hospitalised overnight anytime during the past year? (x where appropriate)	**Yes**	**No**
3.2. How many separate medications do you take daily?	**Western Medicine**	**Traditional Chinese Medicine**

3.3. Are you currently being treated for any of the following problems? (x all that apply)		**3.4. Have you ever been treated by a health care professional for any of the following?** (x all that apply)			
Osteoarthritis			**Last 5 years**	**Ever**	**Never**
Lupus or SLE (systemic lupus erythematosus)		Major depression			
Parkinson's Disease or other neurological disorder		Bipolar disorder			
High blood pressure		Anxiety or stress disorder			
Heart condition, angina or heart attack					
Cancer					

Other (please indicate if there is a condition you are currently being cared for by a doctor that has not been covered previously or being prescribed (ongoing) medication for):

3.5. During the past year, have you had 2 consecutive weeks or more during which you felt sad, down, or depressed, or lost pleasure in things you usually cared about or enjoyed? (x where appropriate)		**3.6. Walking ability** (x where appropriate)	
Yes		I CAN walk unaided	
No		I CANNOT walk unaided	
		(If you "cannot", what do you regularly use to	

		get around?) *e.g. a walking stick*	
3.7. Some people find they can sometimes get confused as they get older. In the past year, about how often did you get confused? (x where appropriate)		**3.8. We'd like to get an idea about how often you use various medical, social or health services. HOW MANY TIMES have you used the services below over the past 12 months…**	
Never		Doctor's surgery or health centre (please DO NOT include repeat prescription visits – only GP or other consultations)	
Rarely		Accident and emergency	
Sometimes		Hospital outpatient department	
Frequently		Hospital an in inpatient	
3.9. Have you fallen in the past 12 months (falling includes falling on the ground or falling in a chair)? (x where appropriate)		**3.10. Have you experienced a fall within the last 5 years that resulted in an injury (e.g., a broken bone)?** (x where appropriate)	
Yes		Yes	
(If yes, how many times have you fallen in the **past 12 months**?)		No	
No			
3.11. Do you currently smoke? (x where appropriate)		**3.12. In general, would you say your health is:** (x where appropriate)	
Yes		Excellent	
(If yes, how many cigarettes do you smoke **per day**?)		Very good	
No		Good	
No, but I did so in the past		Fair	
(If you have smoked in the past, how many cigarettes did you used to smoke **per day**?)		Poor	

SECTION D. Contact details

4. YOUR CONTACT DETAILS. Again, all of your information will be kept **strictly** confidential.	
Name	

Address			
Postcode			
Email address			
Home telephone		Mobile	

Date:

Thank you very much for taking time to complete this questionnaire

SECTION E. Anthropometric details (for office use only)

5. Data to be taken by a researcher at Deakin University on the day of the appointment.	
Height (cm)	
Weight (kg)	
Waist circumference (cm)	
Hip circumference (cm)	
Waist-to-hip ratio	

INTERNATIONAL PHYSICAL ACTIVITY QUESTIONNAIRE

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think *only* about those physical activities that you did for at least 10 minutes at a time.

1. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling?

    _____ days per week

    ☐ No vigorous physical activities → ***Skip to question 3***

2. How much time did you usually spend doing **vigorous** physical activities on one of those days?

    _____ hours per day

    _____ minutes per day

    ☐ Don’t know/Not sure

Think about all the **moderate** activities that you did in the **last 7 days**. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

3. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

_____ **days per week**

☐ No moderate physical activities ➡ ***Skip to question 5***

4. How much time did you usually spend doing **moderate** physical activities on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

Think about the time you spent **walking** in the **last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you might do solely for recreation, sport, exercise, or leisure.

5. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time?

_____ **days per week**

☐ No walking ➡ ***Skip to question 7***

6. How much time did you usually spend **walking** on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

The last question is about the time you spent **sitting** on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the **last 7 days**, how much time did you spend **sitting** on a **week day**?

   _____ hours per day

   _____ minutes per day

   ☐ Don't know/Not sure

This is the end of the questionnaire, thank you for participating

Appendix 16: Short Physical Performance Battery

Study ID __________
Date _____________
Tester Initials ______

PHYSICAL PERFORMANCE BATTERY

1. STANDS

The participant must be able to stand unassisted without the use of a cane or walker. You may help the participant to get up.

Now let s begin the evaluation. I would now like you to try to move your body in different movements. I will first describe and show each movement to you. Then I d like you to try to do it. If you cannot do a particular movement, or if you feel it would be unsafe to try to do it, tell me and we ll move on to the next one. Let me emphasize that I do not want you to try to do any exercise you feel might be unsafe.

