ROLE OF THE SOCIAL AND PHYSICAL NEIGHBOURHOOD ENVIRONMENT IN PHYSICAL ACTIVITY IN DEPRIVED COMMUNITIES

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Declaration

I, Alexia Sawyer, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

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List of abbreviations

ALIGN: Active Living in Glasgow's Neighbourhoods study
ANOVA: Analysis of variance
CAPI: Computer-assisted personal interviewing
CI: Confidence interval
COREQ: Consolidated Criteria for Reporting Qualitative research checklist
CS: Community survey
EA: Environmental audit
GCPH: Glasgow Centre for Population Health
GHA: Glasgow Housing Association
GIS: Geographic information system
GoWell: Glasgow Community Health and Wellbeing Research and Learning programme
GPS: Global positioning system
HIA: Housing Improvement Area
IAT: Intervention Area Type
ICC: Intraclass correlation coefficient
IPAQ-SF: International Physical Activity Questionnaire – Short Form
IPEN: International Physical activity and Environment Network study
KMO: Kaiser-Meyer-Olkin statistic
LR: Likelihood ratio
LRA: Local Regeneration Area
LRFs: Low-rise flats
MPA: Moderate physical activity
MRC/SCO SPHSU: Medical Research Council/Chief Scientist Office Social and Public Health Sciences Unit
MSFs: Medium-rise flats
MVPA: Moderate-to-vigorous physical activity
NCD: Non-communicable disease
NICE: National Institute for Health and Care Excellence
OR: Odds ratio
PCA: Principal components analysis
PE: Peripheral Estate
RESIDE: RESIDential Environment study
SD: Standard deviation
SE: Standard error
SES: Socioeconomic status
SHARP: Scottish Health, Housing and Regeneration Project
SHS: Scottish Household Survey
SIMD: Scottish Index of Multiple Deprivation
SPOTLIGHT: Sustainable Prevention of Obesity through Integrated Strategies study
TRA: Transformational Regeneration Area
VPA: Vigorous physical activity
WSA: Wider surrounding area

Abstract

Physical activity is associated with numerous physical and psychosocial health benefits, yet population levels in the United Kingdom remain low, particularly in lower socioeconomic groups. Socioecological models posit that social and physical environments have independent and interactive influences on physical activity. Although a growing body of literature has examined the independent effect of aspects of the social and physical environment, interactive effects are rarely assessed. In addition, there is limited research specifically examining independent or interactive environmental influences in populations vulnerable to lower levels of physical activity, such as those living in neighbourhoods with high levels of deprivation. This thesis examines the association between quality of the neighbourhood physical environment (aesthetics, maintenance, physical disorder) and social environment (cohesion, safety, social interaction, support, trust, empowerment) on physical activity in adults living in income-deprived communities, using Glasgow as a case study. Cross-sectional analyses, conducted using a socioecological approach, suggested independent and interactive effects of objectively measured physical environmental factors and perceived social environmental factors on neighbourhood-based walking and moderate physical activity. Longitudinal analyses found little evidence that changes in environmental measures predict change in self-reported walking. However, qualitative analyses provided insight into potential causal pathways through a system of interacting environmental factors. Together, findings from this thesis suggest a role for the quality of the neighbourhood physical and social environment on activity, providing some evidence of interactive effects of the neighbourhood social and physical environment. Further research is needed to elucidate causal relationships between the quality of the neighbourhood environment and physical activity. Findings call for a complex systems approach to understanding contextual environmental effects on physical activity in deprived communities.

Chapter 1 Introduction: Environmental correlates of physical activity in adults

1.1 Physical activity benefits and trends

Physical activity is defined as energy expenditure resulting from any bodily movement created by skeletal muscle (Caspersen, Powell and Christenson, 1985). In adults, there are four widely recognised domains in which physical activity can be performed: occupational, household, transport and recreational, and a number of physical activity types performed at different levels of intensity (e.g. walking, cycling, sports, housework) (Sallis *et al.*, 2006). Regular participation in physical activity contributes to good health through the prevention and management of non-communicable chronic diseases (NCDs), such as cancer, diabetes, cardiovascular disease and dementia, which are leading causes of morbidity and mortality worldwide (Allender *et al.*, 2007; Reiner *et al.*, 2013; World Health Organisation, 2014; Ekelund *et al.*, 2015; Mueller *et al.*, 2015; Sallis *et al.*, 2016). Indeed, a meta-analysis in 2011 estimated that 3,400 cancer cases every year in the United Kingdom (UK) are attributable to performing an insufficient level of moderate-to-vigorous intensity physical activity (MVPA) (Parkin, 2011). High-quality meta-analyses and cohort studies unpack some of the mechanisms through which participation in physical activity can benefit health, including maintenance of healthy blood pressure levels (Whelton *et al.*, 2002), reductions in inflammatory markers (Hamer *et al.*, 2012) and reductions in the negative impact of risk factors for NCDs, including stress, obesity and poor sleep (Fox, 1999; Baillot *et al.*, 2015; Kredlow *et al.*, 2015).

In light of its associated health benefits, guidelines for physical activity have been published in the UK (Chief Medical Officer, no date). For adults (19-64 years old), guidelines recommend participation in daily activity with an accumulation over a week of either ≥150 minutes of moderate activity (e.g. brisk walking), 75 minutes of vigorous activity (e.g. running) or a combination. It is also recommended that adults participate in muscle-strengthening activity and reduce waking sedentary time. Regular brisk walking for periods of ≥10 minutes can contribute to an accumulation of MVPA and meeting physical activity guidelines (Chief Medical Officer, no date). Guidelines for older adults (≥65 years old) are similar, with an additional recommendation to participate in activities to improve co-ordination and balance.

Despite these guidelines, the UK has particularly low levels of physical activity compared with other Western European countries (UK Active, 2014; Sport England, 2015), accruing large personal, healthcare and wider societal costs as a result (British Heart Foundation, 2013; Biswas *et al.*, 2015). Objective measures of physical activity in 4,507 adults aged >16 years, collected as part of the 2008 Health Survey for England, showed that only 6% of males and 4% of females met the recommended guidelines for physical activity, although self-reported estimates of meeting guidelines were much higher at 39% for men and 29% for women (Health and Social Care Information Centre, 2009). Moreover, objective data showed that 50% of males and 58% of females not only failed to meet recommended guidelines but were classified as physically inactive, i.e. achieved less than 30 minutes of moderate-intensity physical activity (MPA; conducted in >10 minute sessions) over a week (Health and Social Care Information Centre, 2009).

Levels of inactivity are particularly high among socioeconomically deprived groups, who can be categorised using Townsend's definition: "*a state of observable and demonstrable disadvantage, relative to the local community or the wider society or nation to which the individual, family or group belongs*", i.e. a high level of unmet social and economic need in individuals or groups (Townsend, 1987; Giles-Corti and Donovan, 2002; Van Lenthe, Brug and Mackenbach, 2005; Kamphuis *et al.*, 2008). Self-reported physical activity data from the 2013 Active People Survey revealed that levels of inactivity (<30 minutes MVPA/week) in England are almost 10 percentage points higher in local authorities with the highest levels of deprivation compared with those with the lowest deprivation levels, suggesting spatial inequalities in activity (UK

Active, 2014). Within Scotland, Scottish Health Survey data from 2016 illustrate variation in meeting physical activity guidelines and physical inactivity by area deprivation calculated using the Scottish Index of Multiple Deprivation (SIMD).[1] In self-report data, 54% of adults met physical activity guidelines and 29% were inactive (classified as <30 minutes of MPA/week) in the most deprived quintile, while 74% met guidelines and 13% were inactive in the least deprived quintile (Bardsley *et al.*, 2017).

Reducing levels of inactivity is critical to the health of the population. A large European cohort study including 334,161 males and females estimated that moving adults from inactivity to a level of activity equivalent to a daily 20-minute walk resulted in reductions in all-cause mortality by 7%, which was a statistically significant amount when assessed using Cox proportional hazards models (Ekelund *et al.*, 2015). Additionally, longitudinal analyses across 15 years in Norway identified low-intensity physical activity performed over longer durations (i.e. ≥1 hour of activity which does not cause sweating or loss of breath plus <1 hour of high intensity activity/week) as a priority target for reducing mortality in inactive populations (in this instance classified as those currently achieving <1 hour of low intensity activity/week) (Kopperstad *et al.*, 2017).

Walking for transport or recreation has been identified by the National Institute for Health and Care Excellence (NICE) as a key target for increasing physical activity in inactive adults living in the UK (National Institute for Health and Care Excellence, 2012). This is because walking accounts for a large proportion of the physical activity of adults who meet national physical activity guidelines (and are therefore likely to obtain activity-related health benefits) (NICE, 2012). Walking is also low-cost and therefore more accessible for individuals with a low income: a notion reflected in Scottish Household Survey (SHS) data showing that individuals with a household income of <£30,000 were more likely to report walking at least 2-4 times/week compared with those with higher household incomes (Anable *et al.*, 2010). However, a

[1] The SIMD is a tool used by the Scottish Government to rank deprivation in small area geographies ('data zones') according to income, employment, crime, education, access and housing data.

decline in walking trips has been reported, with data from the National Travel Survey in England revealing a 30% decline in the average number of walking trips reported per person per year between 1995/1997 (292 trips) to 2013 (203 trips) (NatCen Social Research, 2014). In addition, SHS data showed that between the years 1990/2000 and 2005/2006, the proportion of trips undertaken by foot declined at a faster rate for adults in the most deprived areas (30% to 20% in the most deprived areas as assessed by the SIMD; 16% to 12% in the least deprived areas) (Anable *et al.*, 2010).

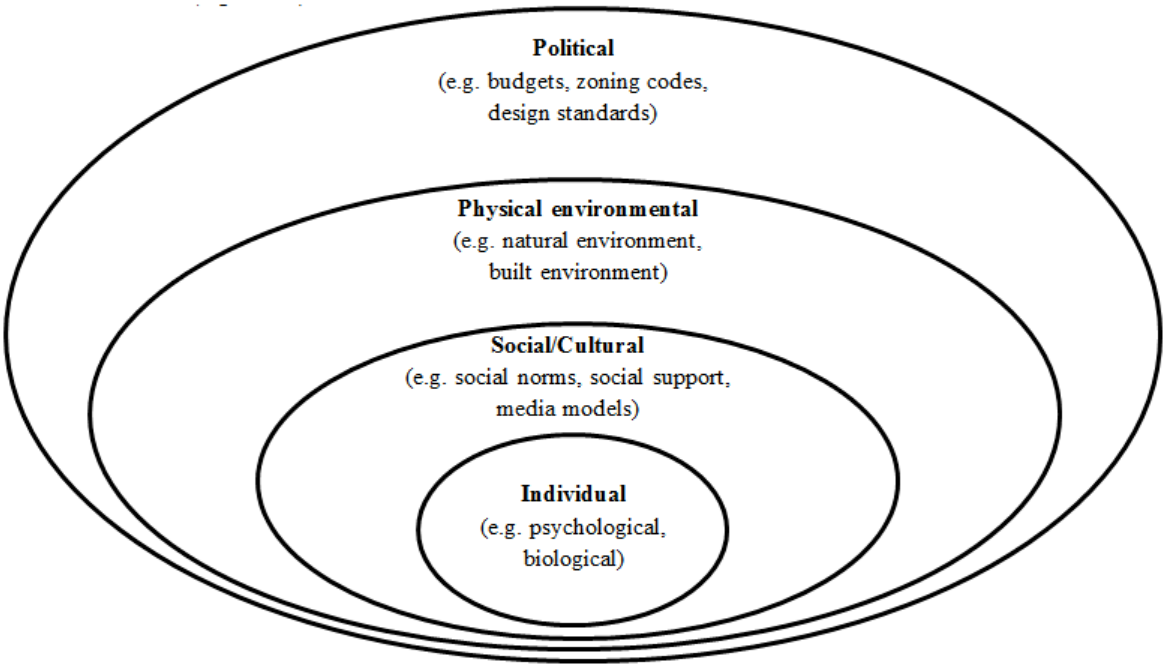
Understanding the determinants of moving individuals from inactivity to some level of physical activity, particularly in populations at higher risk of inactivity, could contribute to the development of effective interventions at a population level, and is therefore a public health priority.

1.2 Socioecological models of physical activity

A socioecological approach to physical activity posits that physical activity is influenced by individual characteristics, the social environment, the physical environment and policies (**Figure 1.1**). A core tenet of socioecological models is that correlates are embedded in a system, acknowledging that multiple environmental and individual characteristics are interrelated and act simultaneously upon the outcome through independent and interactive effects (Sallis *et al.*, 2006; Cummins *et al.*, 2007; Kremers, 2010). Interventions targeting multiple levels of influence are thought to be the most effective at increasing population activity levels (Spence and Lee, 2003). This is reflected in psychological behaviour change frameworks, such as the COM-B framework, which embrace a socioecological approach by explicitly incorporating environmental influences of behaviour (Michie, van Stralen and West, 2011).[2] Conceptualisations of environmental influences on physical activity discussed in this thesis adopt a socioecological approach.

[2] The COM-B model comprises capability, opportunity - encompassing physical and social environmental characteristics - and motivation; both capability and opportunity can act directly upon behaviour, or indirectly through motivation (Michie, van Stralen and West, 2011).

Figure 1.1 A socioecological model of physical activity adapted from Sallis, Floyd, Rogrigues and Saelens (2012)



1.2.1 The 'neighbourhood' as a physical activity setting

A socioecological approach acknowledges that physical activity can be performed in a number of contexts or settings (e.g. neighbourhood, home, workplace, school, recreational facilities inside or outside home or workplace/school neighbourhoods) encompassing indoor and outdoor environments. The neighbourhood is a key physical activity context in socioecological models (Sallis *et al.*, 2006) and the work in this thesis will focus on the neighbourhood, conceptualised as encompassing physical, social and psychosocial environments (Kearns and Parkinson, 2001; Siegrist and Marmot, 2004). In a socioecological approach, the neighbourhood can be considered as a context within the mesosystem (sitting between the microsystem representing smaller-scale contexts such as the home and the macro-system representing larger-scale contexts such as national policies or culture).

Neighbourhood variation in physical activity according to factors such as spatial distribution of socioeconomic status (SES) has been used to demonstrate potential neighbourhood environmental effects on activity (Van Lenthe, Brug and Mackenbach, 2005; Kamphuis *et al.*, 2008). As such, improving the neighbourhood to support healthy lifestyles is gaining support and recognition as an attractive approach to intervention (NHS England, no date; Kleinert and Horton, 2016). ‘Active design’ strategies to increase neighbourhood walkability are increasingly recognised as valuable in policy domains which aim to strategically apply these practices within public health and planning (e.g. Centre for Active Design’s ‘Active Design Guidelines’ (Centre for Active Design, 2010); Public Health England’s ‘Healthy People, Healthy Places’ (Public Health England & Local Government Association, 2013), World Health Organisations’ ‘A healthy city is an active city’ (Edwards and Tsouros, 2014) and Scottish Government’s ‘Good Places, Better Health’ (Scottish Government, 2008)). Such strategies are also seemingly popular with the public, with reported positive associations between measures to increase walkability and self-reported neighbourhood satisfaction (Lee *et al.*, 2017).

Furthermore, it has been argued that increasing population levels of activity by intervening at the environmental level in the neighbourhood, rather than individual level (which might lead to socially-patterned uptake and maintenance of the intervention, dependent on individual factors such as motivation and capability) it is possible to address observed inequalities in activity and engender sustainable change in vulnerable populations (Hanson and Jones, 2015; Egan *et al.*, 2016; Zapata Moya and Navarro Yanez, 2017). As such, area-based initiatives such as targeted urban regeneration (the renewal and development of social and physical environments of areas exposed to economic, environmental and social decline) (Egan *et al.*, 2015) presents an opportunity to implement environmental strategies to physical activity intervention in deprived neighbourhoods, alleviating an observed burden of lower levels of physical activity in resident populations (Van Lenthe, Brug and Mackenbach, 2005; Kamphuis *et al.*, 2008; UK Active, 2014).

1.2.2 Conceptualisation of neighbourhood contextual effects on physical activity in line with a socioecological approach

In order to study the neighbourhood as a physical activity setting, it is necessary to conceptualise 'the neighbourhood' and its potential relationship with activity. The neighbourhood comprises individuals, social relationships, shared resources, the physical environment and the historical and cultural milieu of a geographical area (Galster, 2001; Kearns and Parkinson, 2001). The definition of the neighbourhood is nebulous, both in geographical boundaries – which vary in shape and size according to numerous factors (e.g. administrative boundaries, multiple types of geographically-derived boundaries, historical or cultural boundaries etc.), and what it means to different people, in terms of the way it is used or experienced by the people who inhabit the neighbourhood as residents, workers or visitors but also in its importance and relevance (Kearns and Parkinson, 2001). Neighbourhood variation in outcomes can be attributable to the spatial distribution of individual characteristics (i.e. compositional factors, such as ethnicity or individual-level SES) or area characteristics (e.g. contextual factors such as quality of the local green space or level of social cohesion in the community). The level at which compositional and contextual neighbourhood factors are defined and measured can vary in scale, from small sub-areas ('home area') to the larger localities ('locality') and their setting within a wider context (i.e. 'urban district or region') (Kearns and Parkinson, 2001). These factors can be measured at different scales, from the level of the individual (e.g. subjective perceptions of the environment) to larger scales such as the neighbourhood (e.g. objective measures of the neighbourhood environment or aggregated perceptions of residents within a neighbourhood).

Measurement of the physical environment in a neighbourhood context of residential and non-residential areas can encompass built and natural environments, including streets, roads, transit infrastructure, buildings, facilities and amenities (e.g. commercial premises, leisure premises, public institutions) and green or blue space (e.g. parks, natural trails, riversides) (Sallis *et al.*, 2012). This thesis considers the presence, layout, maintenance and quality or condition of these physical features. Broad conceptualisation of physical environment can also be drawn from the planning literature. In particular, the development of the 'walkability' construct, which has been specified as comprising the three 'Ds': <u>d</u>ensity (population and employment opportunities), <u>d</u>iversity of land use and <u>d</u>esign (street layout and sidewalk design) (Cervero and Kockelman, 1997). Jane Jacob's seminal text on urban design and planning: 'Life and Death of Great American Cities', identified four conditions necessary for diverse, vibrant neighbourhoods: diversity of primary uses (i.e. land use mix: a combination of development types such as commercial and residential), high connectivity (i.e. a high number of street intersections), buildings diverse in age and appearance; and high building density (Jacobs, 1961). Jacobs conceived conditions as working simultaneously, each being a necessary, but not sufficient, condition for pedestrian activity.[3]

The social environment in a neighbourhood context can be defined in multiple ways. This thesis focuses on perceived contextual features of the social environment measured at the individual level. These were conceptualised using a broad definition of social capital. In line with other research and in accordance with the Office for National Statistics definition, social capital encompassed: social cohesion, trust and reciprocity between neighbours, social interaction and support, participation and membership of clubs and organisations, civic participation (e.g. voting, influence over decisions) and views of the neighbourhood in terms of perceived safety from crime (Harper, 2002; McNeill, Kreuter and Subramanian, 2006). A sense of belonging to the neighbourhood, defined as emotional attachment and familiarity, was also considered (Finney and Jivraj, 2013). Cultural aspects of the neighbourhood environment such as shared traditions and values can also be conceived as falling within the social environment.

[3] Notably, in this text Jacobs also demonstrated the interplay between the physical and social aspects of the street and neighbourhood, describing that a well-designed sidewalk would facilitate feelings of safety, social interaction and inter-generational contact (Jacobs, 1961).

The use of a theoretical basis to conceptualise potential mechanisms operating between the neighbourhood environment and physical activity is necessary to advance research examining how numerous types of environmental features may work together to influence physical activity. As Nelson *et al.* noted: "*the lack of theoretical grounding pervades both [public health and urban planning fields], resulting in a plethora of exploratory research… it is important to recognise the limitation of analysing the effect of individual features of the environment on physical activity behaviour. These features do not exist in isolation*" (Nelson *et al.*, 2008). In a socioecological approach, features of the environment are not treated as isolated and reciprocal relationships between levels of influence on physical activity are assumed, pertaining to reciprocity between different types of environment but also between environments and the individual.

A reciprocal relationship between the individual and environment is specified in the theory supporting the concept of 'behaviour settings', which draws on social cognitive theory and the concept of 'affordances'. Bandura's social cognitive theory describes how the individual is embedded within a nuanced and non-static (i.e. dynamic) social and physical environment, establishing a reciprocal relationship with the environment whereby the environment influences the individual's behaviour and vice versa (Bandura, 1989). The concept of 'affordances' concerns the cues emerging from the information available in the environment which influence individuals' perceptions of, and behaviour within, that environment (Gibson, 1979). While some environments provide information that is supportive of certain actions, such as physical activity, others provide information that discourages these actions. Moreover, the way such information is interpreted is determined by a host of factors pertaining to the individual (cognitive, affective and physical), attached social and cultural meaning and physical design characteristics. Newman's theory of 'defensible space' could be understood within this framework, whereby the physical design and layout of an environment produces more or fewer opportunities for behaviours such as causal surveillance of shared spaces, in turn influencing the sense of control and safety of the residents and how a physical space is used (Newman, 1972).

‘Behaviour settings’ can be viewed as the product of affordances within a specific context, determining physically, socially and culturally appropriate behaviour for that setting (Barker, 1976). For example, Goličnik and Ward Thompson (2010) note that while a patch of grass of a certain size within a public park may be a behaviour setting for informal sports, this behaviour would not be performed on a patch of grass of the same size that is situated in front of corporate buildings. This theoretical stance highlights the nuance of the relationship between environment and behaviour, emphasising the importance of examining individuals’ lived experience of place, in addition to the quantification of an empirical relationship.