Do you have any questions before we begin?

A. SIDE-BY-SIDE STAND

1. *Now I will show you the first movement (DEMONSTRATE).*

2. *I want you to try to stand with your feet together, side-by-side, for about 10 seconds.*

3. *You may use your arms, bend your knees, or move your body to maintain your balance, but try not to move your feet. Try to hold this position until I tell you to stop.*

4. Stand next to the participant to help him/her into the side-by-side position.

5. Supply just enough support to the participant s arm to prevent loss of balance.

6. When the participant has his/her feet together, ask *Are you ready?*

7. Then let go and begin timing as you say, *Ready, begin.*

8. Stop the stopwatch and say *stop* after 10 seconds or when the participant steps out of position or grabs your arm.

9. If participant is unable to hold the position for 10 seconds, record result, and go to the measured walks.

B. SEMI-TANDEM STAND

1. *Now I will show you the second movement (DEMONSTRATE).*

2. *Now I want you to try to stand with the side of the heel of one foot touching the big toe of the other foot for about 10 seconds. You may put either foot in front, whichever is more comfortable for you.*

3. *You may use your arms, bend your knees, or move your body to maintain your balance, but try not to move your feet. Try to hold this position until I tell you to stop.*

4. Stand next to the participant to help him/her into the semi-tandem position

5. Supply just enough support to the participant s arm to prevent loss of balance.

6. When the participant has his/her feet together, ask *Are you ready?*

7. Then let go and begin timing as you say, *Ready, begin.*

8. Stop the stopwatch and say *stop* after 10 seconds or when the participant steps out of position or grabs your arm.

9. If participant is unable to hold the position for 10 seconds, record result and go to the measured walk test.

C. TANDEM STAND

1. *Now I will show you the third movement (DEMONSTRATE).*

2. *Now I want you to try to stand with the heel of one foot in front of and touching the toes of the other foot for about 10 seconds. You may put either foot in front, whichever is more comfortable for you.*

3. *You may use your arms, bend your knees, or move your body to maintain your balance, but try not to move your feet. Try to hold this position until I tell you to stop.*

4. Stand next to the participant to help him/her into the semi-tandem position.

5. Supply just enough support to the participant s arm to prevent loss of balance.

6. When the participant has his/her feet together, ask *Are you ready?*

7. Then let go and begin timing as you say, *Ready, begin.*

8. Stop the stopwatch and say *stop* after 10 seconds or when the participant steps out of position or grabs your arm.

SCORING:

A. SIDE-BY-SIDE STAND

Held for 10 seconds .. _ **1 point**
Not held for 10 seconds ._ **0 points**
Not attempted . ... . _ **0 points**
If 0 points, end Stands Test

Number of seconds held if less than 10 seconds __.___seconds

IF NOT ATTEMPTED, CIRCLE ANSWER:

Tried but unable 1
Participant could not stand unassisted. 2
Not attempted, you felt unsafe 3
Not attempted, participant felt unsafe.. ...4
Participant unable to understand instructions ..5
Other (SPECIFY)____________________6
Participant refused ...7

B. SEMI-TANDEM STAND

Held for 10 seconds . _ **1 point**
Not held for 10 seconds.. .. _ **0 points**
Not attempted ... _ **0 points**
If 0 points, end Stands Test

Number of seconds held if less than 10 seconds . __.___seconds

C. TANDEM STAND

Held for 10 seconds _ **2 points**
Held for 3 to 9 seconds .. . _ **1 point**
Not held for at least 3 seconds ... _ **0 points**
Not attempted . _ **0 points**

Number of seconds held if less than 10 seconds . __.___seconds

D. TOTAL STANDS SCORE ________(sum points)

Comments: ____

2. MEASURED WALKS

Now we are going to observe how you normally walk. If you use a cane or other walking aid and would feel more comfortable with it, then you may use it.

A. FIRST USUAL WALK

1. *This is our walking course. I want you to walk to the other end of the course at your usual speed, just as if you were walking down the street to go to the store. Walk all the way past the other end of the tape before you stop. I will walk with you. Do you feel this would be safe?*

2. Demonstrate the walk for the participant.

3. *When I want you to start, I will say: Ready, begin.*

4. Have the participant stand with both feet touching the starting line.

5. *WHEN THE PARTICIPANT IS PROPERLY POSITIONED AT STARTING LINE, SAY: Ready, begin.*

6. Press the start/stop button to start the stop watch as the participant begins walking.

7. Walk behind and to the side of the participant.

8. Stop timing when one of the subject s feet is all the way across the end line.

B. SECOND USUAL WALK

Now I want you to repeat the walk. Remember to walk at your usual pace, and go all the way past the other end of the course.