Conceptual models and frameworks provide a schematic representation of putative relationships between multiple aspects of the neighbourhood environment and physical activity. In attempting to unpack the ‘black box’ of neighbourhood effects on health more broadly, Macintyre, Ellaway and Cummins (2002) present an organising framework through which enables separation of a hierarchy of levels through which neighbourhood environments influence health. These levels are:

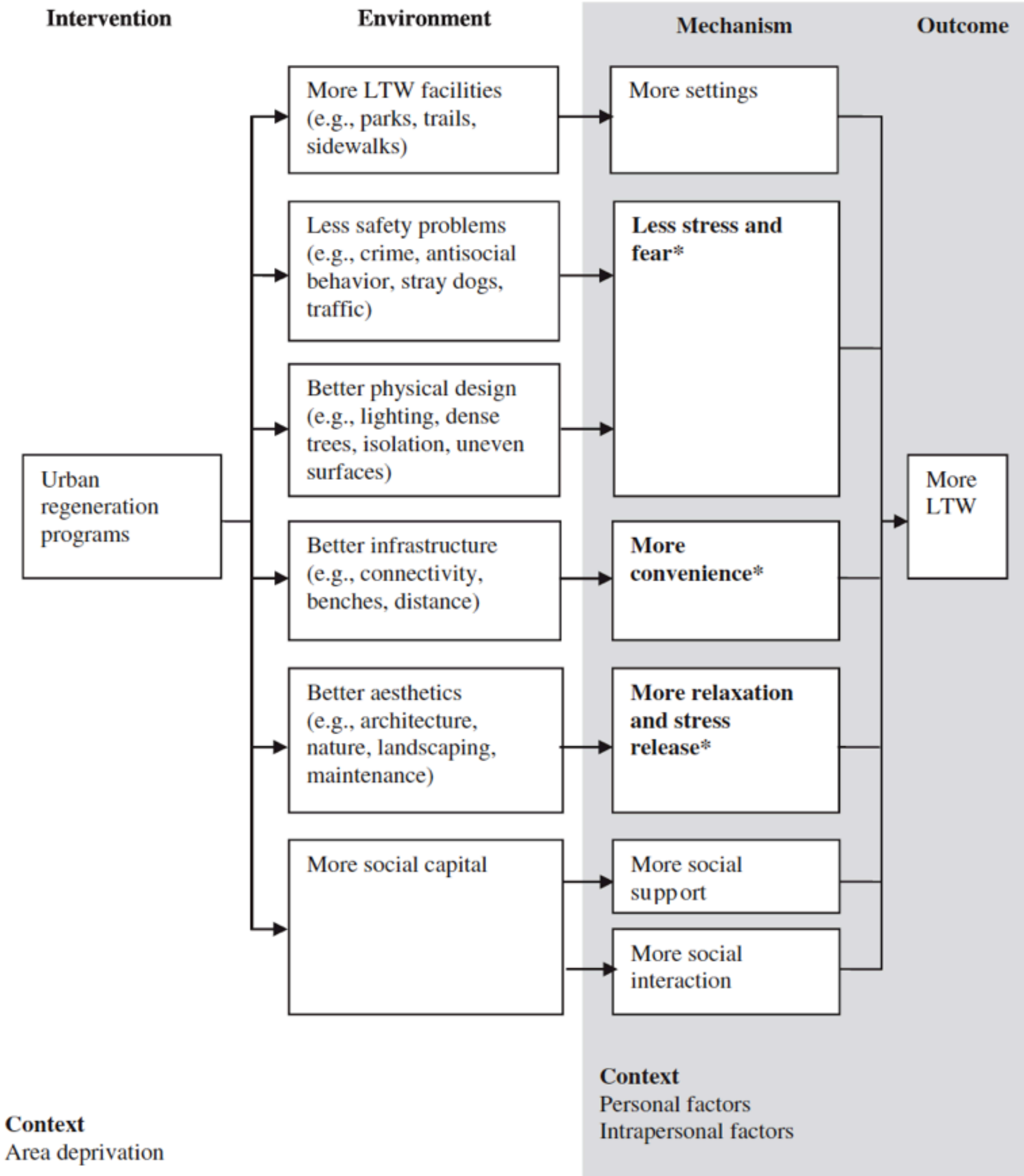
1. **Material or infrastructural resources** *“Opportunity structures” to lead healthy lives through direct and indirect influences from the local physical and social environment, including:*
    a. Physical factors experienced by all residents, e.g. climate, air quality, geography;
    b. Availability of healthy environments for living, e.g. provision of safe residential, leisure and occupational environments;
    c. Public and private services supporting healthy living, e.g. adequate social, transport, education and health services.

2. **Collective social functioning and practices** *Features that influence use and perception of the area and relationships and social resources shared by the community, including:*
    a. Socio-cultural factors, e.g. political and cultural environment and history, social capital;
    b. Internal and external neighbourhood reputations, e.g. perceptions of the area held by residents, outsiders and those in authority such as service providers or investors.

A limitation of this framework acknowledged by the authors is the breadth of the categories, which hamper the generation of specific hypotheses about pathways of influence on specific outcomes (Macintyre, Ellaway and Cummins, 2002). A specific context and pathway through which the environment might influence health, such as environmental influences on physical activity in deprived neighbourhoods, offers the possibility to operationalise the organising framework by drawing on empirical and theoretical evidence in the public health literature.

Kramer *et al.* (2017) recently published a theory of the mechanisms through which urban regeneration programmes can encourage leisure-time walking in deprived neighbourhoods (**Figure 1.2**). Drawing on 13 qualitative studies in the area, the authors reported strong support that safer, well-designed environments with better infrastructure and aesthetics increased walking by creating more relaxing, attractive and convenient settings for the behaviour. There was some support in the literature that more physical activity facilities and higher levels of social capital facilitated walking by increasing settings for physical activity and opportunities to develop social relationships (Kramer *et al*., 2017).

Figure 1.2 Kramer et al.'s (2017) theory of urban regeneration programmes' influences on leisure-time walking in deprived populations

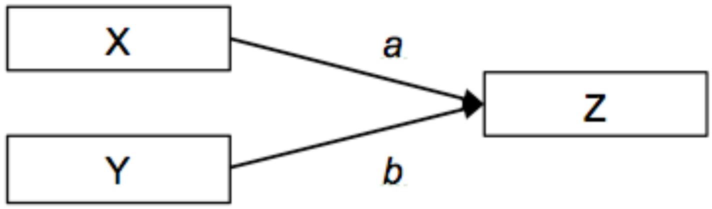


* With bold typeface indicates the pathways with the most supporting evidence. LTW: leisure-time walking.

In order to develop this conceptualisation, Kramer *et al.* (2017) call for quantitative research focusing on mechanisms of how changes in physical activity might be engendered through urban regeneration activities. The authors state: "*Mechanisms describe how a program produces its outcome(s)… whether and how these mechanisms are enacted upon depends on the context in which they are activated*" (Kramer *et al.*, 2017).

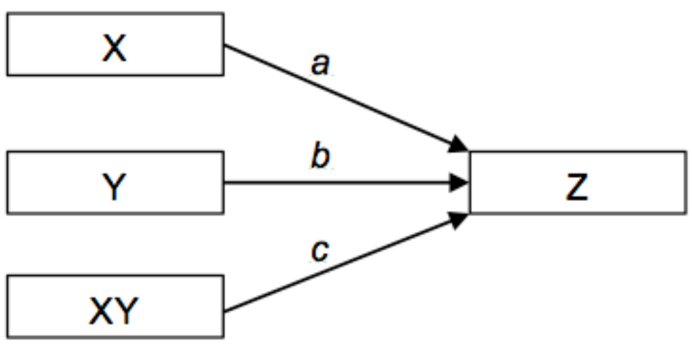
As already alluded to, a socioecological approach acknowledges different types of *mechanisms* which might operate between environmental influences and physical activity in a *system*. As such, it postulates that different levels of influence have both *independent* and *interactive* effects on physical activity. An independent effect occurs when a variable has a direct effect on the outcome that is not dependent on another variable. **Figure 1.3** illustrates independent effects of variables (X and Y) upon the outcome (Z); the variance is decomposed into two separate pathways: *a* and *b*.

Figure 1.3 Schematic of independent effects of variables X and Y on outcome Z



An interactive effect occurs when variables are interrelated and work together to produce an effect on the outcome. **Figure 1.4** illustrates independent (X; Y) and interactive effects (X by Y = XY) on the outcome (Z); the variance in the outcome is decomposed into three separate pathways: *a*, *b* and *c*. A significant interactive effect can be indicative of a mediating, moderating or synergistic function of the independent variables (Baron and Kenny, 1986). For example, Y could sit on the causal pathway between X and Z (mediating effect) or Y could moderate the strength and/or direction of the effect of X on Z (moderating effect). Alternatively, X and Y could act in combination (XY) to exert a greater effect on Z than the independent effects of X and Y alone (i.e. the interactive effect is greater than the sum of its parts and manifest in a multiplicative rather than additive manner; synergistic effect). If the effect of X (pathway *a*) is substantially weakened but the effect of Y (pathway *b*) is not substantially changed by the introduction of XY (pathway *c*), this indicates a mediating or moderating effect of Y (pathway *c* now explains part of the variance originally explained by pathway *a*). If the effects of both X and Y (pathways *a* and *b*) are substantially weakened by the introduction of XY (pathway *c*), this is indicative of a moderating or synergistic effect (pathway *c* now explains part of the variance originally explained by pathways *a* and *b*) (Baron and Kenny, 1986; Slinker, 1998). In the absence of evidence to hypothesise a linear pathway from antecedent variable to intervening variable to outcome, it is valuable to first establish an interactive effect by testing the significance of pathway *c*. Furthermore, it is a worthwhile consideration that interactive effects may not be amenable to operationalisation through linear pathways of influence: proponents of a 'chaotic' paradigm of health promotion purport that interactions between variables within a complex system may be non-linear, with variables acting upon one another in a recursive fashion (supporting the examination of non-linear synergy between variables, rather than specifying antecedent and intervening variables) (Resnicow and Vaughan, 2006). The notion of 'complexity' also endorses a focus on the pathways of influence rather than linear cause-and-effect relationships, proposing that effect modification (i.e. interaction, mediation and moderation), feedback (i.e. recursive effects whereby change in one factor affects the function of another factor) and adaption (i.e. compensatory behaviour in a factor owing to change in another factor) are common characteristics of the relationship between factors along a pathway (El-Sayed and Galea, 2017).

Figure 1.4 Schematic of independent and interactive effects of variables X and Y on outcome Z, adapted from Baron & Kenny (1986)



Examining independent and interactive effects of the social and physical environment on physical activity could advance our understanding of the potential mechanisms of influence operating between the neighbourhood environment and activity. The literature exploring independent effects of environmental factors on physical activity is more developed than the literature examining interactive effects. It is therefore useful to provide an overview of the literature investigating independent effects as an introduction to a broader evidence base of neighbourhood environmental effects on physical activity.

1.3 Independent associations between social and physical neighbourhood environments and physical activity

Reviews of the literature and large cross-country studies such as the International Physical activity and Environment Network (IPEN) study support a consistent association between higher levels of participation in physical activity and features of the neighbourhood physical environment, in particular: connectivity, increased land use mix, walkability and adequate pavement provision (Duncan, Spence and Mummery, 2005; Sallis *et al.*, 2009; McCormack and Shiell, 2011; Ding *et al.*, 2013; Sallis *et al.*, 2016). However, less consistent associations have been revealed for access to public transit and facilities, residential density and perceived traffic safety (Duncan, Spence and Mummery, 2005; Sallis *et al.*, 2009; McCormack and Shiell, 2011; Ding *et al.*, 2013; Sallis *et al.*, 2016). In terms of walking, a 2008 review of reviews found consistent positive associations between walking for transport and density, land use mix and distance to non-residential destinations, but more equivocal results for associations between walking for recreation and physical environment attributes (Saelens and Handy, 2008).

In a systematic review of 38 studies, higher-quality social environments increased the likelihood of higher levels of overall physical activity, walking and sports participation (Samuel, Commodore-Mensah and Himmelfarb, 2014). In a preliminary conceptual framework, the authors conceptualised social environmental factors as two over-arching constructs: 'social capital', encompassing sense of community, trustworthiness, reciprocity between neighbours, and 'collective efficacy', encompassing social control and social cohesion (Samuel, Commodore-Mensah and Himmelfarb, 2014). A recent review which excluded studies with samples of less than 500 participants reported some evidence of positive associations between perceived and objective safety from crime and leisure-time and transport-related physical activity in adults, but found most evidence for null associations (da Silva *et al.*, 2016). The authors stated that more qualitative research in specific groups is needed to elucidate the influence of safety on individual's behaviour, in addition to prospective and quasi-experimental studies. In an earlier review, associations between crime rates and perceived safety and physical activity were also inconsistent (Foster and Giles-Corti, 2008). Possible factors contributing to inconsistent results include: measurement error resulting from inadequate crime measures; physical activity outcomes that are not context-specific (and therefore may obscure the potential effect of contextual factors upon behaviour); and lack of consideration of physical and social environmental variables that may mediate or moderate examined relationships (Foster and Giles-Corti, 2008).

The literature examining independent effects of the neighbourhood environment is dominated by cross-sectional studies, meaning that studies might be subject to selection bias, whereby more active individuals select to live in neighbourhoods with particular attributes (McCormack and Shiell, 2011). However, evidence from longitudinal or quasi-experimental studies is emerging which strengthens the assumption of a causal association between social and physical environments and physical activity by assessing temporal associations and minimising potential selection bias. For example, longitudinal analysis of data from the Netherlands Housing Survey revealed that changes to perceived social cohesion, social and physical disorder and green space were significantly associated with self-reported physical activity and sports participation (Jongeneel-Grimen *et al.*, 2014). However, a quasi-experimental study conducted in Western Australia found non-significant differences in self-reported walking at 12 and 36 months' follow-up between individuals who relocated to housing developments with activity-supportive characteristics (e.g. land-use mix, traffic calming or increased street connectivity) and those who relocated to a conventional development (Christian *et al.*, 2013).

Evaluations of area-based urban regeneration programmes in terms of impact on physical activity can adopt a quasi-experimental design. However, they are currently few in number and unfortunately those that exist provide equivocal evidence (Batty *et al.*, 2010; Lawless *et al.*, 2010; Kramer *et al.*, 2014; Mohan, Longo and Kee, 2017). Evaluation of holistic, multifactorial area-based regeneration in 40 of the most deprived neighbourhoods in the Netherlands reported a small effect of intervention at 3.5 years (Kramer *et al.*, 2014), yet this effect was non-significant compared with control neighbourhoods 6.5 years after intervention (Ruijsbroek *et al.*, 2017). Relative to control neighbourhoods, neighbourhoods receiving area-based intervention through the New Deal for Communities in the UK saw a decrease in frequent physical activity, over a 6-year period (Batty *et al.*, 2010). Furthermore, an area renewal intervention in 36 deprived neighbourhoods in Northern Ireland targeting economic, social and physical factors (e.g. employment opportunities, crime prevention and green space improvements) found a non-significant increase in self-reported weekly physical activity in intervention neighbourhoods compared with control neighbourhoods using a difference-in-difference regression analysis (Mohan, Longo and Kee, 2017).

Although such evidence does not provide support for a causal relationship between the neighbourhood environment and physical activity, potential mechanisms of causal influence might be obscured by broad evaluations of interventions which disproportionately target certain features of the environment. This could lead to difficulty in accurately attributing (significant and non-significant) effects (Ruijsbroek *et al.*, 2017). For example, Kearns et al. noted that improvements in more tangible, physical aspects of the environment (i.e. housing) may be prioritised by those implementing area-based regeneration programmes over covert upstream features of the environment (i.e. social and economic conditions) (Kearns *et al.*, 2013). As such, upstream social causes underpinning health outcomes and behaviours might remain unresolved, hindering actual examination of the relationship between environmental change and physical activity.

In line with a focus on mechanisms of influence, Petticrew (2011) suggests it might be meaningful to unpack complex interventions such as urban regeneration programmes into 'processes' and 'outcomes', not only examining outcomes from the whole programme but also taking a 'simpler' approach by focusing on processes influencing individual outcomes, such as individual-level physical activity within specific contexts. Although longitudinal and quasi-experimental studies are growing in number, they remain relatively few and could benefit from being broader in their interrogation of physical and social changes in the neighbourhood environment, while attempting to elucidate specific pathways of influence (McCormack and Shiell, 2011).

1.3.1 Independent associations between social and physical environments and physical activity in deprived communities

As discussed, spatial inequalities in physical activity demonstrated in the UK might suggest that area deprivation has a role in the relationship between the environment and physical activity (Anable *et al.*, 2010; UK Active, 2014; Bardsley *et al.,* 2017). Deprivation is a multidimensional construct pertaining to access to resources and opportunities arising from economic and social circumstances. Measures of relative deprivation including the SIMD and English Index of Multiple Deprivation can be used to assess small area geographies nationally in terms of disadvantage or poverty by area. In these tools, seven domains are used to capture socioeconomic deprivation: income, employment, crime, education (including school performance, skills and training), access to services, access to housing (including over-crowding and central heating) and health. As such, these measures calculate area deprivation by also taking account of individual or household measures such as income.

The concept of 'deprivation amplification' suggests that areas ranked as high in multiple deprivation are less likely to have resources and attributes which support healthy lifestyles; for example, fewer physical activity facilities and a lower frequency of street sweeping. However, analysis from Glasgow suggests that spatial distribution of facilities or resources does not necessarily disadvantage socioeconomically deprived areas (Macintyre, 2007). It has been suggested that rather than the presence of physical resources, the quality of these resources and social factors, might be more important (Macintyre, 2007). In addition, Walsh *et al.* (2010, 2016) allude to the importance of social capital and political empowerment (alongside other economic and physical factors and methodological limitations) in making the city 'vulnerable' to excess mortality arising from deprivation which is not observed in other cities in the UK with similar deprivation profiles. In light of observed area variation in physical activity by deprivation, there is a need for a clearer understanding of the mechanisms operating between deprivation and poorer health or health-related behaviours such as physical activity.

In the wider literature, the quality, or condition, of aspects of neighbourhood social and physical environment might be able to explain important differences in physical activity by neighbourhood deprivation (Van Lenthe, Brug and Mackenbach, 2005; Kamphuis *et al.*, 2008). Importantly, evidence drawn from North America (Wilson *et al.*, 2004; Neckerman *et al.*, 2009; Steinmetz-Wood and Kestens, 2015), Australia (Sugiyama *et al.*, 2015) and the UK (Zandieh *et al.*, 2016) suggests exposure to poorer neighbourhood environmental quality is significantly higher in deprived, low-SES neighbourhoods.

For example, a study of 2,172 census tracts in New York City, combining Geographic Information Systems (GIS) and observation, found that income-deprived communities did not differ from non-deprived communities in structural walkability indices (i.e. connectivity, land use mix and density) but did differ in objectively-measured (audited) quality-related aspects including crime-related complaints, narcotics arrests, cleanliness of streets, number of street trees and number of landmarked buildings, with deprived communities faring worse (Neckerman *et al.*, 2009). The authors recommended that future research examines how neighbourhood conditions such as crime and physical disorder may interact and synergistically affect physical activity. In a sample of older adults in Birmingham, UK, disproportionate exposure to lower perceived levels of safety and aesthetics in deprived than in non-deprived neighbourhoods was related to lower levels of walking in deprived neighbourhoods, while a similar disparity in amenity provision was not related to activity outcomes (Zandieh *et al.*, 2016). Despite these insights, the role of the quality of the neighbourhood environment in neighbourhood-based physical activity remains comparatively under-researched – with the focus tending to fall upon structural aspects of the environment.

1.3.2 Glasgow Community Health and Wellbeing Research and Learning (GoWell)

Glasgow Community Health and Wellbeing Research and Learning (GoWell) is a research programme exploring the effect of an urban regeneration programme on multiple health and wellbeing outcomes in deprived neighbourhoods in Glasgow, UK. *Will Glasgow Flourish?* describes Glasgow Housing Association's (GHA) holistic approach to a 10-year programme of regeneration and renewal across income-deprived neighbourhoods in Glasgow (Crawford, Beck and Hanlon, 2007). The programme included housing, economic, social, physical and cultural regeneration. Key physical environmental regeneration activities intended to improve: high quality public realm; retail and other private sector facilities; development of brownfield sites; enhanced natural environment; and access to green space and attractive communities which attract new residents and businesses (**Appendix 1.1**). Key social regeneration activities aimed to improve and promote: sustainable, mixed communities; financial inclusion; sustainable tenancies; healthier lifestyles; skills and employment potential and strong and safe communities and also to reduce: homelessness, anti-social behaviour and crime (**Appendix 1.1**). Variations in type and intensity of regeneration activities is discussed in more detail in *Will Glasgow Flourish?* (Crawford, Beck and Hanlon, 2007).

Income-deprivation (i.e. percentage of residents in receipt of income-related benefits), rather than multiple deprivation was used as a measure of deprivation in GoWell due to the relative ease of calculating it in absolute terms while obtaining comparable measure across each GoWell neighbourhood (Walsh 2008). However, it is important to note that most SIMD domains correlate very highly within the GoWell neighbourhoods, indicating socioeconomic deprivation across the seven domains (Walsh, 2008).

Using cross-sectional self-reported data from the first wave of the GoWell programme, Mason, Kearns and Bond (2011) examined the associations between neighbourhood-based walking on at least 5 days/week and a number of individual items assessing individual, economic, residential and physical and social environmental factors. In terms of physical environment correlates, logistic regression analyses revealed that while use of parks and play areas doubled an individual's likelihood of frequent walking, there was no effect of perceived quality of local parks and play areas. The built form of participants' accommodation (i.e. multi-storey flat, low-rise flat, house) and use of other amenities including sports facilities, supermarket and shops and libraries was also reported to have no effect while there was an effect of using social venues in the neighbourhood, with regular use predicting 1.28 greater odds of frequent walking. Within this context, the relationship between objectively measured structural walkability metrics (residential density and street connectivity) and self-reported physical activity is being examined (personal communication). However, no exploration of the role of objective measures of the quality of the physical environment on physical activity has been conducted within the GoWell programme.

Again using data from the first wave of GoWell, self-reported internal reputation (i.e. sense of progress from residing in the neighbourhood) and external reputations of the neighbourhood has been reported to have, respectively, a significant negative and positive effect on walking (Mason, Kearns and Bond, 2011). A surprising negative effect was also reported for participation in local clubs and organisations and perceived trust of others in the neighbourhood, while there was a positive effect of perceived belonging to the neighbourhood, informal social control and perceived harmony between residents of different backgrounds. The largest effect was for sense of belonging which predicted 1.69 increased odds in walking on at least 5 days/week. Using geocoded objective crime data from wave 2, Mason, Kearns and Livingston (2013) explored cross-sectional effects of perceived and objective safety and crime on frequent neighbourhood-based walking in the GoWell sample. In this study there was a positive effect of perceived safety walking in the neighbourhood after dark and safety at home, which persisted after consideration of socio-demographics, while an association between walking and objective five-year person-related (opposed to property-related) crime rate for the neighbourhood was rendered non-significant in multivariable models. Qualitative research in GoWell samples illustrate the multifaceted nature of perceived safety and anti-social behaviour within this context and the diversity in inter-generational experiences negotiating this aspect of the neighbourhood social environment (Egan *et al.*, 2012; Neary *et al.*, 2013). However, previous GoWell research has not investigated interactions between social and physical environment measures and how this might also explain potentially counter-intuitive findings.

GoWell is unique in offering the opportunity to elucidate hypothesised mechanisms through which the *quality* of the perceived social environment and perceived and objectively-assessed physical environment might exert independent and interactive influences on walking and physical activity in deprived communities in the UK, using recent data from a community-based sample. A review of the current evidence base assessing interactive effects of the social and physical environment on physical activity would be useful in informing such research.

1.4 Interactive or simultaneous associations between social and physical neighbourhood environments and physical activity

As previously mentioned, a central hypothesis of socioecological models is that different levels of influence (i.e. political, physical, social, individual) produce interactive effects on physical activity (Sallis *et al.*, 2006). Such effects are predicated on associations between the physical and social environment, as reported in the literature (Coley, Sullivan and Kuo, 1997; Bothwell, Gindroz and Lang, 1998; Kuo *et al.*, 1998; Wood *et al.*, 2008; Brown *et al.*, 2009; Mehta, 2009; Child *et al.*, 2016). For example, physical environment characteristics such as green space, street layout, diversity of facilities and provision of porches or balconies (permitting casual surveillance) have been associated with more social interaction, a greater sense of community and social support in adults and older adults (Coley, Sullivan and Kuo, 1997; Bothwell, Gindroz and Lang, 1998; Kuo *et al.*, 1998; Wood *et al.*, 2008; Brown *et al.*, 2009; Mehta, 2009; Child *et al.*, 2016). The quality or condition of the physical environment is also important: higher levels of upkeep in neighbourhoods were related to a 5% higher mean score on a social capital scale, including items on reciprocity, social network, trust and civic engagement, in residents of 3 suburbs in Perth, Australia (Wood *et al.*, 2008). However, although associations exist, the direction of the relationships between the physical environment and social environment is not clear. It is possible that individuals who experience a better quality social environment are more likely to protect or improve their physical environment. Likewise, it may be that the characteristics and quality of the physical environment, such as pleasant communal spaces, generate a higher quality social environment. Moreover, much of the evidence supporting an association between the social and physical environment predominantly comes from American and Australian samples, limiting generalisability (Coley, Sullivan and Kuo, 1997; Bothwell, Gindroz and Lang, 1998; Brown *et al.*, 2009). It is possible that the relationship would operate differently in other populations where different social and cultural factors are at play and there are divergences in the traditions of urban planning, urban design and housing practices. Where social and spatial inequalities in physical activity are apparent, as in the UK, it may be particularly important to differentiate between deprived and non-deprived populations (UK Active, 2014; Bardsley *et al.*, 2017).

Qualitative studies provide initial insight into the potential effect the interplay between the social and physical environment might have on physical activity and indicate the usefulness of simultaneously measuring the social and physical environment in order to effectively evaluate and develop multilevel interventions to increase physical activity. In Belfast, Northern Ireland, 113 parents, adolescents, older adults and community activists participated in 14 focus groups aimed at examining factors that impeded or facilitated the use of local physical activity infrastructure (Prior *et al.*, 2014). Participants revealed that they didn't view physical activity participation as being determined by discrete facilitators and barriers but a "complex web of concerns" including threats of violence, vandalism, actions of neighbours, weather and the wider political environment (Prior *et al.*, 2014). Another study in Ireland, with a sample of 53 adults, explored the reasons behind a null effect for an intervention involving the introduction of walking route improvements and signage (Burgoyne, Coleman and Perry, 2007). The authors found that multiple social and physical environmental barriers persisted in the environment and mitigated the effect of the intervention. For example, anti-social behaviour discouraged route use; an intervention to enhance the physical attractiveness of the route did little to overcome this social barrier.

In addition to examining the interplay between the physical and social environment to understand null effects of interventions (e.g. Prior *et al.*, 2014), or interrogate inconsistencies in the literature which could arise for variance which has not be accounted for (e.g. Foster and Giles-Corti, 2008) simultaneous consideration of the social and physical environment could also help to elucidate counter-intuitive cross-sectional relationships between physical environments and physical activity. For example, walkability (assessed by physical metrics including density, connectivity and land use mix) has been associated with leisure-time and transport-related physical activity in high-income and low/middle-income countries (McCormack *et al.*, 2012; Reis *et al.*, 2013). However, in some studies in Canada and USA, *lower* levels of physical activity were self-reported in areas that were objectively classified as *highly* walkable (according to physical metrics such as connectivity) than in areas that were objectively less walkable (King, 2008; Jack and McCormack, 2014). Such findings raise questions about the importance of quality-related features of the physical environment or aspects of the social environment in ostensibly 'walkable' environments.

1.4.1 Systematic review of literature testing simultaneous and interactive associations of environment on physical activity

Investigating simultaneous or interactive effects of multiple levels of influence (e.g. the social and physical environment) on physical activity could test a key tenet of socioecological models of physical activity while also exploring reasons behind current inconsistencies in the literature (e.g. Foster and Giles-Corti, 2008). To the best of my knowledge, at the time of writing there was no review of research which simultaneously assessed the effect of social and physical environment (as conceptualised for this thesis) on physical activity at the neighbourhood scale.

As such, a systematic review was conducted with the aim to i) synthesise empirical research which simultaneously examined associations between physical activity and both social and physical environmental variables and ii) assess the extent to which social and physical environmental variables have been considered simultaneously and interactively in the literature. In such research, simultaneous examination of physical and social environmental variables might have been achieved using a number of different statistical methods, including multivariate models, structural equation modelling or models examining effect modification (e.g. mediation or moderation) while also testing for direct effects. In each case, effects of social and physical variables on physical activity had to be reported.

A version of this systematic review has been published in *SSM - Population Health* (**Appendix 1.2**) (Sawyer *et al.*, 2017a). The search and results have been updated since publication.

1.4.1.1 Search strategy

PRISMA guidelines informed the design, execution and presentation of the review. Four scientific databases (Ovid MEDLINE, Embase, PsycINFO and Social Policy and Practice) were searched in June, 2017. Reference searches of relevant articles were also performed and original articles were found from conference proceedings obtained in the database search.

Search terms are presented in **Table 1.1**. Search terms were selected to identify literature investigating relevant physical and social constructs and all types of physical activity outcome. In line with the focus of this thesis, search terms pertaining to the social environment encompassed neighbourhood social capital constructs but not constructs relating to neighbourhood social composition, such as socioeconomic status (Moore and Kawachi, 2017). Social variables measuring latent constructs pertaining directly to physical activity (e.g. support for or modelling of physical activity) were not targeted as they were seen to assess individual aspects of socialisation in relation to physical activity, rather than the social environment of the neighbourhood. Such variables are not usually included at the environmental level in socioecological models of activity. Terms pertaining to the physical environment were fairly broad and did not explicitly target transport-related constructs (e.g. access to transit); it was expected that selected search terms would be sufficient to identify research examining these aspects. Owing to an anticipated lack of research, the review was not limited to studies using a sample from deprived neighbourhoods. Additionally, it was not limited to studies using exclusively urban populations, to ensure large studies using national survey samples were not excluded from review.

Table 1.1 Systematic review search terms and syntax

Construct	Search terms
Physical environment	(built environment or physical environment or connectivity or walkab* or neighbourhood or neighbourhood or green space or greenspace or office or workplace or housing or gym or school or community centre or care home or nursing home or park or recreation* facilit* or recreation* space) in abstract OR title
Social environment	(social capital or social control or social* cohesi* or social network or trust or safety or crime or social environment or social interaction or socio-cultural) in abstract OR title.
Physical activity	(physical activity or walk or sedentary or exercis* or sit* or active travel* or active transport*) in abstract or title

Studies had to have the following criteria for inclusion in the review:

- A healthy (non-clinical) adult sample (≥15 years old) residing in rural, suburban or urban neighbourhoods in a developed country (countries);
- A minimum of one social and one physical environmental characteristic included within a single statistical model, with reported results for their association with the outcome;
- Physical activity as a primary outcome;
- Results from quantitative, observational analyses reported in an academic, peer-reviewed journal after the year 1980.

The following data were extracted from selected studies: author(s), publication year, sample characteristics (sample size, urbanity, sex, age group, deprivation characteristics), exposure and outcome measurement tools (subjective/objective), operationalisation of exposure variables and independent and interactive associations between exposures and outcomes in simultaneous analyses. Where both within-neighbourhood and between-neighbourhood results were reported, within-neighbourhood results were reported. It was not possible to compare results from multivariate analyses with results from univariate analyses as univariate results were often not presented. Therefore, conclusions about whether associations were attenuated in multivariate models compared with univariate models could not be drawn.

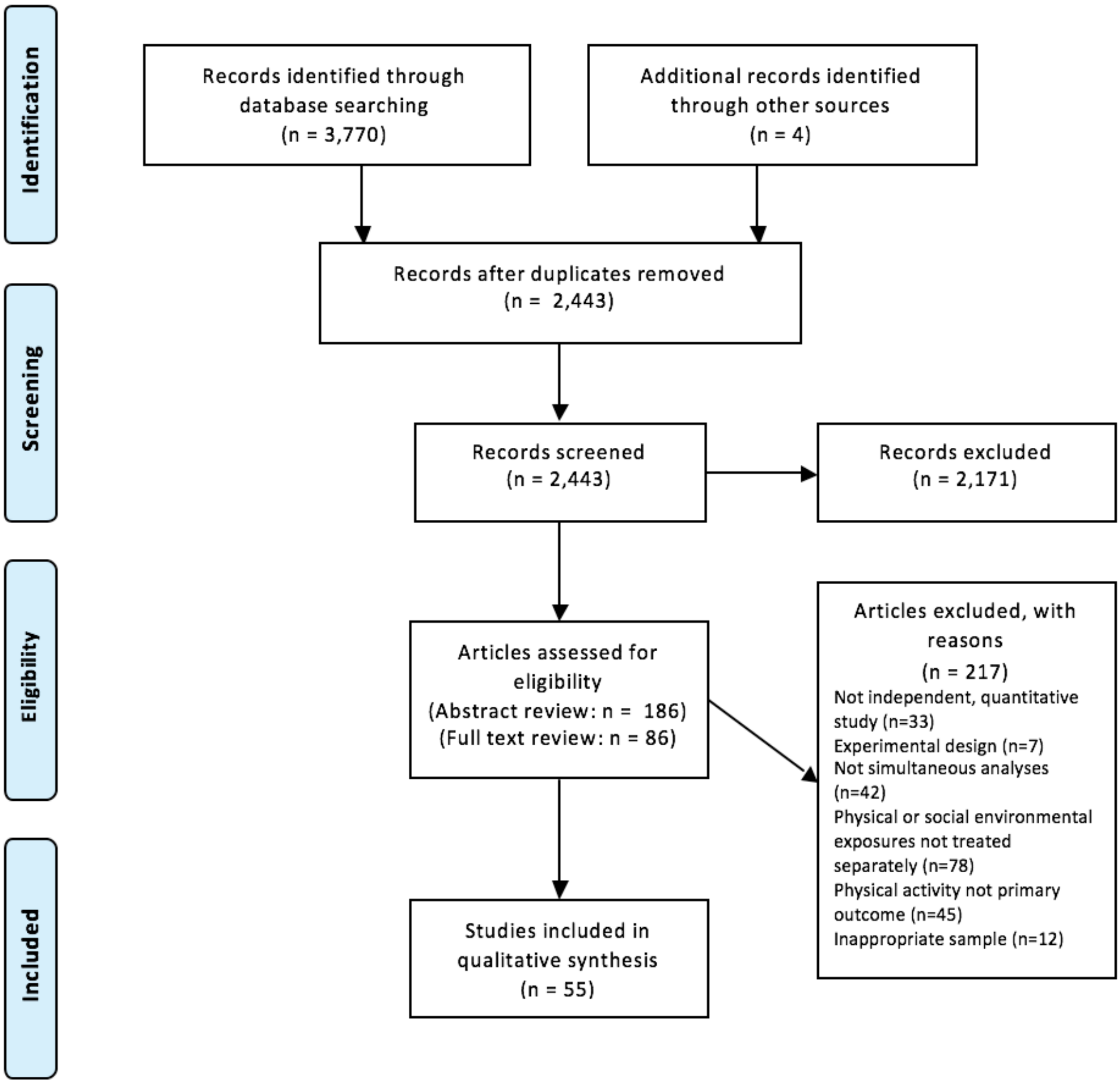
To ensure only studies of sufficient rigour were included in the review, study quality was assessed using an existing tool to appraise the study's research question, theoretical underpinning, design, sampling, context, data collection, statistical analysis, generalisability of results, acknowledgment of study limitations and ethical issues (Croucher *et al.*, 2003, 2013). Studies needed to meet 'essential' criteria to be considered of sufficient quality (**Appendix 1.3**).

I conducted the search of the literature, the screening of study eligibility against inclusion criteria at every stage (title, abstract and full-text), quality assessment and data extraction. My primary supervisor (AF) independently performed the full-text screening. Inter-rater reliability between myself and AF was 94%; disagreements were discussed and resolved.

1.4.1.2 Identified literature

The flow of studies through the review process is shown in **Figure 1.5**.

Figure 1.5 Flowchart depicting the stages of the search process and study selection



The literature search obtained 2,443 independent records. Following title, abstract and full-text screening, 55 studies reporting results from 77 separate statistical models were obtained for inclusion in a narrative review. Study characteristics are presented in **Table 1.2**. It was not advisable to conduct a meta-analysis of studies due to heterogeneity of exposure and outcome variables which could have produced an inaccurate quantification of summary results (Higgins Green, no date). All studies were deemed to be of sufficient quality for inclusion in the review; assessment against the quality criteria is presented in **Appendix 1.2**.

Table 1.2 Characteristics of included studies

Reference	Sample	N	Country	Physical activity outcome	Social environmental measure(s)	Physical environmental measure(s)
Ali *et al.*, 2017	Adults (>19 years); urban	5,034	UK	MPA; self-reported	Subjective	Subjective
Amorim, Azevedo and Hallal, 2010	Adults (20-69 years); urban	972	Brazil	Overall active travel, overall leisure-time; self-reported	Subjective	Subjective
Adlakha *et al.*, 2015	Adults (21-65 years); urban	2,015	USA	Overall; self-reported	Subjective	Subjective
Bird *et al.*, 2009	Older adults (>60 years); urban	333	Australia	Overall; self-reported	Subjective	Subjective
Booth *et al.*, 2000	Older adults (>60 years); urban	449	Australia	Overall; self-reported	Subjective	Subjective
Bracy *et al.*, 2014[β]	Adults (20-65 years); older adults (>66 years); urban	2,068; 718	USA	MVPA; objective (accelerometer); walking active travel, walking leisure-time; self-reported	Subjective	Objective, subjective
Caspi *et al.*, 2013	Adults (>18 years); urban	729	USA	Walking active travel, walking leisure-time; self-reported	Subjective	Objective
Cleland *et al.*, 2010[β]	Women (18-45 years); urban/rural	4,108	Australia	Overall leisure-time; self-reported	Subjective	Subjective
Eichinger *et al.*, 2015	Adults (18-91 years); urban/rural	904	Austria	Overall, overall leisure-time, overall active travel; self-reported	Subjective	Subjective
Fisher *et al.*, 2004[†]	Older adults (64-94 years); urban	582	USA	Walking*; self-reported	Subjective	Objective
Florindo, Salvador and Reis, 2013[β]	Adults (>18 years); urban	890	Brazil	Overall; self-reported	Subjective	Subjective
Foster, Hillsdon	Adults (16-74 years);	4,265	England	Walking; self-reported	Subjective	Subjective

and Thorogood, 2004	urban/rural					
Gomes *et al.*, 2011	Adults (>18 years); urban	6,166	Brazil	Walking leisure-time; self-reported	Subjective	Subjective
Gomes *et al.*, 2016	Adults (>18 years); urban	5,779	Brazil	Overall leisure-time; self-reported	Objective	Objective
Granner *et al.*, 2007	Adults (>18 years); urban/rural	2,025	USA	MVPA, walking; self-reported	Subjective	Subjective
Handy, Cao and Mokhtarian, 2008[β]	Adults; urban	1,682	USA	MVPA*; self-reported	Subjective	Objective, subjective
Heesch, Giles-Corti and Turrell, 2014	Adults (40-65 years); urban	10,233	Australia	MVPA; self-reported	Subjective	Subjective
Huston *et al.*, 2003	Adults (>18 years); urban/rural	1,701	USA	Overall leisure-time; self-reported	Subjective	Subjective
Jack and McCormack, 2014[β]	Adults (>18 years); urban	1,875	Canada	Walking active travel*, walking leisure-time*; self-reported	Subjective	Objective, subjective
Jauregui *et al.*, 2016	Adults (20-65 years); urban	659	Mexico	MVPA; objective	Subjective	Subjective
Jia, Usagawa and Fu, 2014[β]	Adults (15-75 years); urban	1,582	China	Walking active travel, walking leisure-time; self-reported	Subjective	Subjective
Kamphuis, Van Lenthe, *et al.*, 2008 [β]	Adults (25-75 years); urban	3,839	Netherlands	MVPA; self-reported	Subjective	Subjective
Karusisi *et al.*, 2012	Adults (30-79 years); urban	7,105	France	MVPA*; self-reported	Subjective	Subjective
King *et al.*, 2006[β]	Adults (18-85 years); urban	645	USA	Walking active travel, walking leisure-time, MVPA; self-reported	Subjective	Subjective

King, 2008	Older adults (>65 years); urban	190	USA	Overall*; self-reported	Subjective	Objective
Li and Fisher, 2004[β]	Older adults (>65 years); urban	582	USA	Overall*; self-reported	Subjective	Subjective
Lovasi *et al.*, 2013	Adults (>18 years); urban	8,034	USA	Overall active travel; self-reported	Objective	Objective
Mason, Kearns and Bond, 2011[β]	Adults (>16 years); urban	5,657	Scotland	Walking*; self-reported	Subjective	Objective, subjective
Perez, Carlson, *et al.*, 2016	Adults (18-65 years); urban	86	USA	MVPA*; objective	Subjective	Subjective
Perez, Slymen, *et al.*, 2016	Adults (18-65 years); urban	436	USA	Overall active travel; self-reported; MVPA; objective and subjective	Subjective	Subjective
Poortinga, 2006	Adults (>16 years); urban/rural	14,836	England	Walking, MVPA, overall; self-reported	Subjective	Subjective
Prince *et al.*, 2011[†]	Adults (>18 years); urban	3,383	Canada	Overall; self-reported	Objective, subjective	Objective
Prince *et al.*, 2012	Adults (>18 years); urban	4,727	Canada	Overall; self-reported	Objective	Objective
Richardson *et al.*, 2017[β]	Adults; urban	791	USA	MVPA; objective	Objective	Objective
Rohm Young and Voorhees, 2003	Women (20-50 years); urban	234	USA	MVPA; self-reported	Subjective	Subjective
Salvador *et al.*, 2009[β]	Older men (>60 years); urban	152	Brazil	Overall; self-reported	Subjective	Subjective
Strath *et al.*, 2012	Older adults; urban	148	USA	Light, MVPA, overall; objective	Objective, subjective	Objective, subjective
Troped *et al.*, 2011	Women (40-59 years); urban/rural	68,968	USA	Walking, MVPA; self-reported	Subjective	Subjective
Trumpeter and	Adults (>18 years);	290	USA	Walking leisure-time; self-	Subjective	Subjective

Wilson, 2014	urban			reported		
Van Cauwenberg *et al.*, 2017	Adults (55-65 years); urban/rural	2,700	Australia	Walking, MVPA; self-reported	Subjective	Subjective
Van Dyck *et al.*, 2013	Woman (18-46 years); urban/rural	4,139	Australia	Walking leisure-time, walking active travel; self-reported	Subjective	Objective
Van Dyck *et al.*, 2015	Adults (18-66 years); urban	7273	11 countries	MVPA; objective	Subjective	Subjective
Van Holle *et al.*, 2016	Older adults (>65 years); urban	438	Belgium	Walking active travel; self-reported	Subjective	Objective, subjective
Van Lenthe, Brug and Mackenbach, 2005[β]	Adults (20-69 years); urban	8,767	Netherlands	MVPA, overall active travel, overall leisure-time; self-reported	Objective	Objective
Voorhees and Rohm Young, 2003	Women (20-50 years); urban	285	USA	MVPA; self-reported	Subjective	Subjective
Wallmann, Bucksch and Froboese, 2012	Adults (18-65 years); urban	310	Germany	Walking, MVPA; self-reported	Subjective	Subjective
Weber Corseuil *et al.*, 2012[β]	Older adults (>60 years); urban	1,656	Brazil	Overall leisure-time, overall active travel; self-reported	Subjective	Subjective
Wen, Kandula and Lauderdale, 2007	Adults (>18 years); urban/rural	41,545	USA	Walking; self-reported	Subjective	Subjective
Wen and Zhang, 2009[†]	Adults (>18 years); urban	3,530	USA	MVPA; self-reported	Subjective	Objective
Wilbur *et al.*, 2003a	Women (20-50 years); urban	399	USA	MVPA; self-reported	Subjective	Subjective
Wilbur *et al.*, 2003b[β]	Women (20-50 years); urban	300	USA	MVPA; self-reported	Subjective	Subjective
Wilcox *et al.*,	Women (>40 years);	2.338	USA	Overall; self-reported	Subjective	Subjective

2000	urban/rural					
Yuma-Guerrero, Cubbin and von Sternberg, 2017	Women (>15 years); urban/rural	2,750	USA	Overall; self-reported	Subjective	Subjective
Zhou *et al.*, 2013	Adults; urban	478	China	MVPA, overall leisure-time, overall active travel; objective (accelerometer), self-reported	Subjective	Subjective
Zoellner *et al.*, 2012	Adults (>18 years); urban	372	USA	Walking, overall; self-reported	Subjective	Subjective

*Neighbourhood-based physical activity; $^{\beta}$ predominantly deprived sample; † within-neighbourhood results unavailable, therefore between-neighbourhood results are reported. Objective measures of physical activity were all accelerometry.
N.B. Karusisi *et al.* (2012) studied location non-specific and neighbourhood-based physical activity.

There were no studies published before the year 2000 and over two thirds of the studies (n=40) were published in the last 10 years (i.e. since 2007). Nearly half of the studies (n=22) used data exclusively from samples living in the USA and 43 studies were conducted in exclusively urban contexts. Deprived samples were used in 15 studies. Nine studies had a female-only sample and 1 study had a male-only sample. An older adult sample was used in 9 studies, although the definition of an older adult ranged from >60 years old to >66 years old. Sample sizes varied substantially from n=86 to n=8,767; 19 studies had a sample over 3,000 participants. Most studies used self-reported physical activity outcomes (only 8 studies included objective measures), self-reported social environment measures (only 7 studies included objective measures) and self-reported physical environment measures (only 17 studies included objective measures, which were predominantly used to assess structural rather than quality-related aspects of the environment).