Measured Walks

Length of walk test course: Four meters . _
Three meters _

A. Time for First Usual Walk (in seconds)

1. Time for 3 or 4 meters _ _ . _ _seconds

2. IF NOT ATTEMPTED/COMPLETED: Refused _ Unable _ Felt Unsafe _
(GO TO CHAIR STANDS TEST)

3. Aids for first walk None _ Cane _ Other _

Comments: ____

____

B. Time for Second Usual Walk (in seconds)

1. Time for 3 or 4 meters _ _ . _ _seconds

2. IF NOT ATTEMPTED/COMPLETED Refused _ Unable _ Felt Unsafe _

3. Aids for second walk None _ Cane _ Other _

WHAT IS THE TIME FOR THE FASTER OF THE 2 WALKS?

Record the shorter of the two times .._ _ . _ _seconds [If only 1 walk done record that time]

If the participant was UNABLE to do the walk: _ **0 points**

For 4 Meter Walk:

If time is more than 8.70 seconds : _ **1 point**

If time is 6.21 to 8.70 seconds: . _ **2 points**

If time is 4.82 to 6.20 seconds: . _ **3 points**

If time is less than 4.82 seconds: . ._ **4 points**

For 3 Meter Walk:

If time is more than 6.52 seconds : ..._ **1 point**

If time is 4.66 to 6.52 seconds: . _ **2 points**

If time is 3.62 to 4.65 seconds: . _ **3 points**

If time is less than 3.62 seconds: .._ **4 points**

3. CHAIR STANDS

A. *Do you think it would be safe for you to try to stand up from a chair without using your arms?*

B. *The next test measures the strength in your legs.*

C. (Demonstrate and explain the procedure): *First, fold your arms across your chest and sit so that your feet are on the floor; then stand up keeping your arms folded across your chest.*

D. *Please stand up keeping your arms folded across your chest.* (Record result).

E. <u>If participant cannot rise without using arms</u>, say *Okay, try to stand up using your arms.* This is the end of their test. Record result and go to the scoring page.

REPEATED CHAIR STANDS

A. *Do you think it would be safe for you to try to stand up from a chair five times without using your arms?*

B. (Demonstrate and explain the procedure): *Please stand up straight as* ***QUICKLY*** *as you can five times, without stopping in between. After standing up each time, sit down and then stand up again. Keep your arms folded across your chest. I ll be timing you with a stopwatch.*

C. When the participant is properly seated, say: *Ready? Stand* and begin timing.

D. Count out loud as the participants arises each time, up to five times.

E. Stop if participant becomes tired or short of breath during repeated chair stands.

F. Stop the stopwatch when he/she has straightened up completely for the fifth time.

G. If the participant sits down after the fifth stand-up, stop timing as she/he begins to sit down.

H. Also stop:
1. If participant uses his/her arms
2. After 1 minute, if participant has not completed rises
3. At your discretion, if concerned for participant s safety.

I. IF THE PARTICIPANT STOPS AND APPEARS TO BE FATIGUED BEFORE COMPLETING FIVE STANDS, CONFIRM THIS BY ASKING: *Can you continue?*

J. If participant says *Yes*, continue timing. If participant says *No*, stop and reset the stopwatch.

SINGLE CHAIR STAND

		YES	NO
A.	Safe to stand without help	.._	_

B. Results:

Participant stood without arms .._

Participant used arms to stand _

Test not completed. _

C. IF NOT COMPLETED/or NOT ATTEMPTED:

Unable to stand _

Participant refused _
(Go to Scoring Page).

REPEATED CHAIR STANDS

		YES	NO
A.	Safe to stand five times	_	_

B. IF FIVE STANDS DONE SUCCESSFULLY. RECORD TIME IN SECONDS

Time to complete five stands __ __ . __ seconds

C. IF NOT COMPLETED/or NOT ATTEMPTED:

Unable to complete repeated stands _

Participant unable to understand instructions . _

Participant refused . _

SCORING REPEATED CHAIR STANDS

If the participant was unable to complete the 5 chair stands: _ **0 points**

If chair stand time is 16.7 seconds or more: _ **1 points**

If chair stand time is 13.7 to 16.6 seconds: .. _ **2 points**

If chair stand time is 11.2 to 13.6 seconds: .. _ **3 points**

If chair stand time is 11.1 seconds or less: .. . _ **4 points**

SCORING BATTERY OF TESTS

TOTAL TEST SCORES

Balance test score _____ points

Measured walks ______ points

Chair stands _________ points

TOTAL SCORE ______ (sum points)