Physical or social environmental variables which were deemed conceptually similar (e.g. housing density and housing type, or neighbourhood networks and socialising) were clustered into illustrative categories to facilitate the interpretation of results. Composition of these categories is displayed in **Figure 1.6** and **Figure 1.7**. Independent categories were created for variables which featured in more than 5 studies (i.e. approximately 10% of included studies); 2 variables (WCs and pollution) which appeared in less than 5 studies each but were not conceptually similar to other variables were also treated as independent categories. More categories for physical environmental variables were obtained due to a broader examination of various physical environment characteristics across studies and the wider use of commonly used conceptualisations of social capital which prompted wide-spread use of coherent terminology to characterise social variables.

Figure 1.6 Illustrative categories for physical environment variables

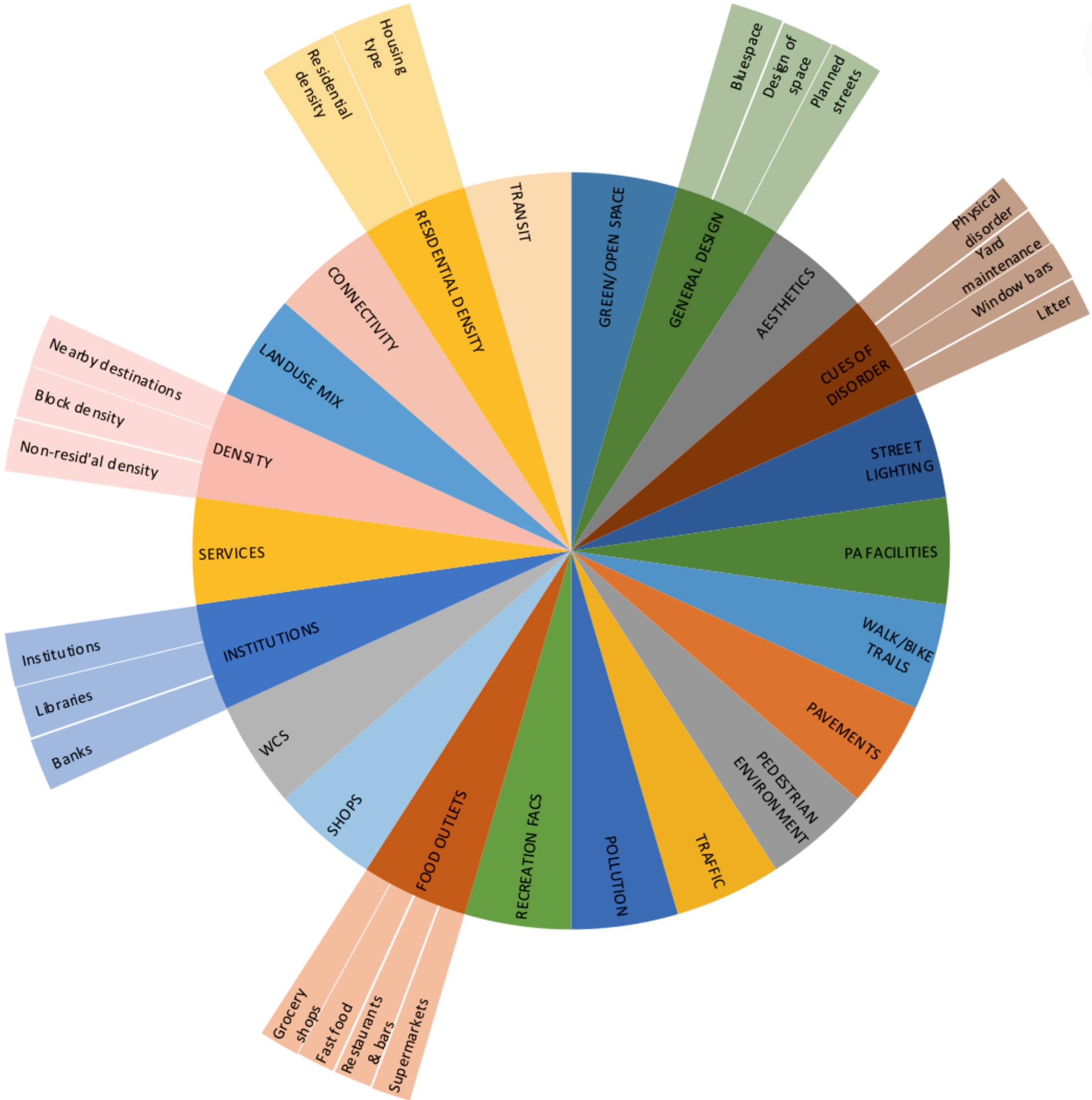


Figure 1.7 Illustrative categories for social environment variables

1.4.1.3 Independent physical environment correlates

Independent associations between physical environment variables and physical activity outcomes are presented in **Table 1.3**. When features of the social environment were simultaneously considered, overall there was weak or inconsistent evidence of an association between walking and variables assessing: outdoor communal space, street condition and physical activity facilities. There was a positive relationship between walking for active travel and perceived access to services including shops, transit stops and post offices (Jack and McCormack, 2014; Jia, Usagawa and Fu, 2014) but a null association was reported for leisure-time walking and access to services (Jack and McCormack, 2014; Jia, Usagawa and Fu, 2014; Trumpeter and Wilson, 2014). There was inconsistent evidence of an association between recreation facilities and overall walking, walking for active travel and leisure-time walking. Similarly, conflicting results were reported for land use mix and self-reported walking for active travel, self-reported leisure-time walking and accelerometry-assessed light-intensity physical activity (King *et al.*, 2006; Strath *et al.*, 2012; Van Holle *et al.*, 2016). Greater connectivity was associated with high levels of walking for active travel in 3 studies (King *et al.*, 2006; Jack and McCormack, 2014; Van Holle *et al.*, 2016); null associations with leisure-time walking were reported in 2 of these studies (King *et al.*, 2006; Jack and McCormack, 2014). When connectivity was included in a 'walkability' index, including aspects such as non-residential density and land use mix, there was a positive relationship with walking for active travel but a negative association with leisure-time walking (Van Dyck *et al.*, 2013; Van Holle *et al.*, 2016).

Table 1.3 Results for separate analyses testing for physical environment variables

		Walking & Light physical activity			MVPA			Overall physical activity		
	Studies(N)	Negative	Null	Positive	Negative	Null	Positive	Negative	Null	Positive
COMMUNAL SPACE										
Green/open space	17		4†	3†		7	4†		7†	2
General design	4						1†		5	2†
Aesthetics	14		6	1†	1	6	4†		7†	2
Cues of disorder	6		4			2		1†	2	2
FACILITIES/AMENITIES										
Recreation facilities	15	1†	5	4†		4	4†		5	3
Food outlets	6		1				1†		5†	1†
Institutions	3		1			1				1
Shops	8		2†	2		1	2		4	2
WCs	1		1			1			1	
Services	4	1†	1	4†		1				1
STREET CONDITIONS										
Pavements	15	1	2	1		8	1	1	8	2†
Pedestrian envir	10		4	2		3	2†		5	
Street lighting	8					4			5	1
Traffic	20		6			9	2	2†	12	
Pollution	4		1			1		2	2	1†
PA FACILITIES										
PA/health clubs/facs	14		1			5	2		1	4
Walk/bike trails	10		3	1		2			10	3
LAND USE										
Density	9		2			6	1		3†	1
Land use mix	7	1	1	2		5	2†		2	1
Resid'l density	4	1	2	1		3	1		1	1
CONNECTIVITY										
Connectivity	9		2	3†		4	3†	2†	2	1†

Walkability index with connectivity	3	1		2			1			
Transit	6		1			6†	1		4	

Table shows number of analyses in each category. † Conflicting results, e.g. results differing in stratified analyses; in these cases, the key result was reported. Physical outcomes were reported individually for studies with multiple physical activity outcomes, e.g. walking for active travel and leisure-time walking. Institutions included public, social, educational, financial or religious organisations. MVPA: moderate-to-vigorous physical activity.

For MVPA, there were some positive relationships between MVPA and green space and aesthetics, but results predominantly revealed non-significant associations. Results were equivocal for associations between MVPA and recreation facilities, pedestrian environment and connectivity. Studies were more consistent in reporting null effects for pavement provision and condition, traffic volume, land-use mix, residential and non-residential density and proximity to transit.

Pollution (capturing perceived air pollution, sewage and objectively measured noise pollution) had a negative association with overall physical activity (Van Lenthe, Brug and Mackenbach, 2005; Florindo, Salvador and Reis, 2013) but a positive association with overall active travel (Van Lenthe, Brug and Mackenbach, 2005). There was relatively strong evidence that physical activity facilities were positively related to overall physical activity. In contrast, only 3 of 13 tested associations between overall physical activity and walking or cycle trials reached significance: Adlakha *et al.* (2015) and Eichinger *et al.* (2015) both reported positive associations with overall leisure-time physical activity, although Adlakha *et al.* (2015) reported a stronger effect on overall active travel than overall physical activity. The only study using data from a sample in China revealed a differential effect of street connectivity on overall active travel (null effect) and overall leisure-time physical activity (negative effect) (Zhou *et al.*, 2013), reflecting reported associations with walking outcomes (King *et al.*, 2006; Jack and McCormack, 2014).

1.4.1.4 Independent social environment correlates

Independent associations between physical environment variables and physical activity outcomes are presented in **Table 1.4**. When features of the physical environment were simultaneously considered, overall there were positive associations between walking and social cohesion and sense of belonging to the neighbourhood. Most studies reported null effects of crime on walking and conflicting results for safety, social networks, composite measures of social disorder (encompassing cues such as police presence and loitering or intoxicated individuals), engagement and trust. Surprisingly, perceived sense of progress for your neighbourhood (i.e. internal reputation) and a composite social capital measure (encompassing social cohesion, trust and reciprocity) were negatively related to leisure-time walking and overall walking (Mason, Kearns and Bond, 2011; Caspi *et al.*, 2013). However, the composite social capital measure had a positive association with walking for active travel (Caspi *et al.*, 2013).

Table 1.4 Results for separate analyses testing for social environment variables

		Walking & Light physical activity			MVPA			Overall physical activity		
	Studies(N)	Negative	Null	Positive	Negative	Null	Positive	Negative	Null	Positive
SOCIAL CAPITAL										
Capital	2	1†		1†			1†			
REPUTATION										
External reputation	1			1						
Sense of progress	1	1								
SOCIAL NETWORK										
Networks	7	1	2	1	1		4		2	
TRUST & EMPOWERMENT										
Trust	2	1		1			1		1	
Trust & cohesion	1			1†		1				
Engagement	4	1		1			1		2	1
COHESION & SAFETY										
Cohesion	12		2	4		1	3		5†	2
Belonging	5			4			1		1	1†
Crime	25	2†	7		6†	10†		4	13†	1
Safety	24	2	7†	5†		4	1†	2†	4	6†
Disorder	7	2	2	1	1	5			1	

Table shows number of analyses in each category. † Conflicting results, e.g. results differing in stratified analyses; in these cases, the key result was reported. Physical outcomes were reported individually for studies with multiple physical activity outcomes, e.g. walking for active travel and leisure-time walking. Institutions included public, social, educational, financial or religious organisations. MVPA: moderate-to-vigorous physical activity.

Studies revealed more consistent positive associations between MVPA and social networks. Single studies reported a positive effect of trust, engagement and a composite social capital measure on MVPA and a null association between a composite score for trust and engagement and MVPA, but it is difficult to draw conclusions owing to the paucity of research. More studies examined the relationship between MVPA and crime, safety and social disorder, but associations rarely reached significance.

There were also predominantly null associations between overall physical activity and objectively-measure crime. The effect of safety on overall physical activity was equivocal: 6 of the tested associations were in the expected positive direction, while 4 were null and 2 were in a negative direction. Finally, an inconsistent set of results were reported for examined relationships between overall physical activity and social cohesion (Li and Fisher, 2004; King, 2008; Cleland *et al.*, 2010; Eichinger *et al.*, 2015); sense of belonging to the neighbourhood (Prince *et al.*, 2011, 2012); and engagement (Poortinga, 2006; Prince *et al.*, 2011, 2012). Only null effects were reported for an effect of social networks (Poortinga, 2006; Bird *et al.*, 2009).

1.4.1.5 Simultaneous and interactive environmental influences

Table 1.5 presents the number and percentage of statistical models which had both statistically significant social and physical environmental correlates of walking (48% of models), MVPA (42% of models) and overall physical activity (33% of models). Studies reported fewer models with only physical environmental correlates, only social environmental correlates or neither social nor physical environmental correlates for walking and MVPA, suggesting social and physical correlates operated simultaneously on these outcomes. There was an equal number of models with both social and physical environmental correlates (33%) and only physical environmental correlates (33%) for overall physical activity. There were fewer models with only social environmental correlates across physical activity outcomes; this might be in part due to the inclusion of fewer social variables in models. Most models which tested interactive effects were for walking; a majority of these models (71%) reported an interactive effect of social and physical environmental correlates on the outcome. There was less evidence of interactive effects of the social and physical environment on MVPA (33% of models) and overall physical activity (50% models). Of the 77 statistical models across 55 studies included in this review, only 12 models from 7 studies included interactive terms for social and physical environmental exposures.

Table 1.5 Significance of physical and social correlates across models with different physical activity outcomes

Significant correlates	Walking N (% of models)	MVPA N (% of models)	Overall PA N (% of models)
Both physical and social	13 (48.1)	11 (42.3)	11 (33.3)
Physical only	8 (29.6)	6 (23.1)	11 (33.3)
Social only	2 (7.4)	2 (7.7)	4 (12.1)
Neither	4 (14.8)	7 (26.9)	7 (21.2)
Interaction*	5 (71.4)	1 (33.3)	1 (50.0)

*Interaction terms were included for 12 models with walking (n=7), MVPA (n=3) and overall PA (n=2) as outcomes. The denominator used to calculate percentages for 'both physical and social', 'physical only', 'social only' and 'neither' rows is the number of models for each physical activity outcome. The denominator used to calculate percentages for the 'interaction' row is the number of models with interaction terms for each physical activity outcome. PA: physical activity; MVPA: moderate-to-vigorous physical activity.

Five studies explored an intervening role of crime or safety (King, 2008; Van Dyck *et al.*, 2013; Bracy *et al.*, 2014; Jack and McCormack, 2014; Perez *et al.*, 2016). Perez *et al.* (2016) revealed a significant interactive effect of pavement maintenance and safety on performing objectively-measured neighbourhood-based MVPA, with maintenance only increasing activity in participants who perceived their neighbourhoods as safe (Perez *et al.*, 2016). Similarly, aesthetics was only positively related to performing any daily MVPA in participants who reported high levels of social cohesion within in this sample of 86 adults in the USA (Perez *et al.*, 2016).

Two other studies found an interactive effect between perceived crime and a composite score of walkability constructed from a number of metrics including non-residential density, connectivity and access to transit). In a sample of 1,700 adults living in deprived urban neighbourhoods in Canada, perceptions of crime were lower in neighbourhoods classified as highly walkable by objective measurement (Jack and McCormack, 2014). However, self-reported walking for active travel in the neighbourhood was significantly decreased in participants who perceived greater levels of crime in neighbourhoods which were highly-walkable – not in neighbourhoods with middle or low levels of walkability.

The majority of interactive terms tested by Bracy *et al.* were non-significant although an interactive effect of walkability and crime on objectively-assessed MVPA reached significance (Bracy *et al.*, 2014). In a sample also drawn from deprived neighbourhoods in North America, the authors observed that among participants reporting low levels of crime in the neighbourhood, participants living in neighbourhoods deemed highly walkable by objective measurement increased their likelihood of performing on average 91 additional minutes of MVPA/week compared with those in neighbourhoods which were deemed to have low levels of walkability. There was a significantly smaller difference in MVPA in participants who reported high levels of crime and lived in neighbourhoods with high walkability (performing on average 38 additional minutes/week) compared with low walkability.

In another deprived context, in Australia, perceived safety and social cohesion were also reported to partially mediate a significant relationship between GIS-assessed walkability metrics including connectivity and non-residential density (in this instance: supermarkets, food outlets, playgrounds and physical activity facilities) on leisure-time walking but not walking for active travel in a sample of women (Van Dyck *et al.*, 2013). Perceived safety explained 20% of the reported effect of walkability on leisure-time walking, suppressing any significant effect of the physical environment variable, while social cohesion was found to explain less but still a substantial amount (13%) of the effect of walkability.

Finally, perceived safety from crime mediated an association between overall neighbourhood-based physical activity and garden maintenance in 645 older adults living in Denver, USA (King, 2008). In addition, Sobel's test of mediation was used to identify a modifying effect of social cohesion in the relationship between activity and window bars, garden maintenance and litter. Inclusion of these two social variables in the statistical model rendered associations between activity and window bars and garden maintenance non-significant.

Two studies examined the role of social cohesion in hypothesised relationships between park (e.g. green space) access and activity. Van Cauwenberg *et al.* (2017) reported no main effect of park proximity but did observe an interactive effect of park proximity with a composite measure of trust and social cohesion. In 2,700 adults aged 55-65 years living in Australia, those with higher level of perceived trust and cohesion in their neighbourhood and who perceived a shorter distance to the nearest park were more likely to engage in higher levels of self-reported walking; there was no such effect on MVPA (Van Cauwenberg *et al.*, 2017). Another study from 2017, but conducted in the USA in a similarly large sample (n=2,750), found no main effect of park proximity to self-reported overall physical activity, nor a mediating effect of self-reported social cohesion (Yuma-Guerrero, Cubbin and von Sternberg, 2017). However, the authors did report a main effect of safety on activity, which operated partly through social cohesion, indicating a possible pathway of influence for these variables.

Other studies were excluded from the review at full text screening because they did not report associations for social or physical environment and physical activity. However, they add to preliminary evidence on interactive effects. For example, Foster *et al.*'s (2016) longitudinal study of environmental effects on physical activity over 7 years of the RESIDential Environment Study (RESIDE) in Australia found that the association between perceived safety and neighbourhood-based walking was attenuated (although retained significance) when social cohesion and objectively-measured physical variables (i.e. aesthetics, lighting and traffic volume) were entered into the model.

In a large sample of 23,693 adults in Sweden, a positive association between objectively measured green space quality and self-reported overall physical activity was only observed in adults who perceived their neighbourhood as safe; a negative association was revealed in adults who perceived their neighbourhood as unsafe (Weimann *et al.*, 2017). It is noteworthy that the vast majority of adults perceived their neighbourhood as highly safe (92% of males and 80% of females) (Weimann *et al.*, 2017). Also investigating interactive effects with safety, in a sample of 380 adults in Canada, Kaczynski and Glover (2012) revealed the highest levels of leisure-time walking were in participants who perceived their neighbourhoods as highly-walkable and socially-connected (a composite measure of social cohesion and trust), although walkability appeared to be more important in predicting walking for active travel. Furthermore, crime was found to mediate an effect of recreational facilities on self-reported MVPA in adults in Chicago (Berchuck *et al.*, 2016). However, there was spatial heterogeneity in the mediating effect: it was only evident in neighbourhood in south Chicago which historically are more deprived and ethnically-diverse with higher crime rates (Berchuck *et al.*, 2016).

Finally, Van Holle *et al.* (2016) reported a 3-way interaction between neighbourhood income, GIS-assessed walkability (i.e. connectivity, residential density and land use mix) and a self-reported composite of social trust and cohesion on accelerometer-assessed MVPA. In this sample of 431 older adults in Belgium, a negative association between social trust and cohesion and minutes of MVPA was elicited in participants living in low-income neighbourhoods which were highly walkable. In this context, compared with participants reporting a better social environment, those reporting a poorer social environment (trust and cohesion) obtained over 90 minutes more MVPA/week. However, in highly-walkable neighbourhoods, participants reporting more diversity in the social composition of their neighbourhood accumulated on average 57 additional minutes of walking for active travel than those those reporting a lack of social diversity. In neighbourhoods with low walkability, non-significant associations were reported between social environment and MVPA and between social diversity and walking for active travel (Van Holle *et al.*, 2016).

1.4.1.6 Neighbourhood-based physical activity

Neighbourhood-based physical activity was the primary outcome in 8 of 55 studies; 3 assessed walking (Fisher *et al.*, 2004; Mason, Kearns and Bond, 2011; Jack and McCormack, 2014), 3 assessed MVPA (Handy, Cao and Mokhtarian, 2008; Karusisi *et al.*, 2012; Perez *et al.*, 2016) and 2 assessed overall physical activity (Li and Fisher, 2004; King, 2008). Although there was some support for more consistent relationships with activity at the level of environmental categories (e.g. common space), it was not possible to draw reliable inferences from the few studies which had heterogeneous exposure and outcome measures.

1.4.1.7 Group differences

There were some reported sex differences (Wen and Zhang, 2009; Prince *et al.*, 2011; Jia, Usagawa and Fu, 2014; Trumpeter and Wilson, 2014; Eichinger *et al.*, 2015; Van Dyck *et al.*, 2015) and age differences (Van Dyck *et al.*, 2015) in salient environmental features for activity. However, there were no obvious patterns between study results and sample characteristics (age, sex, deprivation) or measurement tools (e.g. self-reported or objective measurement). One study conducted in 659 adults living in urban areas of Mexico elicited differential effects of the aesthetics of the physical environment across neighbourhood SES, whereby an effect of aesthetics on objectively-assessed MVPA was only revealed in low-SES neighbourhoods (Jauregui *et al.*, 2016). Although a cursory presentation of group differences is provided here, assessment of the interaction between sample characteristics and environmental variables was not within the scope of this review.

1.4.1.8 Insight and implications of systematic review

In conclusion, the 55 studies included in this review provided inconsistent evidence for independent effects of individual social and physical environmental variables on physical activity when the other level of the environment (social or physical) was simultaneously considered. For physical environmental variables, there was some evidence of a positive relationship between physical activity facilities and overall activity and walking, but weaker support for an effect of communal space and street condition. The role of the physical environment (in particular, connectivity, service access and pollution) in leisure-time and active travel appeared to differ in presence and direction of an effect, supporting domain-specificity of environmental influence as posited in socioecological models (Sallis *et al.*, 2006). For social environmental variables, there was some consistent evidence for a positive effect of social cohesion (the most examined correlate along with safety and crime) and sense of belonging on levels of walking, MVPA and overall activity.

While there was limited support for significant effects of individual variables, when assessed together, studies more frequently revealed simultaneous effects for both social and physical environmental variables than only social, only physical or neither type of variable, strengthening the hypothesis for multiple levels of neighbourhood environmental influence on physical activity. However, statistical models were rarely 'balanced' and fewer social environmental variables were included in analyses than physical environmental variables, suggesting more research has examined the role of the neighbourhood physical environment on physical activity.

Only two studies investigated the association between walking and trust and engagement (i.e. participation in neighbourhood organisations and activities) (Poortinga, 2006; Mason, Kearns and Bond, 2011), reporting conflicting results: Poortinga (2006) reported a positive association with the social environment measures while Mason, Kearns and Bond (2011) found a negative association with neighbourhood-based walking, using data from the first wave of the GoWell programme. The studies were both conducted in the UK and used single-item measures for their exposures; however, Poortinga (2006) used a sample of adults in owner-occupied accommodation while Mason, Kearns and Bond (2011) used a sample living in predominantly socially-rented accommodation in income-deprived neighbourhoods. Owing to the cross-sectional nature of the data, Mason, Kearns and Bond (2011) suggested reverse causality might have underpinned a negative association whereby participants accumulating less activity in their neighbourhood were less exposed to features of the environment determining lower perceptions of trust in those who were active. This finding garners support from Van Holle *et al.*'s (2016) study which also found a negative association between perceived trust and MVPA in low-income, highly walkable neighbourhoods in Belgium. Interpretation of such results would be helped by causal inferences afforded by qualitative and longitudinal studies which are better able to understand the temporal order of associations and conditions under which effects manifest. There were inconsistent results between studies examining crime or safety. This was not a surprising finding and reflects previous reviews exploring the role of neighbourhood safety and crime in physical activity (Foster and Giles-Corti, 2008; da Silva *et al.*, 2016).

Although recent systematic reviews provide evidence of associations between physical activity and features of the neighbourhood social environment (Samuel, Commodore-Mensah and Himmelfarb, 2014) and physical environment (McCormack and Shiell, 2011; Astell-Burt, Feng and Kolt, 2014), null or inconsistent findings were commonly reported in the 55 studies in this review. Indeed, null associations may have been under-reported here due to step-wise approaches and the removal of non-significant exposure variables after univariate analyses, meaning they would not have been reported in this review of multivariate analyses.

The overwhelming inconsistency and lack of effect of physical variables may be attributable in part to the focus of the review: studies which simultaneously assessed the influence of social environmental variables. However, it is speculative to suggest that accounting for physical or social variables contributed to the observation of null effects, as a comparison of the importance of social or physical variables is not possible without estimating differences between univariate and multivariate models or standardised adjustment of specific social correlates across studies. Moreover, a greater number of physical environmental variables were included in analyses, making multicollinearity or over-adjustment of models a more pertinent issue for physical variables. Methodological limitations potentially amplified by the complexity of pathways of association could also be obstructing the observation of real effects. This review identified several methodological issues which should be ameliorated in future research.

Firstly, insufficient sensitivity and specificity in investigations could obscure identification of significant associations. Matching the geography of the exposure and outcome measures by using corresponding geographical boundaries is likely to increase the sensitivity to detect hypothesised environmental effects: physical activity performed in the neighbourhood is arguably more likely to be influenced by the neighbourhood environment (Giles-Corti *et al.*, 2005). When measuring perceptions of the environment or using self-reported measures, this could be achieved by presenting participants with pre-determined neighbourhood boundaries (especially if measures are used alongside objective measures using the same boundaries) or asking participants to self-define their neighbourhood using specified guidelines, for example, the area within a 5-10 minutes' walk from their home (Smith *et al.*, 2010). Recently, there is growing interest in using 'activity space' to define participants' neighbourhoods (Boruff, Nathan and Nijenstein, 2012). One approach to creating individualised neighbourhood 'activity spaces' is to pair accelerometry data with Global Positioning System (GPS) data to map the size and shape of local spaces which are used by the participants, permitting researchers to obtain corresponding geocoded objective data on the environment (Boruff, Nathan and Nijenstein, 2012). Only 8 of 55 studies in this review used neighbourhood-based physical activity outcomes, highlighting the scope for future research to optimise sensitivity by using such outcomes.

Increased specificity in the operationalisation of environmental variables and conceptualisation of associations between the environment and activity in multiple contexts and groups would also be valuable. For example, in older adults in Denver, USA, self-reported neighbourhood-based physical activity was significantly associated with the presence of window bars but had no association with neighbourhood-watch signs (King, 2008). Divergent results illustrate the need for careful operationalisation of variables: while both variables measure crime prevention strategies, there was a differential effect of a collective surveillance strategy (neighbourhood-watch signs) and an individual strategy using physical obstruction (window bars). However, specificity of measures must be balanced with the need to organise the literature and reduce the current heterogeneity in measures, which restricts quantitative synthesis of the research. In their 2010 systematic review of the physical environment and obesity, Feng *et al.* (2010) recommended the use of clearly-defined composite scores of the physical environment to facilitate comparison across studies while also permitting future research to examine specific features of these scores. With the exception of walkability indices (usually assessing connectivity, density and land-use mix), composite measures are not used widely or in multiple contexts and can be very broad (e.g. ‘environmental quality’ which encompassed appearance, location, safety, walking opportunities, air quality and quietness) (Stronegger, Titze and Oja, 2010). Such scores should be theoretically and analytically coherent; for example, using factor analysis to assess which measures share variance and load onto a factor measuring a singular environmental dimension. As such, measures of potentially disparate environmental dimensions (e.g. window bars and neighbourhood-safety signs) would not be included in a single composite score.

In addition to specificity of variables, reviewed research also underscores potential advantages of context- and group-specific approaches to the conceptualisation and examination of environmental influences on activity. Importantly, the salience, direction and strength of environmental correlates could vary across neighbourhood income or deprivation. In Van Dyck *et al.* (2013) study with 4,139 women in 40 income-deprived neighbourhoods in Australia, objective walkability metrics operated partly through perceived social cohesion, safety and physical aesthetics to affect leisure-time walking. The authors suggested that the social environment and micro-scale features of the physical environment could ‘override’ macro-scale, structure aspects of the physical environment which otherwise create ostensibly walkable environments in this context. Spatial heterogeneity of associations observed in Chicago by Berchuk *et al.* (2016) and interactive influences of neighbourhood income observed by Jauregui *et al.* (2016) further underline the importance of context-specific investigation of effects.

Secondly, this review underlined a need to use existing evidence to further conceptualise pathways of influence between environmental correlates and physical activity. Conceptualisation would aid the use of appropriate statistical analysis to test hypothesised direct and indirect effects. While there were a reasonable number of studies examining simultaneous influences of the social and physical environment on physical activity, only 1 in 8 of these studies explored interactive effects. This finding provides empirical support to observations that while there is a move in the literature towards the integration of environmental influences in multivariate analyses, there is a paucity of research examining the interaction of these influences (Nelson *et al.*, 2008; Gubbels *et al.*, 2014). However, studies which did examine interactive effects afforded preliminary insight into the potential complexity of the pathways through which the neighbourhood environment might influence physical activity and help to elucidate current inconsistencies arising from unaccounted for variance. Alongside calls from other researchers (Nelson *et al.*, 2008; Gubbels *et al.*, 2014; Rutter, Glonti and Lakerveld, 2016), this review identified the interrogation of a central tenant of socioecological models - that multiple, interactive influences of the environment operate on physical activity – as a priority for future research.

The conclusions that can be drawn from this systematic review are limited in several ways. Firstly, it was not possible to meta-analyse study results to obtain pooled effects of environmental variables on physical activity as studies were too heterogeneous is exposure and outcomes; as the literature in this area grows and converges on common measurement and operationalisation this might become a possibility. Secondly, the review aimed to explore hypothesised relationships between social or physical environmental variables (i.e. two levels of environmental influence) and physical activity while accounting for the other level of environmental influence; however, the specific environmental variables accounted for in models were not consistent across studies, rendering it unviable to estimate the comparative importance of social environmental and physical environmental variables. This limitation is unavoidable due to the breadth and variety of the literature but should be recognised in the interpretation of review findings.

Despite the limitations, this systematic review evidenced the value of interaction analyses in elucidating direct and indirect effects of the neighbourhood social and physical environment on activity. Addressing additional methodological limitations of the wider literature will also facilitate hypothesising and testing potential pathways of neighbourhood influence on activity in order to ultimately identify effective targets for intervention. Using a theoretical basis to conceptualise potential mechanisms underlying contextual neighbourhood environment effects on physical activity is also necessary to advance the field (Nelson *et al.*, 2008). However, as demonstrated in this review, there remains a lack of research conceptualising and testing interactive environmental effects on physical activity.

1.5 Logic model of neighbourhood environmental influences on neighbourhood-based physical activity in deprived communities

A logic model was developed to support the structure of this thesis. It was developed in light of the review of the literature of independent, simultaneous and interactive effects of the neighbourhood environment on physical activity, reported in **Sections 1.3** and **1.4** and a review of relevant theories described in **Section 1.2.2**. The model is a hypothetical schematic of putative relationships. Logic models are used to describe components of progress from an input to an outcome. Rather than being explanatory models of pathways to change (e.g. why or how events occur, as would be explained in a theory of change or conceptual framework), they represent and describe the core components (inputs and outputs) that contribute to defined outcomes, in the order in which they can act upon those outcomes. Logic models are useful in aiding critical thinking of the process and influence of distal, intermediate and proximal influences on an outcome; this can facilitate study design (i.e. hypothesis development) and conceptual interpretation of results. It can also provide a context within which the focus of a specific study can be understood. The setting of thesis studies in this logic model is discussed at the end of the study and drawn together in **Chapter 8**. The aim was to provide a schematic of findings, rather than to develop a conceptual framework of tested associations. The logic model is oriented in a socioecological approach to the study of neighbourhood-based physical activity. The rationale for this focus is expounded below.

As reported in **Section 1.2**, models developed by Sallis *et al.* (2006) propose that individual, social, physical and political factors affect physical activity through independent and interactive pathways of influence. Social and physical environments are presented as complex entities whereby focus on one part of the environment to the neglect of other unresolved barriers to physical activity may be insufficient to elicit sustainable behaviour change (Belon *et al.*, 2014).

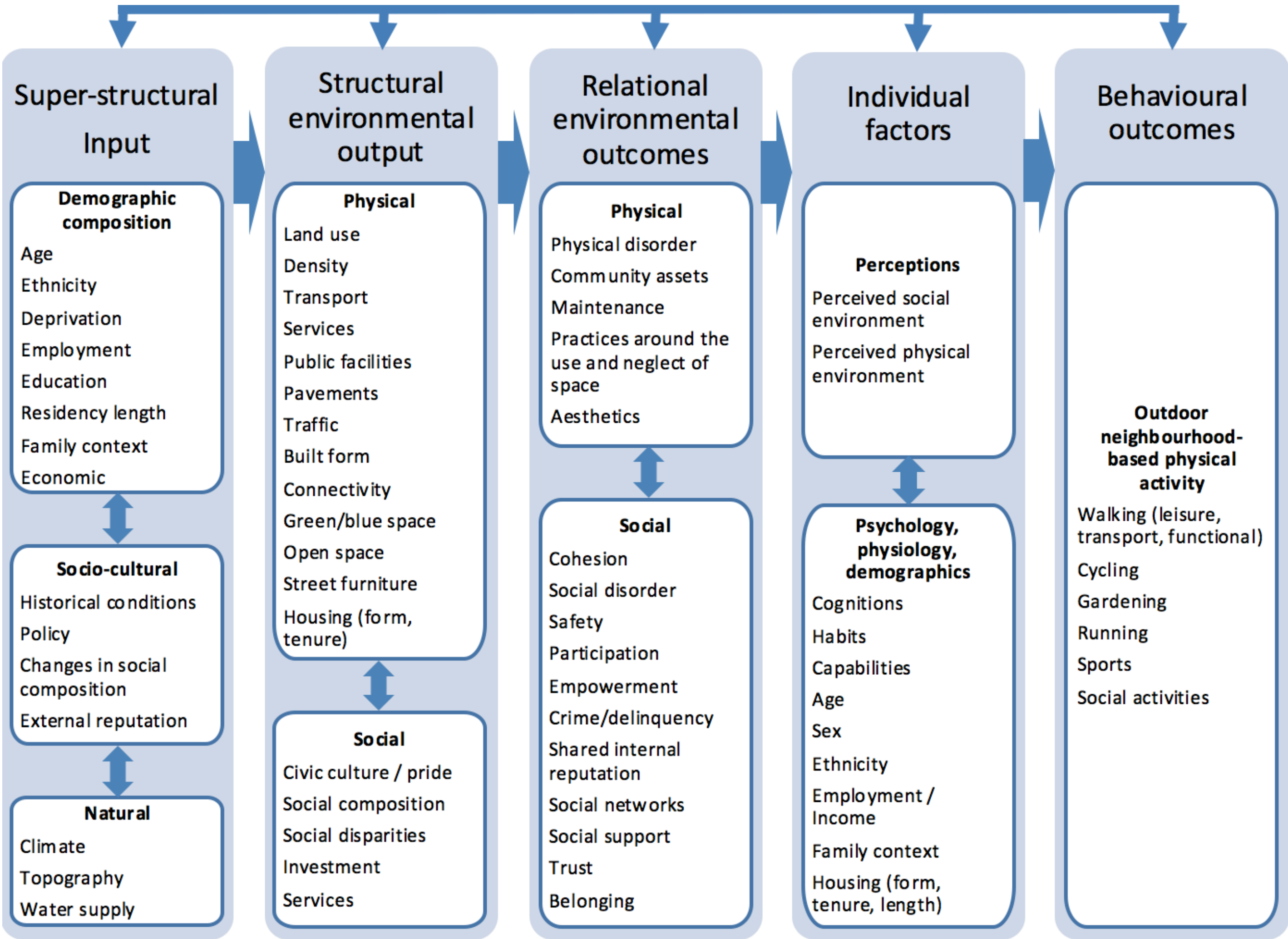
There is a growing recognition of a need to focus on complex mechanisms through which features of the environment may exert interactive and reciprocal influences on physical activity (Nelson *et al.*, 2008; Gubbels *et al.*, 2014; Tremblay and Richard, 2014; Rutter, Glonti and Lakerveld, 2016). Gubbels *et al.* (2014) highlight that, despite a growth in the number of studies which recognise the multivariate and multilevel structure of socioecological influences on physical activity, there is limited interrogation of interactive environmental influences; they state: "*integration is not synonymous to interaction… the relationships between these contributors are often ignored in these studies. By doing so, they disregard the assumption of interaction between behavioural determinants that is right at the core of a true ecological perspective*". Furthermore, Tremblay & Richard (2014) state that "*systems cannot be defined according to their constituent components: the whole is greater than the sum of its parts*" and highlight the need to examine dynamic, non-linear and adaptive relationships in the determinants of health behaviours. Additionally, such an approach speaks to the suggestions for the next steps in the field of obesogenic environments, the researchers from the Sustainable Prevention of Obesity through Integrated Strategies study (SPOTLIGHT; an international consortium investigating cross-country associations between environment and obesity-related behaviours) assert that future research must address the complexity of relationships between environmental influences and outcomes (Rutter, Glonti and Lakerveld, 2016). Finally, a principal finding from the systematic review presented in **Section 1.4** was the paucity of research examining interactive effects of neighbourhood environmental factors on physical activity, providing empirical support to calls from other researchers.

A focus on deprived communities acknowledges that specificity of context is an important consideration when examining the scale of place effects on health: "*rather than their being one single, universal 'area effect on health' there appear to be some area effects on some health outcomes, in some population groups, and in some types of areas*" (Macintyre, Ellaway and Cummins, 2002). The systematic review presented in this chapter also highlights the advantages of examining neighbourhood environmental effects within a context defined by specific characteristics (e.g. geography, deprivation, demography). The hypothesis is that the salience and mechanisms operating between factors might vary in a context-specific manner, whereby certain factors and mechanisms would be heightened in deprived contexts.

Finally, as discussed in the summary for the systematic review, focusing on context-specific behaviour enhances the sensitivity to assess the impact of environmental factors. This logic model therefore conceptualises neighbourhood environmental effects on neighbourhood-based physical activity. Physical activity is conceptualised at every level of intensity and domain, but acknowledges that a priority within the field is moving adults from inactivity to any level of physical activity; therefore, walking and moderate physical activity were the primary outcomes in this thesis (Kopperstad *et al.*, 2017).

In light of these considerations, the logic model of environmental influences on neighbourhood physical activity in deprived communities, developed for this thesis, is presented in **Figure 1.8**. It includes: super-structural factors (input); structural environmental factors (input); relational environmental factors (output); individual factors (output) and physical activity outcomes.

Figure 1.8 Logic model of neighbourhood environmental influences on neighbourhood-based physical activity in deprived communities



'Super-structural input' factors are compositional variations in general demographic, socio-cultural and natural conditions. Demographic compositional factors could include factors such as the proportion of residents who are adults employed within a specific industry requiring a certain level of education, and therefore in receipt of a certain income. Socio-cultural factors could include historical industry in an area that may have changed over the years, generating a shift in the population (e.g. workers leaving the area) and the external reputation of the area (e.g. a post-industrial area in decline). Natural factors may include the positioning of the locality to natural assets or other localities. Super-structural factors encompass physical features which are shared by all individuals residing in a broad locality, as described by Macintyre, Ellaway and Cummins (2002).

'Structural environmental output' factors are contextual factors pertaining to a neighbourhood's social and physical infrastructure. In terms of the physical environment, these factors are at the level of urban planning and design and include the density of commercial and residential uses and the design of the built form (e.g. high-rise or low-rise flats) or the investment in services and resources tied to the physical environment (e.g. transportation). In terms of the social environment, structural factors pertain to the investment in social services and investment and engagement in the area by decision makers. Structural factors also describe the level of difference in composition (e.g. income inequality). Such factors could contribute to affordances within the environment such as ease of walking between residential and employment destinations, where the environment has sufficient land-use mix, a connective street design and opportunities for employment in the local area. Structural factors correspond to the material and infrastructural resources which Macintyre, Ellaway and Cummins (2002) refer to as opportunity structures emerging from the local social and physical environment.

'Relational environmental outcome' factors describe the collective use or function of the shared physical and social environment. In terms of physical factors this describes whether residents maintain the physical features (e.g. not littering, maintaining gardens) and whether individuals feel inclined to use or neglect shared space (e.g. alley ways, shared garden space or green space) or use certain spaces for particular uses (e.g. dog walking, anti-social behaviour) or during particular times (e.g. used during day-time only). In terms of social factors, this describes individuals' propensity to engage and develop local social capital, i.e. the relationships and resources shared between residents, and behavioural norms. Practices and valuations are specific to 'behaviour settings' and the perceived 'affordances' within a context. It acknowledges that the use of specific areas in specific ways may be stigmatizing or elicit social judgments, e.g. littering in the street or socialising in communal areas, and thereby acknowledge the social meaning attached to space.

'Individual factors' include psychological factors contributing to neighbourhood-based physical activity. Psychological determinants of behaviour are included at this stage, drawing on the COM-B model of behaviour. This model states that an individual must have the physical and psychological capability, physical and psychological opportunity and motivation to perform a behaviour and that behaviours are determined by automatic and reflective processes (Michie, van Stralen and West, 2011). Previous research has demonstrated a relationship between these psychological constructs and neighbourhood-based physical activity (McCormack *et al.*, 2013). Perceptions of the environment are also conceptualised as an individual factor. As referred to in Bandura's social cognitive theory (discussed in **Section 1.2.2**), perceived and objective measures of the environment differ in important ways and can be influenced by individual characteristics (Orstad *et al.*, 2016); as such, they are separated in the logic model. While perceptions capture lived experiences of the neighbourhood and could be influenced by individual factors such as physical and mental health, objective measures are not. For example, Ferreira *et al.*'s systematic review reported that perceived safety was not associated with adolescents' physical activity while objective measures of crime were inversely associated (Ferreira *et al.*, 2007). Within the GoWell programme, Mason, Kearns and Livingston (2013) reported similar findings, with a positive relationship between perceived personal safety and self-reported walking but a non-significant relationship between objective crime and walking after adjusting for covariates. In terms of the physical environment, Macintyre, Macdonald and Ellaway (2008) revealed significant differences in objective distance and perceived distance to public green space in adults residing in Glasgow. In the USA, discordance between perceived and objective measures of the physical environment was greater in adults who had attained lower levels of education, held more negative perceptions of the local environment and lived in urban neighbourhoods, indicating the influence of socio-demographic factors on perceptions of the environment (Bailey *et al.*, 2014). Finally, in a cross-European analysis in urban areas of 5 countries, Mackenbach *et al.* (2016) found that social cohesion explained 52% of a difference in neighbourhood perceptions between deprived and non-deprived neighbourhoods. These findings support separate consideration of perceived and objective measures of the environment.

Social and physical factors are considered simultaneously at each stage of the logic model (e.g. social and physical factors within relational factors), acknowledging the reciprocity between people and place as propositioned by Cummins *et al.* (2007), whereby individuals and the neighbourhood environment interact and recursively influence one another throughout the system. Arrows depict feedback loops and recursive relationships within and between each component in addition to depicting direct influences of earlier components of the logic model on physical activity. As such, the logic model attempts to represent factors underpinning a complex system of influences on physical activity in deprived neighbourhoods.

An example of a progression through the logic model might be: super-structural factors determine the positioning of a neighbourhood close to riverbank which historically provided opportunities for industry, leading to dense composition of local communities who travel to work within the neighbourhood. In turn, structural factors determine the investment from local authorities to develop a walking path alongside the riverbank.

Relational factors then determine the use and condition of the walking path, according to the prevailing local social and cultural environment and maintenance of the path and also the behaviours that are (in)formally sanctioned, e.g. graffiti, loitering and whether the walking path is safe and a desirable place to visit. As time proceeds, the perceived social and physical maintenance of the walking path may encourage more pro-social behaviour in that environment, discouraging litter or graffiti. Together, these factors create a place that supports walking and physical activity within that part of the neighbourhood for that population.

1.5.1 Focus within the logic model for original studies in this thesis

Within deprived contexts, there is a growing recognition of the potential role of the quality and condition of environments in creating activity-supportive neighbourhoods (Wilson *et al.*, 2004; Neckerman *et al.*, 2009b; Steinmetz-Wood and Kestens, 2015; Sugiyama *et al.*, 2015; Zandieh *et al.*, 2016). Neighbourhood conditions are often a target for regeneration activities to improve the appearance and desirability of the local area. For example, improvement to the public realm through the creation of clean and attractive spaces is a key activity for the 10-year programme of regeneration led by Glasgow Housing Association (GHA) in neighbourhoods observed by the GoWell programme (Crawford, Beck and Hanlon, 2007). However, in comparison to structural elements of the environment such as connectivity or density, quality-related elements are currently under-researched within the health promotion literature. Therefore, this thesis is largely concerned with the role of the condition and quality of the physical and social environment on neighbourhood-based physical activity. As such, its primary focus is on relational factors (i.e. factors relating to the quality or condition and collective use and treatment of the social and physical environment) and individual factors (i.e. perceptions and experience of the environment). This thesis reacts to a real-world problem of ensuring neighbourhoods in deprived settings support rather than discourage physical activity, by furthering an understanding of how actions within one domain of the physical or social environment might influence physical activity opportunities directly or indirectly through effects on other aspects of the environment.