Appendix 17. Proportion of study #1's participants meeting Freedson et al.'s ≥1952 counts·min^{-1} cut-point

Z-score eqn=1184+-884 (SD)

1952-1184/884=0.869

Proportion of values less than 0.869 is 0.8051 or 80.51%

Appendix 18. Reviewed sedentary behaviour articles (N=7) – Quality assessment and selected information

#	Authors	Participants [Total sample size; urban, rural, or mixed sample; community dwellers or not; geographical location]	Study design [weight: cross-sectional = 0; longitudinal = 1; quasi-experimental = 2]	Stratification of recruitment sites by relevant environmental attributes [weight 1]	Adequate response rate (>60%) or shown to be representative of the population [weight 1]	Outcome measures shown to be reliable and valid [weight 1]	Adjustment for socio-demographic covariates (at least age, gender, and education considered) [weight 1]	Adjustment for self-selection [weight 1]	Appropriate analytical approach – accounting for clustering (if needed) [weight 1/3]	Appropriate analytical approach – accounting for distributional assumptions [weight 1/3]	Appropriate analytical approach –analyses conducted and presented correctly (e.g., formal testing of moderators; presentation of point estimates and p-values, 95% CIs) [weight 1/3]	Categorised continuous environmental exposure (doing so is inappropriate) [weight 1]	Total quality score (maximum of 9)	Findings (0 = nil association w/SB; +ve = positive association w/SB; -ve = negative association w/SB)	Adjustment for physical activity
1	Cerin et al. (2016) [242]	N=402, 65y+, community-dwellers, urban, Hong Kong (China)	Cross-sectional **0**	Yes **1**	Yes **1**	Yes ActiGraph GT3X SB = <100CPM **1**	Yes **1**	No **0**	Yes **0.33**	Yes **0.33**	Yes **0.33**	No **1**	6 = High quality	***Objective sedentary time (mins·day^{-1})*** **Objective environment (GIS):** Distance to nearest recreation destination→Recreational facilities access: 0 **(β=0.005, -0.023, 0.032; *p*=.855)** Distance to nearest transit stop→Public transport access: 0 **(β=-0.009, -0.032, 0.013; *p*=.402)**	No

														Distance to nearest public park→Park/public open space access: **0 (β=-0.004, -0.018, 0.011; *p*=.561)** Distance to nearest trail→Park/public open space access: **0 (β=-0.008, -0.011, 0.027; *p*=.419)** *400m buffer:* Net residential density→Residential density: **-ve (β=-0.096, -0.188, 0.004; *p*=.034)** Intersection density→Street connectivity: **0 (β=-11.42, -24.60, 1.81; *p*=.074)** Retail density→Shops/commercial destination access: **0 (β=0.072, -0.138, 0.281; *p*=.501)** Civic destination density→Government/finance service access: **0 (β=0.059, -0.092, 0.210; *p*=.442)** Entertainment density→Recreational facilities access: **0 (β=-0.168, -0.650, 0.314; *p*=.593)** Food outlet density→Food outlets access: **0 (β=-0.050, -**	

														0.155, 0.254; *p*=.634) Recreation density→Recreational facilities access: **0 (β=-0.140, -0.463, 0.183; *p*=.465)** Public transport density→Public transport access: **0 (β=0.273, -0.145, 0.691; *p*=.199)** Public park area→Parks/public open space access: **0 (β=0.048, -0.493, 0.589; *p*=.861)** *1km buffer:* Net residential density→Residential density: **0 (β=-0.143, -0.522, 0.236; *p*=.457)** Intersection density→Street connectivity: **0 (β=-16.42, -41.48, 8.64; *p*=.198)** Retail density→Shops/commercial destination access: **0 (β=-0.323, -0.846, 0.200; *p*=.220)** Civic destination density→Government/finance service access: **0 (β=-0.015, -0.290, 0.260; *p*=.914)** Entertainment density→Recreational	

														facilities access: 0 (β=0.586, -1.524, 2.696; *p*=.585) Food outlet density→Food outlets access: 0 (β=-0.338, -0.868, 0.192; *p*=.212) Recreation density→Recreational facilities access: 0 (β=-0.051, -0.660, 0.559; *p*=.870) Public transport density→Public transport access: **-ve (β=-1.263, -2.410, -0.117; *p*=.031)** Public park area→Parks/public open space access: 0 (β=0.016, -0.129, 0.161; *p*=.826)	
2	Fleig et al. (2016) [241]	N=174 (w/ valid data), 60y+, who report leaving their home 3-4 days per week, urban, Vancouver (Canada)	Cross-sectional **0**	No—convenience sample in downtown Vancouver ('Walker's Paradise') **0**	20% response rate **0**	Yes—ActiGraph GT3X+ SB = <100CPM **1**	No—Age, sex, BMI, & walking aid **0**	Yes—Attitudes toward walking & behavioural control for walking **1**	Yes (not needed) **0.33**	Yes **0.33**	Yes **0.33**	No **1**	4 = Moderate quality	***Sedentary time (mins·day⁻¹)*** **Perceived environment (NEWS):** *Correlation:* Walking infrastructure and safety→Infrastructure for walking: 0 (r=-06, *p*>.05) Aesthetics→Greenery and aesthetically-pleasing scenery: 0 (r=-07, *p*>.05) Traffic hazards→Traffic-related safety: 0 (r=-04,	No

														$p>.05$) Crime→Crime-related safety: **0 (r=.02, $p>.05$)** *Mediation models:* Direct Diversity of land use→Land-use mix: **-ve (β=-06, $p<.05$)** Street connectivity→Street connectivity: **-ve (β=-08, $p<.05$)** Access to services→Access to destinations and services: **0 ($p>.05$)** Mediated Diversity of land use [0; ($p>.05$)] (w/attitude to walking [0; ($p>.05$)])→Land-use mix Street connectivity [0; ($p>.05$)] (w/attitude to walking [0; ($p>.05$)])→Street connectivity Access to services [0; ($p>.05$)] (w/attitude to walking) [0; ($p>.05$)]→Access to destinations and services Diversity of land use (w/behavioural control walking [-ve (β=--.05; -	

														.03, -.10, p<.05)]→Land-use mix Street connectivity (w/behavioural control walking [-ve (**β=-.05; -.02, -.12** ***p*<.05**)→Street connectivity Access to services [0; (p>.05)] (w/behavioural control walking [0; (p>.05)])→Access to destinations and services	
3	Hsueh et al. (2016) [237]	N=1714, 65y+, community dwellers, mixed sample, Taiwan	Cross-sectional **0**	Yes—urbanisation then stratified by age and sex **1**	Yes—63.9% and participants randomly selected through random digit dialling **1**	Yes—MOST questionnaire (ICC=0.69) **1**	Yes—age, sex, education, marital status, job status, residential area, living status, LTPA, BMI, and household motor vehicles **1**	No **0**	NO—binary logistic regression models **0**	Yes **0.33**	Yes **0.33**	Yes **0**	4.67 = Moderate quality	***TV-viewing ≥2 hr/day*** **Perceived environment (IPAQ-E):** Residential density→Residential density: *Residential density—* *low: ref* *high:* **0** (p>.05) Access to shops→Access to destinations and services: *good: ref* *poor:* **0** (p>.05) Access to public transport→Access to public transport: *good: ref* *poor:* **0** (p>.05) Presence of sidewalks→Infrastructure for walking: *yes: ref* *no:* **0** (p>.05)	LTPA

														Presence of bike lanes→Infrastructure for cycling: *yes: ref* *no:* **0** (*p*>.05) Access to recreational facilities→Access to recreational facilities: *good: ref* *poor:* **0** (*p*>.05) Crime safety→Crime-related safety: *safe: ref* *not safe:* **0** (*p*>.05) Traffic safety→Traffic-related safety: *safe: ref* *not safe:* **+ve (OR=1.36, 95%CIs: 1.02-1.82; *p*=.04)** Aesthetics→Greenery and aesthetically-pleasing scenery: *good: ref* *poor:* **0** (*p*>.05)	
4	Shaw et al. (2017) [240]	Community dwellers, urban, Scotland (United Kingdom): 1930's cohort: mean age = 83y, n=129 1950's cohort:	Cross-sectional	1930's cohort: No—SES and unemployment 1950's cohort: No—SES and unemployment LBC1936 cohort:	1930's and 1950's cohort: No—55% LBC1936 cohort: No—45% when eligible participants included	Yes—ActivPAL	No—sex, education, marital status, area deprivation	Yes—Feeling about area	No—multivariable regression	Yes	Yes—Exact p-values not presented, but point estimates and 95% CIs were	Yes	2.67 = Low quality	**<u>1950's retired cohort:</u>** **Objective environment:** Natural space (%)→Greenery and aesthetically-pleasing scenery: **0** (*p*>.05) Green space (%)→Greenery and aesthetically-pleasing scenery: **0** (*p*>.05)	**No**