Chapter 2 Aims of the thesis

Evidence presented in **Chapter 1** highlighted a lack of research simultaneously assessing social and physical environmental correlates of neighbourhood-based physical activity in residents of deprived neighbourhoods. It demonstrated a need for more research using context-specific physical activity outcomes and aiming to further operationalise and conceptualise environmental correlates. Research specifically testing the hypothesis that aspects of the social and the physical environment interactively affect physical activity was also limited. **Chapter 1** also presented preliminary evidence that the quality of the social and physical environment might be particularly important to neighbourhood-based physical in deprived communities, where levels of physical activity are typically lower than average (Giles-Corti and Donovan, 2002; Van Lenthe, Brug and Mackenbach, 2005; Kamphuis *et al.*, 2008; UK Active, 2014; Bardsley *et al.*, 2017).

In light of the gaps in the literature and in line with the logic model developed in **Section 1.5**, the overarching aim of this thesis was to test the hypothesis that the quality of social and the physical environment had significant independent and interactive effects on individual-level physical activity in adults in deprived communities. First, I aimed to systematically review the existing literature simultaneously examining physical and social environmental correlates of physical activity in the general population and found that very few studies had explored interactive effects (**Chapter 1**). A version of this review has been published in *SSM – Population Health* (Sawyer *et al.*, 2017a). Then in line with a socioecological approach, I sought to examine neighbourhood environmental correlates of activity in a specific context: individuals living in neighbourhoods with a high level of income-deprivation in the UK. As such, neighbourhood deprivation was treated as the context of study, rather than an independent variable of interest. The following studies were designed to address specific aims.

Study 1 *Associations between the social environment and the quality of the physical environment in income-deprived neighbourhoods*

This quantitative study aimed to operationalise measures of the quality of the social and physical environment and establish associations between the social environment and physical environment in a deprived context in the UK. A version of this study was submitted to *Environment and Behavior*.

Study 2 *Cross-sectional interactions between quality of the physical and social environment and self-reported physical activity in income-deprived neighbourhoods*

This quantitative study aimed to explore independent and interactive associations between specified measures of the quality of the social and physical environment and self-reported neighbourhood-based walking and moderate physical activity in a deprived context in the UK. A version of this study has been published in *PLOS ONE* (Sawyer *et al.*, 2017b).

Study 3 *A qualitative examination of supportive environments for physical activity in deprived neighbourhoods: Active Living in Glasgow's Neighbourhoods*

This qualitative study aimed to examine social and physical environmental factors that are perceived by residents to support neighbourhood-based physical activity in a deprived context in the UK to further conceptualise how environmental factors manifest and elicit influence over activity. I was awarded a Chadwick Trust Travelling Fellowship to travel to Glasgow to conduct this research. A version of this study has been published in *Social Science & Medicine* (Sawyer et al., 2018).

Study 4 *Change in the quality of the neighbourhood physical and social environment and levels of physical activity over a 7-year period*

This quantitative study aimed to examine how change in the quality of neighbourhood physical and social environment over 7 years affects change in physical activity in a deprived context in the UK, to provide insight into possible causal mechanisms.

Chapter 3 Methods

The work presented in this thesis involved secondary analyses of large-scale quantitative data (**Section 3.1**) and primary analysis of qualitative data (**Section 3.2**). I wrote the original proposal for this thesis and along with my primary supervisor, AF, obtained funding from UCL and Glasgow Centre for Population Health (GCPH) to perform the research. I identified and approached GCPH as collaborators.

Data were drawn from community-based samples in Glasgow. Located in West Central Scotland, Glasgow is the largest city in Scotland with nearly 600,000 residents recorded in the 2011 census (National Records of Scotland, 2016). It has substantial inequalities in health which have not reduced at the same rate as inequalities in many other European countries (Hopper, 2015). The city has high concentrations of social and economic disadvantage and poor health, particularly in areas with post-second world war inner-city and suburban housing estates and 19^{th} to early-20^{th} century inner-city housing estates (Bond *et al.*, 2013). Although such statistics do not render Glasgow especially representative of a typical city in the UK, they do present it as a particularly interesting case study for health research.

3.1 GoWell: Glasgow Community Health and Wellbeing Research and Learning Programme

GoWell was a 10-year research programme conducted by GCPH, the Medical Research Council/Chief Scientist Office Social and Public Health Sciences Unit (MRC/SCO SPHSU) and the Department of Urban Studies at the University of Glasgow (http://www.gowellonline.com/). GoWell was sponsored by GHA, NHS Health Scotland, NHS Greater Glasgow and Clyde and the Scottish Government. The primary aim of this research was to evaluate the health impact of a major programme of housing and neighbourhood regeneration, targeting economic, social and physical decline in deprived neighbourhoods in Glasgow, UK (Egan *et al.*, 2010).

3.1.1 Contribution

I conducted secondary analyses on data from the GoWell study. I identified this dataset and organised access to the GoWell dataset. I was responsible for cleaning and organising the data for these analyses and created and coded new variables from the raw data where necessary. I also linked area audit data to individual survey data for longitudinal analyses. Research proposals and data analysis plans were submitted to the GoWell steering group prior to accessing the data and performing analyses and I was responsible for ongoing communication with the GoWell research team while conducting this research. I performed all analyses presented in this thesis.

3.1.2 GoWell study design

GoWell is a programme of study examining a complex intervention, emerging from a major urban regeneration programme over a 10-year period. The intervention was implemented by stakeholders outside of the research term, following the transfer of more than 80,000 socially-rented homes from public ownership to Glasgow Housing Association (GHA) and other non-profit, third sector landlords in Glasgow (Egan *et al.*, 2010). Activities within the physical environment included aesthetic and structural housing improvements, green space improvement and housing replacement (demolition and new housing). Activities pertaining to the social environment included creation of community engagement activities, mixed tenure communities and cultural activities. Additional activities targeting the economic environment included skill-development and employment opportunities. More details about the specific activities can be found in *Will Glasgow Flourish?* (Crawford, Beck and Hanlon, 2007). GoWell comprises quantitative and qualitative studies and a multi-component, mixed-method evaluation of the intervention administered across a selection of neighbourhoods in Glasgow (Egan *et al.*, 2010).

A primary component of the GoWell programme was the Community Health and Wellbeing Survey ('community survey') (Egan and Kearns, 2006), a community-based survey of resident adults administered over 4 waves of data collection: wave 1 in 2006, wave 2 in 2008, wave 3 in 2011 and wave 4 in 2015. At each wave of data collection, a repeat cross-sectional survey and a nested longitudinal survey were conducted. Wave 1 was administered prior to any substantial regeneration activities and therefore represented a baseline. In addition, an objective environmental audit of the physical environment in all GoWell neighbourhoods was carried out in waves 1 and 4; these data were also used in the thesis. The relevant sections of the survey are presented in **Appendix 3.1** and described in detail in **Section 3.1.5.1**; the full survey can be accessed at: http://www.gowellonline.com/about/components/survey. The environmental audit is presented in **Appendix 3.2** and described in further detail in **Section 3.1.5.2**.

This thesis used baseline data from wave 1 of GoWell, collected before any regeneration, in order to observe cross-sectional relationships (**Studies 1 and 2**). Longitudinal data from waves 1, 2 and 4 were used to assess the effect of change in the social and physical environment on physical activity outcomes (**Study 4**). The data collection timescale and availability and use of data relevant to this thesis are presented in **Table 3.1**.

Table 3.1 Data collection timescale and availability and use of secondary data for this thesis

	Wave 1 (2006)	Wave 2 (2008)	Wave 3 (2011)	Wave 4 (2015)
Socio-demographics (CS)	Studies 1, 2	Study 4	Unavailable	Study 4
Social environment (CS)	Studies 1, 2	Study 4	Unavailable	Study 4
Perceived physical environment (CS)	Unavailable	Study 4	Unavailable	Study 4
Audited physical environment (EA)	Studies 1, 2, 4	-	-	Study 4
Physical activity (single-item; CS)	Studies 1, 2	-	-	-
Physical activity (IPAQ-SF; CS)	-	Study 4	Unavailable	Study 4

Abbreviations: CS: community survey; EA: environmental audit; IPAQ-SF: International Physical Activity Questionnaire – Short Form. Grey highlight demarcates collection of data. ‘Unavailable’ indicates data were collected but not available for analysis in this thesis.

3.1.3 GoWell study population and recruitment

Fourteen neighbourhoods (comprising 32 sub-areas) with appropriate regeneration timescales were initially selected by the GoWell team and GHA[4]. Neighbourhood boundaries were defined by the GoWell team and GHA. Sub-area boundaries were defined using postcode boundaries.

Within Glasgow and Scotland, the GoWell neighbourhoods were some of the most deprived in terms of income deprivation. Data from the SIMD and the Department for Work and Pensions, reveal that in 2004, 25-54% of the populations living in GoWell neighbourhoods were income-deprived (a measure of the proportion of residents in receipt of income-related benefits), compared with contemporaneous averages of 14% across Scotland and 25% in Glasgow (Walsh, 2008). Although GoWell neighbourhoods were classified as income-deprived within this thesis, it is important to note that these neighbourhoods were also classified as deprived according to most other SIMD indicators of multiple deprivation (Walsh, 2008). Table 3.2 shows level of income-deprivation across the GoWell neighbourhoods, using data from 2004.

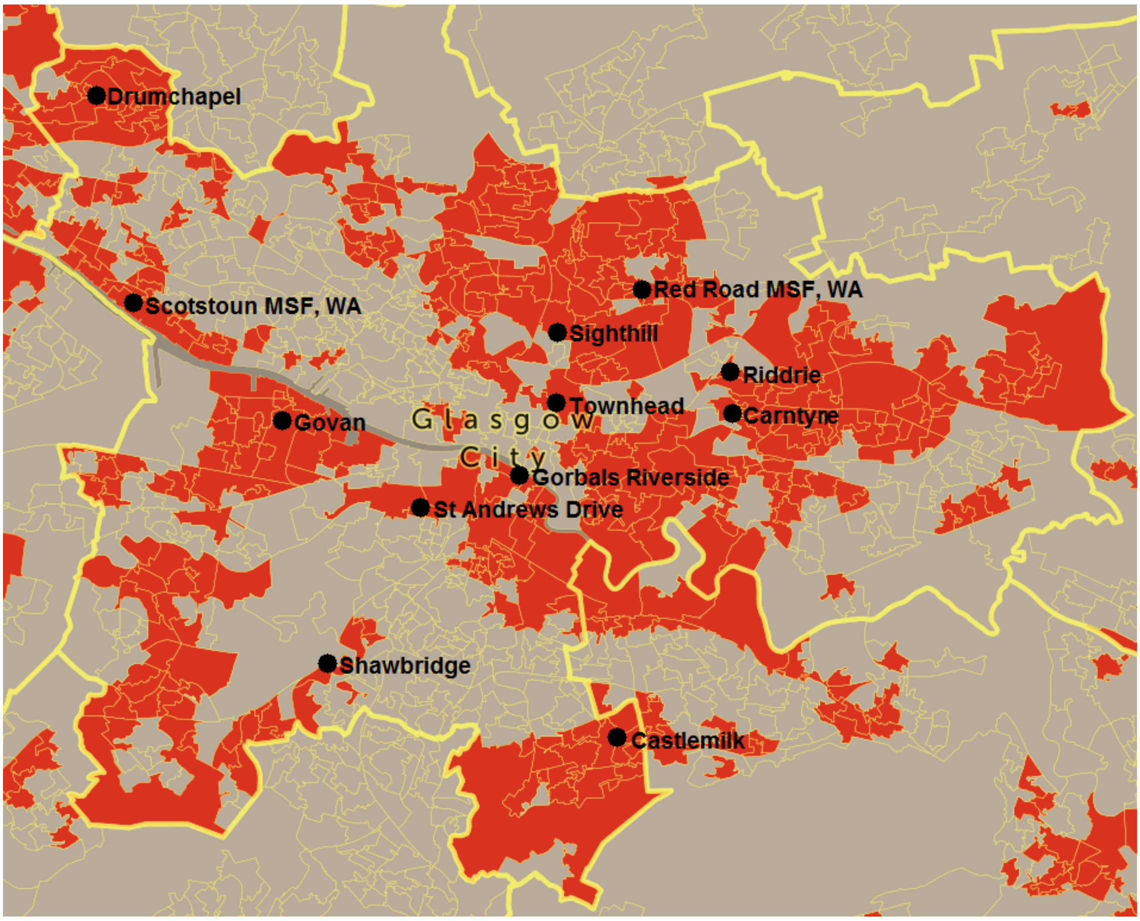
[4] One further neighbourhood was added in 2011, this neighbourhood was not included in any analyses, in the interest of comparability.

Table 3.2 Income-deprivation in GoWell neighbourhoods

Neighbourhood	% of residents in receipt of income-related benefits
Scotstoun MSFs	24.6
Riddrie	27.1
Red Road Surround	28.6
Scotstoun Surround	29.0
Carntyne	29.1
Sighthill	34.8
Red Road MSFs	38.8
Castlemilk	39.9
Gorbals Riverside	42.1
Govan	42.1
Drumchapel	43.2
Townhead	50.0
Shawbridge	52.2
St Andrew's Drive	54.1

GoWell neighbourhoods remained in the highest deciles of deprivation for 2016 SIMD data (www.simd.scot/2016/). **Figure 3.1** highlights the neighbourhoods in the 2 highest SIMD deciles, demarcating the GoWell neighbourhoods in this context (www.simd.scot/2016/).

Figure 3.1 GoWell Neighbourhood locations by level of deprivation



Areas are presented in data zones; those highlighted red are ranked in the highest 2 deciles for deprivation according to 2016 SIMD data. GoWell neighbourhoods are labelled. Where denoted, neighbourhoods were divided into MSF (multi-storey flats) and WA (wider area). Source: www.simd.scot/2016/

GoWell neighbourhoods varied in context and topography. They included inner-city mass housing estates (predominantly high-rise, multi-storey flats [≥5 storeys; MSFs]), inner-suburban garden estates (predominantly semi-detached housing and cottage flats) and large peripheral estates situated on the outskirts of the city (predominantly low- and medium-rise flats [≤2 storeys and <5 storeys, respectively; LRFs; MRFs]).

Within neighbourhoods, participants were recruited into GoWell through postal invitations. Domestic addresses were randomly selected from the Royal Mail Postal Address File for most neighbourhoods; in smaller neighbourhoods all addresses were contacted to ensure adequate representation. Population size of targeted neighbourhoods or neighbourhood areas (e.g. smaller clusters of houses) at wave 1 were estimated to range between approximately 750-10,100 residents (GoWell, 2007). The householder who had most recently celebrated a birthday and was aged ≥16 years was invited to participate in the community survey (Egan *et al.*, 2010). Selected households were visited up to 5 times by fieldworkers in order to obtain consent. Participants completing the community survey at wave 1 were offered no incentive (financial or otherwise); a prize draw was conducted for participants completing the survey at waves 2, 3 and 4.

Adults (aged ≥16 years) were drawn from wave 1 of data collection of the GoWell programme for cross-sectional quantitative analyses in this thesis. A longitudinal sample of participants was drawn from waves 2 and 4 of the GoWell study. Participants who had moved to another sub-area between waves 2 and 4 were not included as change in unmeasured factors could have driven change in neighbourhood exposures, potentially obscuring or confounding possible associations between exposures and outcome. Participants from three neighbourhoods were excluded from the longitudinal sample. These neighbourhoods were: Birness Drive, Shawbridge and Sighthill. Birness Drive was only included in the GoWell programme in 2008, therefore longitudinal neighbourhood audit data were not available. Shawbridge and Sighthill were the only neighbourhoods to have undergone significant change between the years 2006 and 2008 – other neighbourhoods in the study did not undergo expected change during this 2-year period (GoWell, 2010). It was therefore not appropriate to compare change in audit data between 2006 and 2015 and change in self-reported walking between 2008 and 2015 for participants in these neighbourhoods, as needed for longitudinal analyses. Audit data from 2006 was expected to be a reasonable proxy for the objective neighbourhood physical environment in 2008 for all other neighbourhoods. Therefore, the final longitudinal sample was drawn from 12 neighbourhoods comprising 27 sub-areas. An a priori power calculation based on a small effect size in linear multivariate regression model with an alpha of $p<0.01$ and power ($1- \beta$) of 0.95 suggested a minimum sample size of $n=342$ for longitudinal analyses.

3.1.4 Representativeness of GoWell sample

The response rates for the GoWell community survey for repeat cross-sectional samples were: wave 1, 2006 (6,016 interviews; 50% response rate), wave 2, 2008 (4,657 interviews; 48% response rate), wave 3, 2011 (4,063 interviews; 45% response rate) and wave 4, 2015 (3,471 interviews; 47% response rate).

In comparison to data at the time for the whole of Scotland, the wave 1 GoWell sample used for cross-sectional analyses had a slightly higher percentage of female participants (60% compared with 55% female nationally), but approximately equivalent percentage of individuals identifying as Scottish/British (86% in GoWell, compared with 85% nationally; Scottish Government, 2007). GoWell participants reported similar levels of general health to national data for Scotland (24% reported fair or poor health compared with 26% nationally) (Scottish Government, 2012). In comparison with Scottish neighbourhoods with similar levels of deprivation, there is evidence that GoWell areas had broadly similar health and wellbeing profiles (e.g. drug- or alcohol-related hospitalisation, suicide rate, life expectancy) (Crawford and Walsh, 2010). Therefore, the GoWell sample was considered representative of other income-deprived populations in Scotland.

There are limited data to compare GoWell respondents to non-respondents to assess selection bias. Comparisons with the data that are available (neighbourhood-wide data drawn from community health profiles (Glasgow Centre for Population Health, no date)) are greatly limited by non-contemporaneous data collection (i.e. data were not collected at the same time as wave 1 data), different neighbourhood boundaries and the inclusion of residents who did not live within or close to regeneration sites and therefore would not have been approached to participate. In light of these limitations, comparisons using wave 1 data with averaged data from the relevant community health profiles found that a higher percentage of GoWell participants were aged >64 years (25% compared with 16% of the adult population in the area) but a lower percentage of GoWell participants were in employment (potentially partly due to a larger older adult population; 24% compared with 51%) and owned their accommodation (23% compared with 35%). Differences in the proportion of adults belonging to an ethnic minority were negligible (14% compared with 14% for the area). In the longitudinal sample, there were slightly larger discrepancies, as might be expected due to common biases in attrition across socio-demographics, particularly in low-SES samples (Parry *et al.*, 2001; Booker, Harding and Benzeval, 2011). Using data from wave 2 (2008) this sample had more females than population estimates (63% compared with 55% nationally) and, compared with community health profiles averages over the GoWell neighbourhoods, had twice as many participants aged >64 years (32% compared with 16%), fewer participants of non-British ethnicity (3% compared with 14%), fewer participants in employment (24% compared with 51%) and fewer participants who owned their accommodation (25% compared with 35%).

3.1.5 GoWell data collection and measures

As noted, data for this thesis were drawn from the GoWell community survey and environmental audit. Participants provided informed consent and ethical approval was obtained from NHS Scotland B MREC Committee (05/MRE10/89).

3.1.5.1 Community survey

The community survey measured important constructs in the posited relationship between the neighbourhood, housing and health; the conceptual basis for each area of inquiry is described in depth elsewhere (Egan and Kearns, 2006). The survey was developed through an iterative process including liaison with practitioners in key organisations (GHA, NHS Scotland, NHS Greater Glasgow, Glasgow City Council and Strathclyde Police), drawing and adapting items from existing surveys (GHA Social Survey, the Scottish Health, Housing and Regeneration Project (SHARP) Questionnaire, Scottish House Condition Survey, Scottish Household Survey, Home Office Citizenship Survey, Office for National Statistics Measuring Social Capital in the UK, British Social Attitudes and Scottish Social Attitudes Surveys) and developing novel questions to assess context-specific characteristics (Egan and Kearns, 2006). For items pertaining to neighbourhood, participants were asked to consider the area within 5-10 minutes' walk of their home, capturing what Kearns and Parkinson (2001) would consider the 'home area'.

Community survey interviews lasted 40 minutes and were conducted in the participant's home by a trained fieldworker. Surveys were conducted over the summer months. Responses were recorded using Computer Assisted Personal Interviewing (CAPI) or paper. Interpreters were made available if the participant did not speak English.

3.1.5.1.1 Socio-demographics

Socio-demographic data were self-reported in the community survey; items are presented in **Appendix 3.1**. The following socio-demographic variables were assessed at the level of the participant and were used to characterise the sample: sex (male, female); age group (16-24, 25-39, 40-54, 55-64, 65+); citizenship (British, non-British); employment status (working, not working, retired); tenure (owned accommodation, private- or socially-rented accommodation); household structure (adult only, family, older adult); mobility-limiting illness (yes, no); regular access to a vehicle (yes, no); distance to environmental assessment site (metres); and neighbourhood income deprivation (% of residents in receipt of income-related benefits in 2008). These socio-demographic variables have been reported to be associated with the exposure and outcome variables of interest (Mason, Kearns and Bond, 2011; Mason, Kearns and Livingston, 2013; Mason, Curl and Kearns, 2016) and were therefore controlled for in analyses.

3.1.5.1.2 Social environment

Items assessing the social environment were selected from the community survey and are presented in **Appendix 3.1,** along with details on the source of the item. The selected items pertaining to the conceptualisation of the social environment for this thesis were included across each wave of data collection. Items covered: residents' attitudes towards the neighbourhood and local community (i.e. reputation; belonging to the neighbourhood; influence over decisions; neighbours getting on well with each other; intervention in harassment; honesty); neighbourhood problems (e.g. gang activity); perceptions of safety (i.e. walking alone after dark); social interaction and networks (e.g. frequency of meeting relatives; number of neighbours from whom you receive help); and engagement (i.e. participation in clubs). The social environment was conceptualised as a broad measure of social capital; all items directly pertaining to social cohesion, trust and reciprocity, social support, social networks, participation in local organisations and views of the area in terms of safety and reputation were selected. Of the items assessing social contact with friends, neighbours and relatives, only one item was selected for each of the contact groups (e.g. friends, neighbours and relatives) due to multicollinearity between variables within the same contact group (correlations >0.8).

Items were predominantly scored on 4-6 point Likert scales (e.g. '*a great deal/a fair amount/not very much/not at all*'; '*none/one or two/more than two/would not ask/don't know'*). For consistency with previous GoWell studies (Mason, Kearns and Bond, 2011), '*don't know*' responses were classified as neutral. Although there are no available data on the validity and reliability of these items, they have been used previously in national monitoring surveys to generate reliable, valuable population-level data (please see source of items in **Appendix 3.1**). Therefore, use of these items enables data from GoWell to be compared to historical and future data generated at population level.