		mean age = 64y, n=340 LBC1936 cohort: mean age = 79y, n=304	**0**	No—age stratified **0**	**0**	**1**	**0**	**1**	**0**	**0.33**	**0.33**	**0**		Walkability→Walkability: **0** (p>.05) *Scottish Index of Multiple Deprivation* access→Access to destinations and services: **0** (p>.05) *Scottish Index of Multiple Deprivation* crime→Crime-related safety: **0** (p>.05) Population density→Residential density: **0** (p>.05) Pensioner density? **Perceived environment:** Social cohesion? Incivilities→Crime-related safety: **0** (p>.05) Absence of goods and services→Access to destinations and services: -ve (β=1.23; .17, 2.29, p<.05) Physical environmental problems→Infrastructure for walking: **0** (p>.05) Fear of crime—walking at night→Crime-related safety *(negative phrasing reversed)*: *No worries*: ref *Do it but feel*	

														uncomfortable: **0** (*p*>.05) *Try to avoid doing it*: -ve (β=4.66; .03, 9.29, *p*<.05) *Never do it*: -ve (β=8.75; 2.12, 15.38, *p*<.05) Feeling about area? **1930's cohort:** **Objective environment:** Natural space (%)→Greenery and aesthetically-pleasing scenery: **0** (*p*>.05) Green space (%)→Greenery and aesthetically-pleasing scenery: **0** (*p*>.05) Walkability→Walkability: **0** (*p*>.05) *Scottish Index of Multiple Deprivation* access→Access to destinations and services: **0** (*p*>.05) *Scottish Index of Multiple Deprivation* crime→Crime-related safety: **0** (*p*>.05) Pensioner density? Population density→Residential density: **0** (*p*>.05)	

														Perceived environment: Social cohesion? Incivilities→Crime-related safety: **0** (*p*>.05) Absence of goods and services→Access to destinations and services: **0** (*p*>.05) Physical environmental problems→Infrastructure for walking: **0** (*p*>.05) Fear of crime—walking at night→Crime-related safety *(negative phrasing reversed)*: *No worries*: ref *Do it but feel uncomfortable*: **0** (*p*>.05) *Try to avoid doing it*: **0** (*p*>.05) *Never do it*: **0** (*p*>.05) Feeling about area? **LBC1936 cohort: Objective environment:** Natural space (%)→Greenery and aesthetically-pleasing scenery: **0** (*p*>.05) Green space (%)→Greenery and aesthetically-pleasing	

														scenery: **0** (*p*>.05) Walkability→Walkability: **0** (*p*>.05) *Scottish Index of Multiple Deprivation* access→Access to destinations and services: **0** (*p*>.05) *Scottish Index of Multiple Deprivation* crime→Crime-related safety: **0** (*p*>.05) Pensioner density? Population density→Residential density: **0** (*p*>.05) **Perceived environment:** **Social cohesion?** Incivilities→Crime-related safety: **0** (*p*>.05) Absence of goods and services→Access to destinations and services: **0** (*p*>.05) Physical environmental problems→Infrastructure for walking: **0** (*p*>.05) Fear of crime—walking at night→Crime-related safety *(negative phrasing reversed)*:	

														No worries: ref *Do it but feel uncomfortable*: **0** (*p*>.05) *Try to avoid doing it*: **0** (*p*>.05) *Never do it*: **0** (*p*>.05) Feeling about the area?	
5	Shibata et al. (2015) [238]	N=1072, 60y+ community dwellers, mixed sample, Australia	Longitudinal **1**	No—geographic units selected at random from each state but stratified by age, population demographics, and rurality **0**	No—geographic units with <100 person aged 25y+, 100% rural dwellings, and ≥10% of geographic unit being indigenous were excluded **0**	Yes—self-report: reliability (ICC=0.82), validity (*r* = 0.3) **1**	Yes—age, sex, education, marital status, household income, work status, change in mobility from baseline to follow-up, waist circumference, TV-viewing time at baseline, and LTPA at baseline **1**	No **0**	Yes—generalised linear modelling **0.33**	Yes **0.33**	Yes—Exact p-values not presented, but point estimates and 95% CIs were. **0.33**	Yes **0**	4 = Moderate quality	***TV-viewing time (min·day^{-1})*** **Perceived environment (NEWS):** Shops easy walking distance→Access to destinations and services: **0** (*p*>.05) Many alternative routes getting from place to place→Street connectivity: **0** (*p*>.05) Footpaths on all streets in local area→Infrastructure for walking: **0** (*p*>.05) Park or nature reserve easy to get to→Access to a park: **0** (*p*>.05) Bicycle or walkway tracks in local area→Infrastructure for walking: **0** (*p*>.05) Attractive neighbourhood→Greenery and aesthetically-pleasing scenery: **0** (*p*>.05)	**LTPA at baseline**