3.1.5.1.3 Perceived quality of the physical environment

Items assessing perceptions of the quality of the neighbourhood physical environment were adapted from the Scottish House Condition Survey 1996 and the Scottish Household Survey and were repeated across all waves of data collection (**Appendix**

3.1). Five items pertained to the quality of the physical environment: quality of the environment, buildings and parks or open spaces ('*Rate the quality of your neighbourhood in terms of attractive environment / attractive buildings / park or open spaces'*; response options: '*very poor/ fairly poor/neutral/fairly good/very good/don't know*') and vandalism and litter as a problem in the neighbourhood ('*Vandalism, graffiti and other deliberate damage to property or vehicles / rubbish or litter lying around is a serious problem in the neighbourhood*'; response options: '*not a problem/slight problem/serious problem/don't know'*). As with the items used to measure the social environment, data on the validity and reliability of these items are not available, but they have been used repeatedly for national surveys (Scottish Homes, 2002; Scottish Government, 2012).

3.1.5.1.4 Physical activity

Measures of walking, MPA and vigorous physical activity (VPA) were taken at each wave of data collection. In wave 1, neighbourhood-based walking was self-reported using a single item: '*In a typical week, on how many days do you go for a walk around your neighbourhood?*'. MPA and VPA were self-reported using single items: MPA: '*In a typical week, on how many days do you do 30 minutes of moderate physical exercise such as brisk walking, cleaning the house – it doesn't have to be 30 minutes all at once?*'; VPA: '*In a typical week, on how many days do you spend 20 continuous minutes doing vigorous exercise, enough to make you sweaty and out of breath such as a fitness workout or some kind of physical work?*'. Items did not distinguish between different domains of physical activity and captured frequency of activity bouts rather than total duration of activity. Because participants did not report number of minutes in each activity type, only number of days on which they were performed, it was not possible to combine this measure with the measure for MPA in order to create an outcome for performing an adequate amount of MVPA (national guidelines recommend performing 75 minutes of VPA, equivalent to 4 days of 20 minutes of VPA and 150 minutes of MPA, equivalent to 5 days of 30 minutes). Walking and MPA were the focus of quantitative analyses, in line with arguments attesting the priority of moving inactive populations into some level of activity which can obtain health benefits (Chief Medical Officer, no date). Responses were collapsed into two binary variables using 5 days as a cut-off, reflecting national guidelines for adults to perform an amount of physical activity equivalent to walking or performing MPA on at least 5 days/week in order to achieve health benefits (Chief Medical Officer, no date).

The item measuring MPA was adapted from the Scottish Health Survey 2003. The item for walking was developed by the GoWell team and has been used in previous research (Mason, Kearns and Bond, 2011). Although these items have not been directly tested for reliability and validity, previous studies using single-item physical activity measures, asking participants to self-report physical activity participation have shown that similar single-item measures have adequate criterion validity against accelerometry and moderate validity and strong repeatability against more extensive self-report tools (Milton and Bauman, 2011; Milton, Clemes and Bull, 2013).

In waves 2 and 4, physical activity was assessed with the International Physical Activity Questionnaire – Short Form (IPAQ-SF) (Craig *et al.*, 2003). This version of the 9-item questionnaire was designed for use with adults and collects information on frequency (days) and duration (minutes) of activity. The item measuring number of days walking for ≥10 minutes in a non-specific location (hereon referred to as 'non-specific walking') was self-reported using the item: *'During the last 7 days, on how many days did you walk?'* (*0-7 days/'don't know'/'not sure'/refused*). The psychometric performance of the short form version has been assessed across 12 counties, revealing an acceptable level of test-retest reliability (Spearman's reliability coefficient; pooled p=0.76) and concurrent validity with the 31-item long version (Spearman's pooled p=0.67) (Craig *et al.*, 2003). Criterion validity measured against accelerometry was acceptable (Spearman's pooled p=0.30) (Craig *et al.*, 2003). Various administration modes and adopted reference periods ('last 7 days', 'in a usual week') performed similarly. Data were scored in line with the IPAQ-SF scoring protocol to obtain number of non-specific days walking for periods of at least 10 minutes.

In waves 2 and 4, number of days walking for ≥20 minutes within the neighbourhood (i.e. 'neighbourhood-based walking') was also self-reported using the item '*In a typical week, on how many days do you go for a walk around your neighbourhood?*' (*0-7 days/'don't know'*). Although psychometric properties are not available for this item, it was included in longitudinal analyses in **Study 4** in order to be consistent with **Study 2** and to respond to findings from the systematic review which highlighted the importance of using context-specific physical activity measures which correspond geographically to environmental exposures (**Section 1.4.1.8**).

Generally, objective measures of physical activity, such as doubly labelled water or accelerometry, are regarded as gold-standard measures, with higher validity and reliability than self-reported measures. However, there are recent arguments highlighting the valuable congruence of using self-reported data to assess adherence to physical activity guidelines, when such guidelines were developed using self-reported data to estimate health benefits (Troiano *et al.*, 2014; Kelly, Fitzsimons and Baker, 2016). In addition, self-report measures are more scalable and incur lower costs allowing larger samples which are needed to detect smaller effects and to conduct interaction analyses (Gubbels *et al.*, 2014).

3.1.5.2 Environmental audit

An environmental field audit of neighbourhoods was conducted at wave 1 and wave 4 by a commissioned company named EKOS Limited. At wave 1, approximately 3 sites were randomly selected from each of the 32 GoWell sub-areas (defined by postcode boundaries) to be assessed for environmental audit (the location of assessment sites are displayed in **Appendix 3.3**). The number of sites selected was specified by sample size of the sub-area, to ensure sufficient representation; a total of 95 sites were selected. Audits were performed on the 100-metre area surrounding the centroid of each postcode comprising the assessment site, encompassing buildings, public spaces, streets, communal areas, gardens and fences. In the audit at wave 1, two trained auditors independently performed the audit in 23 assessment sites according to specified criteria. Agreement between auditors was good with 89% absolute agreement in the 34-item audit. Owing to the close agreement, the remaining 72 assessment sites were audited by one auditor. The audit at wave 4 adhered to the same protocol as the previous audit. Three independent auditors assessed the same 95 assessment sites (**Appendix 3.3**). In cross-sectional analyses, distance to the nearest assessment site centroid was calculated for each participant to permit data linkage; audit data was aggregated at the level of the assessment site. For longitudinal analyses, audit data were aggregated at the level of sub-area (i.e. postcode boundaries) using mean values, to enable the linkage of data to the longitudinal sample. Sub-areas were slightly larger geographies which included 2-3 assessment sites.

The audit was designed by GoWell researchers to be broad in scope rather than focusing on hypothesised correlates of particular health outcomes or behaviours and drew on a number of previous studies exploring neighbourhood effects on health and health behaviours. The wave 1 audit included assessments of the quality and aesthetics of local buildings and wider environment and the presence of facilities, amenities and transit (e.g. '*How many buildings or houses within 100m of this address are marked with graffiti or other signs of vandalism?*'; '*The communal areas and public spaces are tidy and well-maintained*'; '*Private gardens are interesting and attractive*'). The quality of the physical environment was measured using items which directly pertained to the visual aesthetics and maintenance of buildings (residential, commercial, private etc.) and manmade and natural surrounding spaces. Audit responses were recorded using 4-point Likert scales (e.g. '*none/a few/around half/most or all'; 'not at all/to some extent/to a large extent/not applicable*'). Items that referred to structural aspects of the environment (e.g. presence of greenspace, pedestrian crossings or housing typography) or to physical cues of the social environment (e.g.

presence of neighbourhood-watch signs) were not considered to be within the scope of the quality of the physical environment and were not examined in this thesis. One item: '*There are large items of furniture or cars abandoned or dumped in public areas'*, did not have sufficient variance and demonstrated a 'floor effect' whereby <1% of assessment sites were reported in the upper category ('*to a large extent'*) and was therefore not included in analyses. Items in the audit differed slightly between wave 1 and wave 4, responding to emerging research interests of the GoWell team. Items repeated in the wave 4 audit are marked in bold typeface in **Appendix 3.3**. Specific items used for longitudinal analyses are presented in **Section 7.3.3**.

Although the audit was regarded as an objective measure of the physical environment, it is important to note that an element of subjectivity persists as ratings were administered by human auditors and some audit items required subjective judgements, e.g. '*Buildings look visually interesting'*, potentially reducing the external reliability of the measure. However, this issue is common in the field and is difficult to overcome as subjectivity is somewhat inherent in a quality-related construct which cannot be easily quantified. Similar items (in terms of wording and use of categorical responses) assessing aesthetics and maintenance of the streetscape in other audits conducted in the field or virtually (e.g. using Google Street View) have also been reported as having good inter- and intra-rater reliability (Pikora *et al.*, 2002; Bethlehem *et al.*, 2014), reflecting the high inter-rater reliability for this audit.

3.1.5.2.1 Misspecification of exposure

As discussed in **Section 1.2.1**, the 'neighbourhood' as a spatial unit is nebulous. Environmental measures at this spatial scale therefore risk misspecification at the level of the participant, potentially weakening observed associations with the outcome of interest, when it is not possible to audit every street segment and ascertain the specific shape and size of each participants' neighbourhood (Spielman and Yoo, 2009; Perchoux *et al.*, 2013). To an extent, self-reported data can go some way to overcome this limitation, by engaging the participant to self-define their neighbourhood (usually with parameters such as ‘the area within 5-10 minutes’ walking distance’) and therefore their contextual exposure. In comparison, objective assessments of the neighbourhood most often use a static definition of the neighbourhood which is universally assigned to participants. Although technology now offers alternative methods to operationalise individualistic, dynamic definitions of the neighbourhood using GPS or interactive, web-based mapping, such methodologies are resource-demanding and difficult to administer to large samples (Perchoux *et al.*, 2013).

In order to examine the potential risk of misspecification of exposure in the GoWell sample, I used wave 1 data to characterise assessment sites by the range of distance from participants to their assessment site. The highest decile for range (largest range: 1035 meters) and lowest decile for range (smallest range: 0 meters) were mapped using Google Maps and Google Street View. This exercise revealed that assessment sites with the largest ranges were sites with houses and MRFs (i.e. where participants were inherently more spatially dispersed) while assessment sites with the smallest ranges were all sites with MSFs or sites with very low connectivity such as cul-de-sacs (i.e. where participants were less spatially dispersed). More detailed spatial analysis was not possible as individual participant postcodes were not available. However, this examination suggested the possibility of meaningful differences between assessment sites by more or less spatial dispersal of participants, suggesting that exclusion of more dispersed assessment sites in analyses, or in sensitivity analyses would likely introduce bias into the data. Therefore, potential misspecification of exposure was addressed by controlling for participant distance to assessment site in analyses.

3.1.6 Statistical analyses

Descriptive statistics characterised the sample in terms of socio-demographics. Normality of data was tested by visual inspection of histograms and absolute values of skewness and kurtosis statistics (as z-scores of skewness and kurtosis values are not recommended for large samples (Field, 2009)). Absolute values for skewness and kurtosis less than 1 were considered to be normally distributed; values greater than 1 were inspected for non-normality. Variables were scanned for unrealistic values as part of the data cleaning process. Descriptive statistics were produced for primary exposure and outcome variables. **Section 3.1.6** provides a brief overview of analyses; more detail is given in the relevant chapters.

3.1.6.1 Study 1: Associations between the social and physical environment

Principal components analyses (PCA) were performed to explore the underlying structure of the data from the community survey and environmental audit to reveal factors measuring i) the social environment and ii) the physical environment. The PCA was performed in **Study 1** on cross-sectional data drawn from the wave 1 sample.

The aim of this approach is to decompose a number of correlated variables into the smallest set of linear components (i.e. dimensions, or factors) which explain the maximum amount of variance in the observed data, while retaining as much information as possible. This is achieved by systematically determining which variables cluster together (i.e. have high correlations with one another, but low correlations with other variables) and share common variance ('communality') in the data. There are multiple statistical methods for identifying dimensions underlying the data, with PCA and Factor Analysis being the most common. PCA is an exploratory technique which is used to generate hypotheses. It is conceptually and statistically less complex than Factor Analysis while having sound psychometric properties. It was therefore deemed to be the most appropriate approach for this study.

Despite its merits, there are important considerations to acknowledge when conducting a PCA. Firstly, statistical calculations are used to identify factors underpinning observed data – the real-world meaning of these factors must be subjectively assigned by the researcher through examination of the items which contribute to the factor. Secondly, PCA was developed to estimate the factor structure underlying the particular dataset being studied. It is therefore not possible to extrapolate findings from a single PCA to other samples. In order to obtain a stable factor solution from a PCA, several assumptions must be met (Field, 2009). For ease of reading, further details on these assumptions and the extraction, rotation and scoring methods used for the PCA are provided **Section 4.3.3**. In brief, reliable factors were extracted which were scored using standardised variables.

Socio-demographic differences in social and physical environment factors were explored with one-way Analysis of Variance Analysis (ANOVAs).[5] Bivariate associations between factors were assessed using Pearson's product-moment correlation coefficients for variables with normally distributed data and Spearman's rank correlation coefficient for variables with non-normally distributed data. Factors were also collapsed into binary variables using the mean value, as use of binary variables would facilitate interpretation of any future interaction analyses. Chi-squared analyses investigated associations between factors when they were treated as binary variables.

All analyses were conducted in SPSS version 20. A Bonferroni correction was applied and the alpha level was set at $p<0.01$, acknowledging the increased chance of a type 1 error due to the large sample size and multiple testing (Field, 2009).

3.1.6.2 Study 2: Cross-sectional analyses with physical activity

Studies within the field of environmental effects on physical activity predominantly use observational study designs to assess cross-sectional associations (McCormack and Shiell, 2011). Cross-sectional analyses in **Study 2** were performed on the sample drawn from wave 1. Chi-squared analyses tested for socio-demographics differences in binary physical activity outcomes (obtaining at least 5 days/week of walking or MPA). A series of binary logistic regression models were conducted to examine independent

[5] Group differences in factors that displayed deviation from a normal distribution were also tested using non-parametric tests (Mann-Whitney U and Kruskal-Wallis tests) but the results were the same and so are not reported.

and interactive associations between binary environmental exposures developed in **Study 1** and physical activity outcomes. First, models included a single environmental factor and were adjusted for specified socio-demographic covariates, accounting for nesting in participant sub-area (i.e. postcode) as discussed below. Second, a model for each physical activity outcome included all environmental factors and was adjusted for socio-demographic covariates and sub-area. In order to test for interactive effects, a binary logistic regression model for each physical activity outcome was performed, which included all environmental factors as main effects and pairwise interactions between social and physical environmental factors. Socio-demographic covariates were also included in these models and nesting in sub-area was accounted for (please see **Section 3.1.6.4**). In the absence of context-specific evidence to support hypothesis-driven analysis, a data-driven approach was adopted. Following recommendations by Aiken and West (1991) and because these analyses were exploratory and data-driven, all pairwise interaction terms were entered in the first instance; insignificant interaction terms (alpha set at $p<0.05$) were progressively dropped starting with the interaction term with the largest p-value, until only significant terms were retained. Significant interactions were explored with post-hoc testing by stratifying the analyses by a specified environmental factor (e.g. stratified into 'high' and 'low' groups) and estimating effects of the interacting environmental factor for each group. This approach has been adopted in previous examinations of interactive effects on physical activity and is described in further detail by Aiken and West (1991) (Gubbels *et al.*, 2014).

Analyses were conducted in STATA version 12. A Bonferroni correction was applied and the alpha level was set at $p<0.01$, acknowledging the increased chance of a type 1 error due to a large sample size and multiple testing (Field, 2009).

3.1.6.3 Study 4: Longitudinal analyses

Quasi-experimental designs or natural experiments permit examination of the effect of differential exposure to environmental conditions (e.g. pre- and post-intervention) but do not require random allocation of participants (Barreto, 2005). Such designs can or cannot have control groups and examine exposure to experimental conditions using different methods including pre-post evaluations, comparisons with effects on control groups or interrupted time series analysis. To facilitate inference of the direction of relationships between the environment and physical activity, longitudinal observational designs are able to assess the temporality of associations (i.e. whether change in one variables predicts change in another) or whether change in two variables is related when potentially confounding variables remain stable and thus cannot instigate the observed change.

For longitudinal analyses in **Study 4**, data were linked to longitudinal participants from the community survey (socio-demographics, social environment, perceived physical environment, neighbourhood-based and non-specific walking; waves 2 and 4) and the environmental audit (physical disorder; waves 1 and 4). Time point 1 was the earlier wave of data collection; time point 2 was the later wave of data collection. Because data were observed across two time points, change in environmental exposures was calculated for independent variables and change in physical outcomes was calculate for dependent variables. The GoWell progress report for 2016-2017 reported change in perceived environmental measures at the level of individual survey items, supporting the feasibility of these analyses (GoWell, 2017).

Change in a linear variable between two time points can be expressed in two ways: absolute change is the simple difference in the variable value between time points (i.e. time point 1 and time point 2); relative change expresses change as a percentage of the value at time point 1. Because relative change is an asymmetric measure, it is recommended to log transform the variable, although this requires further transformation of negative values (as could be expected in some sub-areas in the context of this study owing to extraneous factors influencing the environment beyond regeneration activities). In addition, it is not mathematically possible to calculate a relative change for values of 0 as a percentage change requires some original value for calculation; in this sample, many participants obtained 0 days of walking at time point 1. In light of these points and the unsuccessful use of log transformation to correct relative change variables, it was decided that using absolute change would be most meaningful. Absolute change was calculated as: *value at time point 2 – value at time point 1*.

In order to assess change in categorical variables measuring perceptions of the physical environment, variables at time point 1 and 2 were collapsed into binary variables ('very poor/fairly poor/neutral/don't know' and 'very good/fairly good'; 'not a problem/don't know' and 'slight problem/serious problem') and change was assessed with the following categories: 'consistently negative', 'declined from positive to negative', 'improved from negative to positive' and 'consistently positive'. Absolute change was calculated for perceived social environment factors, audited physical disorder and self-reported neighbourhood-based walking and non-specific walking.

Socio-demographics differences in physical activity outcomes were tested using chi-squared analysis. A series of linear regression models were performed with change in environmental variables as the exposure variables and absolute change in number of days of non-specific walking or neighbourhood-based walking as the outcome. Model 1 included a single environmental change variable as the exposure variable. Model 2 included a single environment change variable and adjusted for covariates and potential nesting in subarea. Model 3 included all environmental change variables and adjusted for covariates and potential nesting in sub-area. Because this study examined change between two time points, rather than trend analysis, it was not deemed necessary to nest participants within time as each participant had single 'change' value for exposure and outcome variables.

Analyses were conducted in SPSS version 20. A Bonferroni correction was applied and the alpha level was set at $p<0.01$, acknowledging the increased chance of a type 1 error due to the large sample size and multiple testing (Field, 2009).

3.1.6.4 Accounting for nesting within sub-areas

Individuals within a single geographical area might be more similar in characteristics, behaviour or exposure than those outside of that area. When individuals are clustered within groups residing in multiple geographical areas, at least two sources of variance exist: variance between individuals (i.e. individual-level variance, or variance within groups) and variance between the groups in areas (i.e. area-level variance, or variance between groups). Clustering within a hierarchy (individual and area) can be problematic for statistical testing as it violates an assumption of independence of observations, leading to underestimated standard errors and inflated statistical significance (Snijders and Bosker, 2012).

It is possible to overcome this by including a random intercept in a multilevel model, which will allow for an effect of area by permitting the overall probability of performing physical activity to vary across a geographical area.[6] A two-level random intercept model estimates the likelihood the outcome variable using a fixed-effect slope and a fixed-effect and random-effect intercept.

Regression models for cross-sectional analyses were fitted with random intercepts to account for clustering; they included environmental factors and covariates as fixed effects at level 1 and sub-area as a random effect at level 2. As such, it was specified that individuals were drawn from a sample of sub-areas representative of a much larger population of sub-areas. In comparison, including sub-area as fixed effect would specify that participants were drawn from a complete population of sub-areas which

[6] By fitting a random *slope* in addition to a random intercept, it is also possible to allow the effects of specified predictor variables to vary across areas, e.g. testing whether the effect of 'physical disorder' on physical activity is larger in one area compared with another. However, explaining variance in individual-level physical activity, not sub-area-aggregated level of physical activity, was the substantive focus of this thesis. Therefore, only a random intercept was fitted in models.

were all sampled for the analyses, meaning it would be sensible to use one sub-area as a reference category to which one could compare the others. Following previous GoWell studies (Mason, Kearns and Bond, 2011), sub-area (i.e. postcode boundary) was selected as the area-level geography, rather than neighbourhood, as a larger sample for the area-level variable is desirable (Rabe-Hesketh and Skrondal, 2012) and it is plausible that individuals are nested in sub-areas of their neighbourhood.

When performing multilevel models, an intraclass correlation coefficient (ICC) is calculated to assess the extent to which participants in the same cluster (i.e. sub-area) are correlated, indicating the amount of variance they share and the potential extent of clustering in sub-area. First, this statistic was calculated for a 'null' model including only the outcome and sub-area, to permit insight into whether there was potential nesting in sub-areas. Likelihood ratio statistics and corresponding p-values were used to confirm that sub-area effects were observed (i.e. variance between sub-areas was non-zero) and that fitting a random intercept was an improvement on a single-level model in terms of model fit. Secondly, an ICC was calculated for the full model, including all predictor variables, to assess the amount of variance at the sub-area level once predictor variables were accounted for. Changes in variance attributable to the sub-area between the null and full model can sometimes provide an indication of whether the distribution of the predictor variables differ across sub-areas; however, Hox (2010) notes that in multi-level logistic regression models, it is difficult to draw conclusions from comparisons of sub-area level variance estimates in null and full models. Therefore, ICCs were reported for null and full models but inferences as to change in the value were not made.

In longitudinal analyses, the ICC for the null model suggested that there was <1% shared variance in the sub-area level, suggesting there was limited clustering in sub-areas. This might have been due to the smaller sample in the longitudinal analyses, with fewer participants per sub-area. Therefore, to account for non-independence of participants, linear regression models were conducted using generalised estimating equations to obtain robust standard errors. This approach was taken for analyses on samples of a similar size nested in GoWell areas (Egan *et al.*, 2016).

3.1.6.5 Missing data

For cross-sectional analyses, complete data were available for 5,923 participants (>98% of the original sample). For longitudinal analyses, complete data were available for 558 participants (>97% of the original sample of longitudinal participants remaining in same selected sub-areas across selected waves of data collection). It was deemed unnecessary to impute missing data for the very small percentage of participants excluded from analyses, as it was anticipated to have an inconsequential effect on inferences drawn from statistical analyses (Dong and Peng, 2013).

3.1.6.6 Sample size

Large sample sizes are required when testing for interactive effects and is also advantageous in terms of generalisability of the results (Gubbels *et al.*, 2014). While a large sample size offers increased power to detect statistically significant difference, this can increase the risk of type 1 error (Field, 2009). Therefore, the alpha level was set at $p<0.01$ for all analyses.