														Pleasant natural features locally→Greenery and aesthetically-pleasing scenery: **0** (p>.05) A lot of local traffic→Traffic-related safety: **-ve (β=.92; 0.85, 0.99,** p<.05)	
6	Van Cauwenberg et al. (2014) [239]	N=23,641, 60y+, community dwellers, mixed sample, Belgium	Cross-sectional **0**	Yes—participants were randomly sampled from urban, semi-rural, and rural municipalities (stratified by age and sex) **1**	Yes—65%+ **1**	No—'similar questions have been validated …' **0**	Yes—age, sex, education, marital status, functional limitations, income, recreational walking or cycling **1**	No **0**	Yes—multilevel linear regression models **0.33**	Yes **0.33**	Yes—exact p-values missing, but SE and variety of p-values <.05 reported **0.33**	Yes **0**	4 = Moderate quality	***TV-viewing time (min·day^{-1})*** **Objective environment (GIS):** *rural: ref* *semiurban:* **+ve (β=7.3 (SE=2.4),** p**<.01)** *urban:* **+ve (β=10.6 (SE=2.5),** p**<.001)** **Perceived environment (unknown questionnaire):** Distance to facilities→Access to destinations and services: *large: ref* *medium:* **-ve (β=-5.3 (SE=1.7),** p**<.01)** *short:* **0** (p>.05) Presence of shops and facilities→Access to destinations and services: **0** (p>.05) Presence of cultural facilities→Recreational facilities access: **-ve (β=-3.0 (SE=0.7),** p**<.001)** Access to public transport→Public	Recreational walking or cycling included in model

														transport access: **0** (*p*>.05) Presence of sport facilities→Recreational facilities access: **0** (*p*>.05) Presence of greenery →Greenery and aesthetically-pleasing scenery: **-ve (β=-3.5 (SE=1.4), *p*<.05)** Absence of decay →Greenery and aesthetically-pleasing scenery: **0** (*p*>.05) Absence of noise →Pollution: **+ve (β=3.5 (SE=1.6), *p*<.05)** Presence of street lighting →Crime-related safety: **-ve (β=-5.5 (SE=1.6), *p*<.001)** Feelings of unsafety →Crime-related safety: **+ve (β=3.5 (SE=0.7), *p*<.001)** Absence of high curbs →Walking infrastructure: **0** (*p*>.05)	
7	Van der Berg et al. (2014) [374]	N=565, 73-92y, participants without severe cognitive dysfuncti	Longitudinal	No—individuals were randomised	Yes—75%	Yes—ActiGraph GT3X SB = <100CPM	Yes—age, sex, education (in model), follow-up time, MVPA, BMI,	No	Yes (not needed)	Yes	No—95% CIs missing	Yes	4.67 = Moderate quality	***Sedentary time (% sedentary mins of wear time)*** **Perceived environment (unknown questionnaire):** Housing	MVPA (mins·day^{-1})

		on, community dwellers, urban, Reykjavik (Iceland)	**1**	**0**	**1**	**1**	health status, mobility limitation, and joint pain (education measured but only analysed as an independent variable) **1**	**0**	**0.33**	**0.33**	**0**	**0**		type→Residential density: *villa: ref* *duplex:* **+ve (β=2.19),** ***p*****=.016)** *apartment:* **+ve (β=2.16),** ***p*****=.004)**	

Appendix 19. All non-significant interaction effects on associations between built environmental attributes and accelerometer-assessed sedentary time – single interaction models

Interaction	Sedentary time (min·day^{-1}) 0-24 counts·min^{-1} cut-point [205]	
	β (95% CI)	*p*
Residential density*Age	-0.00 (-0.01; 0.01)	.572
Land-use mix—destination diversity*Age	-0.89 (-2.15; 0.36)	.163
Access to destinations and services*Age	-0.45 (-2.77; 1.87)	.703
Physical barriers to walking (e.g., hills)*Age	-1.50 (-3.77; 0.77)	.195
Street connectivity*Age	0.17 (-1.81; 2.15)	.864
Infrastructure for walking*Age	-0.85 (-3.30; 1.61)	.500
Indoor places for walking*Age	-0.85 (-2.14; 0.43)	.194
Aesthetics*Age	1.12 (-0.05; 2.28)	.061
Presence of people on the streets*Age	0.08 (-1.91; 2.07)	.940
Crowdedness*Age	0.27 (-1.75; 2.29)	.793
Traffic and road hazards*Age	1.15 (-0.78; 3.08)	.242
Traffic speed*Age	1.13 (-1.35; 3.60)	.371
Social disorder and littering*Age	-0.44 (-2.49; 1.61)	.674
Crime*Age	1.00 (-1.88; 3.88)	.497
Bridge/overpass connection*Age	-0.07 (-1.06; 0.91)	.887
Easy access to residence*Age	1.36 (-1.09; 3.80)	.277
Fence separating footpath and traffic*Age	-0.36 (-1.40; 0.69)	.504
Sitting facilities*Age	-0.47 (-1.45; 0.45)	.341
Residential density*Sex	0.05 (-0.05; 0.15)	.327
Land-use mix—destination diversity*Sex	11.52 (-6.28; 29.31)	.205
Access to destinations and services*Sex	17.82 (-14.02; 49.66)	.273
Physical barriers to walking (e.g., hills)*Sex	9.66 (-19.58; 38.89)	.517
Street connectivity*Sex	3.84 (-25.06; 32.75)	.794
Infrastructure for walking*Sex	1.88 (-28.40; 32.16)	.903
Indoor places for walking*Sex	4.18 (-14.02; 22.37)	.653
Aesthetics*Sex	-5.52 (-23.74; 12.69)	.552
Presence of people on the streets*Sex	11.96 (-19.19; 43;10)	.452
Crowdedness*Sex	3.15 (-18.88; 25.18)	.779
Traffic and road hazards*Sex	4.29 (-19.55; 28.12)	.724
Traffic speed*Sex	-22.16 (-55.42; 11.10)	.192
Social disorder and littering*Sex	-8.53 (-39.42; 22.37)	.589
Crime*Sex	15.95 (-31.17; 63.07)	.507
Bridge/overpass connection*Sex	-6.65 (-20.56; 7.27)	.349
Easy access to residence*Sex	-27.96 (-58.58; 2.66)	.073
Fence separating footpath and traffic*Sex	8.80 (-8.29; 25.88)	.313
Sitting facilities*Sex	15.78 (-0.86; 32.42)	.063
Residential density*Education	-0.08 (-0.18; 0.03)	.143
Land-use mix—destination diversity*Education	-17.27 (-37.85; 3.30)	.100
Access to destinations and services*Education	-23.78 (-49.96; 2.41)	.075
Physical barriers to walking (e.g., hills)*Education	-6.25 (-30.54; 18.05)	.614
Street connectivity*Education	-15.48 (-41.79; 10.83)	.249
Infrastructure for walking*Education	-22.78 (-55.26; 9.70)	.169
Indoor places for walking*Education	-9.14 (-26.39; 8.12)	.299
Aesthetics*Education	16.89 (-1.13; 34.88)	.066
Presence of people on the streets*Education	17.13 (-7.53; 41.78)	.173
Crowdedness*Education	-2.82 (-24.29; 18.65)	.797
Traffic and road hazards*Education	-10.35 (-32.76; 12.07)	.366
Traffic speed*Education	6.15 (-19.30; 31.61)	.636
Social disorder and littering*Education	12.89 (-12.09; 37.87)	.312
Crime*Education	-3.20 (-39.57; 33.17)	.863
Bridge/overpass connection*Education	7.97 (-5.82; 21.75)	.257
Easy access to residence*Education	-15.47 (-48.24; 17.30)	.355
Fence separating footpath and traffic*Education	-7.90 (-23.14; 7.34)	.310
Sitting facilities*Education	-7.50 (-21.85; 6.84)	.305
Residential density*No. of medical conditions	0.01 (-0.22; 0.04)	.543
Land-use mix—destination diversity*No. of medical conditions	1.93 (-2.97; 6.83)	.441
Access to destinations and services*No. of medical conditions	-0.74 (-9.06; 7.57)	.861
Physical barriers to walking (e.g., hills) *No. of medical conditions	3.46 (-1.76; 8.67)	.194

Street connectivity*No. of medical conditions	1.70 (-6.62; 10.02)	.689
Infrastructure for walking*No. of medical conditions	4.59 (-3.65; 12.83)	.275
Aesthetics*No. of medical conditions	1.92 (-3.04; 6.88)	.449
Traffic and road hazards*No. of medical conditions	4.03 (-3.43; 11.48)	.290
Traffic speed*No. of medical conditions	-0.44 (-7.90; 7.02)	.908
Social disorder and littering*No. of medical conditions	2.10 (-4.11; 8.31)	.507
Crime*No. of medical conditions	6.81 (-2.45; 16.07)	.150
Bridge/overpass connection*No. of medical conditions	-2.35 (-5.83; 1.13)	.186
Easy access to residence*No. of medical conditions	1.84 (-4.70; 8.38)	.581
Sitting facilities*No. of medical conditions	-0.01 (-3.24; 3.21)	.993

Notes: β: regression coefficient. *p <.05; **p <.01; ***p <.001