3.2 Active Living in Glasgow's Neighbourhoods (ALIGN)

Active Living in Glasgow's Neighbourhoods (ALIGN) was a qualitative study which I conducted in two neighbourhoods in Glasgow. Qualitative study designs afford in-depth examination of rich narrative data and are useful in unpacking complex relationships. They rely on participants' lived experience and can offer rich individual insight and interpretation of the research question (Flick, 2009). The primary aim of the study was to gather in-depth data on the impact of neighbourhood social and physical environments on neighbourhood physical activity in deprived communities.

3.2.1 Contribution

I designed all aspects of the ALIGN study including formulation of the research question and development of the study protocol. I conducted participant recruitment, data collection and data analysis (excluding double coding of data which was carried out by my supervisor, AF) and obtained ethical approval for the study. I was awarded a Travelling Fellowship from The Chadwick Trust to travel to Glasgow for 14 weeks to conduct this study.

3.2.2 Study population and recruitment

Two GoWell neighbourhoods were selected for recruitment: Govan, situated around 4 kilometres west of the city centre and Drumchapel, situated around 9 kilometres northwest of the city centre (**Figure 3.1**). These neighbourhoods were selected because they were matched in terms of income-deprivation (both remain in the highest decile of income-deprivation in 2016 SIMD data; www.statistics.gov.scot) and discussions with the GoWell community engagement officer suggested that they had a number of community organisations which could facilitate recruitment.

Govan and Drumchapel differ slightly in location (urban and sub-urban, respectively) and sociocultural and industrial history (Govan is an old neighbourhood with a strong industrial past, most notably in shipbuilding, with traditional tenements and post-war social housing; modern Drumchapel was built in the 1940s as one of 4 post-war housing schemes created in response of Glasgow's 'overspill policy', or 'slum clearances', which relocated residents from excessively-populated inner-city neighbourhoods) (GoWell, 2007). Data from the last national census in 2011 showed neighbourhood resident populations (0 years to >75 years) of 12,976 residents in Drumchapel and 13,509 residents in Govan (National Records of Scotland, 2016). As two of the neighbourhoods sampled in the GoWell programme, both neighbourhoods had experienced recent regeneration activities. Participants had not necessarily been direct recipients of these activities.

Participants were recruited through community organisations (e.g. arts groups, residents' associations) and study advertisements displayed in community facilities (e.g. libraries, sports centres, churches). Participants were eligible if they were aged ≥16 years, resided in socially-rented accommodation and had lived in the neighbourhood for at least 12 months. Participants had not necessarily participated in the GoWell community survey. Recruitment was terminated when interviews had provided adequate 'information power' to cover the issues needed to develop valid themes (Malterud, Siersma and Guassora, 2016).[7]

3.2.3 Data collection

Data were collected between June and October, 2015. Informed written consent was obtained from all participants and ethical approval was granted by the UCL Non-NHS Research Ethics Committee (6967/001). Informed written consent was obtained from all participants for i) participation in the study and ii) publication and appropriate distribution of anonymised participant photography.

A method combining community-based photography and photo-elicitation interviews was adopted (Wang and Burris, 1997). Photo-elicitation interviews were used as they invite the participant to take an active rather than passive role in data collection and the interviewing process, by using participant-produced photography to direct semi-structured interviews and support critical dialogue of the research question. Similar techniques have been pioneered through methodologies such as PhotoVoice, which aim to facilitate deeper insights into the lived experiences of 'hard-to-reach' groups or groups who may not usually have the opportunity to take on more active roles in research (e.g. groups who are frequently studied but not usually directing the subject of observation) (Wang and Burris, 1997). Participant photography and photo-elicitation

[7] The concept of 'information power' was developed by Malterud, Siersma and Guassora (2016) as a way to gauge adequate sample sizes for qualitative research based on five conditions: the specificity of the study aim, the specificity of the target population, the application of specific theory, the quality of interview data and whether analysis is cross-case or case specific. As specificity increases, individual participants can hold more information power on the research question and saturation of information (i.e. no new information is gained from interviews) can be achieved earlier.

interviewing has been used to explore neighbourhood influences on physical activity in other contexts (Seaman, Jones and Ellaway, 2010; Mahmood *et al.*, 2012; Belon *et al.*, 2014).

At an initial face-to-face meeting, participants were provided with a study information sheet and a photography briefing (**Appendix 3.4**) asking them to take photographs of facilitators and barriers to physical activity in their neighbourhood using a 27-exposure disposable camera over a 7-day period. The photography briefing asked participants to consider features of the social and physical neighbourhood environment that got them ‘out and about’. Neighbourhood boundaries were defined by the participant. Participants also defined their social and physical environment, but were prompted to consider the social constructs such as relationships, shared resources and the atmosphere or character of spaces, and manmade or natural physical features including residential and non-residential buildings and environs, streets and public spaces. Physical activity was described broadly as any structured or unstructured activity conducted for recreational or functional purposes. Guidance was provided on safe photography practice (e.g. not entering dangerous situations). After 7 days, participants returned their camera using a stamped-addressed envelope and the photographs were developed. A face-to-face, semi-structured, photo-elicitation interview then took place, using the photographs as aids. A semi-structured interview framework was developed and modified slightly after the first 2 participants (**Appendix 3.5**). Participants were also asked to complete a short questionnaire to record socio-demographics (age, sex, marital status, income, ethnicity, employment status, tenure, household structure and length of residence at current address).

3.2.4 Approach to analysis

3.2.4.1 Interview data

Interviews were recorded digitally and transcribed verbatim (i.e. capturing all verbal utterances). At the time of data analysis, there was no established (i.e. evidenced in multiple studies), overarching theoretical framework which specifically conceptualised neighbourhood influences on neighbourhood-based physical activity in a deprived setting (although, other conceptual models around neighbourhood environmental influences on health behaviours did exist and have been discussed in this thesis). A logic model was also developed from the findings of this thesis (presented in **Chapter 8**), but was not developed prior to qualitative analysis in this study. As such, framework analysis was not considered a feasible option and a data-driven, inductive approach was used for thematic analysis based on grounded theory (Braun and Clarke, 2008). Interpretation of analysis was conducted within an epistemological stance presented in the logic model described in **Section 1.5**. Namely, socioecological, context-specific environmental influences on physical activity were posited and independent and interactive influences were conjectured.

A case study was selected from each neighbourhood to illustrate the expression of themes and their impact on physical activity within specific contexts. These case studies were chosen as they were discussed by nearly every participant in their respective neighbourhoods. Saturation of themes was considered to be achieved when there was apparent replication of themes in participant interview data.

Interview data were managed and analysed using NVivo version 11 software. Findings were reported in line with the Consolidated Criteria for Reporting Qualitative Research (COREQ) checklist (**Appendix 3.6**) (Tong, Sainsbury and Craig, 2007).

3.2.4.1.1 Assessing reliability of qualitative coding for analysis

Campbell, Quincy, Osserman and Pedersen provide some guidelines for assessing the reliability of coding of data from in-depth, semi-structured interviews (Campbell *et al.*, 2013). One aspect of reliability is reproducibility of findings and whether different researchers would code and interpret the data in the same way. When dealing with complex, exploratory qualitative data for which no formal coding systems have been developed and tested, there are several challenges to producing metrics indicating the reliability of analysis. A 'unitisation' problem refers to the difficulty of identifying specific units of transcribed text when ascribing codes, which can then be used for independent coding by multiple researchers. When data are drawn from often open-ended, free responses, meaning can cross sentences or paragraphs, and can blur, or occur simultaneously, across multiple codes. In addition, complex coding systems can emerge from inductive generation of codes from complex data. These can place considerable cognitive demands on coders when interpreting the text, and can often be open to more subjective interpretation than less nuanced coding systems which have fewer, more general codes. Together, these aspects limit the feasibility and accuracy of assessing inter-coder reliability which requires independent coding of the data by more than one researcher and empirical comparison of the coding, usually in some form of percentage agreement. Inter-coder agreement is the assessment of the level of reconciliation of coding discrepancies arising from the coding of data by independent researcher and might be better suited to this type of complex, exploratory qualitative data (Campbell *et al.*, 2013).

In this study, codes were developed inductively and iteratively. The coding system was relatively complex: while overlapping codes were merged and superfluous codes were removed, it was not considered advantageous to simplify the coding system to such an extent that it lacked sensitivity to valuable nuance in the perception of often intangible constructs. Primary codes were initially developed by myself and then collated and reviewed by myself and my primary supervisor (AF). Inter-coder agreement between me and AF was assessed for a random selection of approximately 10% of interviews, as recommended by Hodson (1999). Finally, I developed a coding hierarchy to organise first-level, second-level and thematic codes in Microsoft Excel which was independently scrutinised by AF.

3.2.4.2 Photographic data

Photographic and visual data can be used and analysed in various ways depending on the research methodology and objective (for a comprehensive review of approaches see Rose, 2001). However, the ambiguous nature of visual imagery impels the researcher to apply caution in interpreting and evaluating the meaning of images. Because participants were not asked to provide captions alongside their photographs to explain the photograph's meaning it was not deemed appropriate to code meaning of photographs and a content analytical approach was taken to code the content (not the meaning) of each image and provide a descriptive overview of participant photography. A coding strategy was modified from the VivaCity2020 study which used participant photography as a methodology to explore sustainable urban environments in the UK (www.vivacity2020.co.uk). Photographs were coded as including 1 or more of 84 content items (e.g. 'seating', 'architectural feature') which were grouped into 8 content categories: 'built environment', 'facilities and amenities', 'transport', 'physical disorder', 'social or cultural environment', 'open space', 'services' and 'vistas'. Coding was conducted on all photographs, rather than only selecting those that were explicitly referred to in interviews. This is because participants would often address multiple photographs simultaneously or would refer to the content of their photography without identifying a singular photograph, e.g. historical buildings in the neighbourhood, presented in multiple photographs.

Photographic content analysis was used for descriptive purposes and was not subjected to statistical analysis. This analysis aimed to provide an overview of the types of images participants produced and not validate or corroborate themes developed from participant interviews, which might have obfuscated findings from the interview data. Photographs were also used for illustrative purposes when describing themes drawn from the interview data.

Chapter 4 Study 1: Associations between the social environment and the quality of the physical environment in income-deprived neighbourhoods[8]

4.1 Background

The systematic review presented in **Section 1.4** highlighted a need to further conceptualise and operationalise measures of the physical and social neighbourhood environment. In particular, findings from the review supported the development of measures which are context-specific and, where appropriate, relatively broad in scope. Feng *et al.* (2010) recommended the use of composite scores which are theoretically and analytically coherent and psychometrically sound in terms of internal and external validity. Beyond providing sensitive measures that are valid within a specific context, the development and adoption of broader measures of the neighbourhood environment would assist future attempts to synthesise the literature coherently.

Additionally, the review highlighted the lack of evidence testing for interactive effects of the social and physical environment on physical activity. As discussed in **Chapter 1**, socioecological models of physical activity propose that features of the social and physical environment operate within a system to influence physical activity. Therefore, intervening to affect change in one variable within the system may modify the expression of another unmeasured variable, leading to variance that is unaccounted for in statistical models. It has been suggested that unmeasured variance of this variety could account for inconsistency in observational studies which unsystematically account for related variables operating in the socioecological system (Foster and Giles-Corti, 2008). In testing for independent and interactive effects on physical activity, it is therefore valuable to first understand how key constructs underlying the social environment and the quality of the physical environment relate to one another within a specific context.

[8] A version of this study has been submitted to *Environment & Behaviour*.

Previous research supports associations between aspects of the social and the physical environment (Coley, Sullivan and Kuo, 1997; Bothwell, Gindroz and Lang, 1998; Kuo *et al.*, 1998; Wood *et al.*, 2008; Brown *et al.*, 2009; Mehta, 2009; Child *et al.*, 2016), and theoretical and empirical research in sociology and urban theory has recognised the interplay between the quality of the physical neighbourhood environment and the social environment (Jacobs, 1961; Appleyard, 1969; Sampson and Raudenbush, 1999). However, to my knowledge, there is no contemporary investigation of the relationship between the social and physical environment in a sample of adults living in income-deprived neighbourhoods in the UK.

4.2. Study aim

The aim of this study was to operationalise measures of the quality of the social and physical environment by creating composite measures (factors) and test associations between social and physical factors in an adult sample living in income-deprived neighbourhoods in the UK. In order to comply with a fully socioecological approach acknowledging multiple levels of influence on physical activity, an additional aim was to investigate associations between environmental factors and socio-demographics to explore whether the effect of the environment may be partly dependent on specified individual characteristics. I hypothesised that factors underlying the quality of the social and physical environment would be significantly associated, thereby providing a rationale to examine interactive environmental effects on physical activity. Significant differences in mean scores for environmental factors by socio-demographics were hypothesised, in light of posited individual differences in the experience of the neighbourhood environment.

4.3 Methods

4.3.1 Population

A sample of adults (aged ≥16 years) was drawn from wave 1 of data collection of the GoWell programme. More details on this sample are provided in **Section 3.1.3**.

4.3.2 Measures

Participant socio-demographics and data on the social environment were collected with the GoWell community survey, using CAPI. Information on the quality of the physical environment was collected by independent auditors using the GoWell environmental audit. Measures and data collection are discussed in **Section 3.1.5**.

It is worthwhile noting that, in this study, the physical environment was assessed by trained auditors. Therefore, any socio-demographic differences in the quality of the physical environment cannot be attributed to differences in participants' perceptions of their physical environment.

4.3.3 Assessing the factor structure of environment items

Principal components analysis (PCA) was performed to understand the dimensions underlying the variables of interest (further details are provided in **Section 3.1.6.1**). In order to obtain a stable factor solution from a PCA, several assumptions must be met (Field, 2009).

1. Data must be drawn from an adequate sample size. A Kaiser-Meyer-Olkin (KMO) statistic can be used to confirm the sample is large enough to obtain reliable results (KMO classifications: 0.5-0.7 = satisfactory, 0.7-0.8 = good, 0.8-0.9 = great, >0.9 = superb) (Hutcheson and Sofroniou, 1999).
2. Each variable entered into the PCA should be correlated in a linear fashion with other variables in the analysis, but not be too highly correlated with any other variable. A significant result for Bartlett's test of sphericity can be used to confirm that correlations between variables are high enough to obtain valid variable clustering. In addition, visual inspection of correlation matrices is recommended to ensure variables are not too highly correlated (i.e. confirm the absence of multicollinearity or singularity, i.e. correlation >0.7). Visual inspection of matrices can be supported by the determinant of the correlation matrix, which should be >0.00001.

3. Model ‘goodness of fit’ should be adequate. In order to confirm this, SPSS compares a correlation matrix produced from the model with a correlation matrix based on the observed data. Differences between the matrices are produced as values indicating the residuals of the model; fewer than 50% of these values should be >0.05 in order to indicate that the model fits the data well.
4. Variables entered in the PCA should be approximately normally distributed.

4.3.3.1 Extraction of factors

In PCA, a factor is extracted from the data using an iterative process to examine each possible combination of variable clustering to identify the combination which explains the highest proportion of variance in the data. Factors are extracted sequentially; once one factor is extracted, the subsequent factor is extracted by repeating the process to find the combination which explains the maximum proportion of the remaining variance. The contribution of each factor in explaining variance in the data is represented by an eigenvalue, with larger eigenvalues signifying a greater contribution.

Eigenvalues assist an important process in a PCA, assessing the number of factors that demonstrate substantive statistical importance in explaining the data, and can be used in two ways for factor extraction. Firstly, the point of inflexion in a graphical representation of eigenvalues, plotted in order of magnitude in a scree plot, is recommended by Cattell (1996) as an appropriate cut-off for selecting factors. Secondly, the selection of all factors with eigenvalues greater than 1 is advised by Kaiser (1960). With samples over 250 participants, it is appropriate to use Kaiser’s criterion when the average communality is >0.6. Although larger sample sizes bolster the reliability of the scree plot for factor extraction, Field (2009) recommends using both criteria when fewer than 30 items are included in a PCA. As fewer than 30 items were included in the PCA, both criteria were considered.

4.3.3.2 Rotation method and factor loadings

Factor rotation is a technique used to determine the degree to which variables load on the extracted number of factors and equalise the spread of variables across factors. Orthogonal rotation assumes that factors are not correlated, while oblique rotation works on the premise that factors might be correlated and therefore permits correlation between factors in finding the best factor solution. The hypothesis for this study – informed by theoretical and empirical evidence - was that factors would be correlated. Therefore, oblique ('direct oblimin') rotation was conducted. Pairwise deletion of cases was used in order to retain cases with any data. This method has been shown to be appropriate for large datasets (Tabachnick and FIdell, 2001).

Two component matrices are produced in the oblique rotation technique: a pattern matrix and a structure matrix. A pattern matrix uses the regression coefficient of variables to display their unique contribution to each factor. A structure matrix presents the correlation coefficient of variables to present their contribution to each factor while accounting for potential correlation between factors. Where correlation between factors exists, coefficients can be concealed in the pattern matrix (Graham, Guthrie and Thompson, 2003), therefore both matrices were used to assess factor loadings.

Items with factor loadings greater than 0.40 (i.e. the factor explains approximately 16% of the variance in the variable) were considered to contribute meaningfully to the factor and were retained.

4.3.3.3 Factor reliability and scoring

The internal reliability of factors was estimated using Cronbach's alpha (α). Because factors had a small number of loading items, Cronbach's alpha was deemed to be satisfactory if ≥0.5, consistent with recommendations (Tavakol and Dennick, 2011). Standardised variables were used in the calculation of factor scores and Cronbach's alpha. Two items ('*Buildings are damaged and have signs of disrepair'* and '*Buildings are marked with graffiti or other signs of vandalism*') were reverse coded for these calculations as they were phrased in reverse to other items on the factor and therefore loaded in the opposite direction. These items were reverse coded by adding 1 to the maximum value and subtracting the observed value for each participant (Field, 2009). Higher scores equated more positive ratings on the factors (e.g. higher levels of social interaction, better aesthetics of built form, fewer cues of physical disorder).

4.3.3.4 Checking factor solution for social and physical environment items

In addition to a PCA including all items measuring the social and physical environment, a PCA was conducted separately for social and physical items. Apart from a negligible difference in the factor loading of one item, the same factor solution was obtained (**Appendix 4.1**). Therefore, I have only presented results from the PCA including all environment items in the main text.

4.3.2 Socio-demographic differences in factor scores

Socio-demographic differences in social and physical environment factors were explored with one-way ANOVAs.[9] Tests included the environment factor as the dependent factor and controlled for other socio-demographic variables (age, sex, employment status, citizenship, tenure and household type) in addition to area (neighbourhood) and distance to audit assessment site (metres).

4.3.3 Bivariate associations between factor scores

Bivariate associations between factors were assessed using Pearson's product-moment correlation coefficients for variables with normally-distributed data and Spearman's rank correlation coefficient for variables with non-normally-distributed data. Chi-squared analyses investigated associations between factors when they were treated as binary variables.

[9] Group differences in factors that displayed deviation from a normal distribution were also tested using non-parametric tests (Mann-Whitney U and Kruskal-Wallis tests) but the results were the same and so are not reported.

4.4 Results

4.4.1 Participant characteristics

Participant characteristics are presented in **Table 4.1**. A sample of 5,923 participants from 32 sub-areas was included in analyses. There were slightly more females than males (60% female), more British than non-British participants (86% British), slightly more participants working or retired than not working (53% working or retired) and many more participants living in rented accommodation than owner-occupied accommodation (77% renting). Socio-demographic characteristics were representative of the wider population of adults living in the 14 income-deprived neighbourhoods under study (**Section 3.1.4**). The number of participants per sub-area is presented in **Appendix 4.2**.

Table 4.1 Participant characteristics for the cross-sectional sample (n=5,923)

Characteristic	N(%)
Sex	
Male	2369 (40.0)
Female	3554 (60.0)
Age group	
16-24	464 (7.8)
25-39	1650 (27.9)
40-54	1531 (25.8)
55-64	808 (13.6)
65+	1470 (24.8)
Citizenship	
British	5091 (86.0)
Non-British	832 (14.0)
Employment	
Working	1389 (23.5)
Not working	2773 (46.8)
Retired	1761 (29.7)
Household	
Adult	2364 (39.9)
Family	1885 (31.8)
Older	1674 (28.3)
Tenure	
Own	1379 (23.3)
Rent	4544 (76.7)
Vehicle access	
Yes	1451 (24.5)
No	4472 (75.5)

4.4.2 Data screening

Data screening found that all assumptions for a PCA were met. The KMO statistic suggested the sample size was more than adequate to conduct a PCA (KMO=0.71).

Variables were sufficiently correlated (Bartlett's test of sphericity: $p<0.001$) and there was no indication of extreme collinearity or singularity (determinant of correlation matrix >0.00001 and no variables were correlated >0.7). Absolute values of skewness and kurtosis for items included in the PCA are presented in **Table 4.2**. All variables were normally-distributed, except three items ('*How often do you speak to neighbours?', 'communal areas and public spaces are interesting and attractive'* and *'communal areas and public spaces are tidy and well-maintained'*) which had some degree of leptokurtic (positive) kurtosis suggesting the distributions had a high peak and were 'heavy-tailed'. However, these values were all ≤1.5 and inspection of histograms did not indicate more than moderate departure from normality. Furthermore, the corresponding absolute values of skewness were all acceptable at ≤1. Because of this, it was deemed unnecessary to transform these 3 variables, particularly as transformation would necessitate transformation of all other variables and subsequent disruption to the normality of their distributions. Therefore, all items were judged to have approximately normal distributions and were included in the PCA. Finally, only 19% (i.e. <50%) of the reproduced residuals had values >0.05, suggesting the model fit the data well.

Table 4.2 Absolute values of skewness and kurtosis for items included in the PCA[10]

Item	N	Skewness (SE)	Kurtosis (SE)
Thinking about your relatives, friends and neighbours outside your home, how many people could you ask to go to the shop for messages if you are unwell? (CS)	5923	0.00 (0.03)	-0.38 (0.06)
Thinking about your relatives, friends and neighbourhoods outside your home, how many people could you ask to give you advice and support in a crisis? (CS)	5923	0.03 (0.03)	-0.60 (0.06)
Thinking about your relatives, friends and neighbourhoods outside your home, how many people could you ask to lend you money to see you through the next few days? (CS)	5923	0.14 (0.03)	-0.70 (0.06)
Not counting people you live with, how often do you meet up with friends? (CS)	5923	0.93 (0.03)	0.97 (0.06)
How often do you speak to neighbours? (CS)	5923	1.09 (0.03)	1.52 (0.06)
Not counting people you live with, how often do you meet up with relatives? (CS)	5923	0.82 (0.03)	0.15 (0.06)
People who live in this neighbourhood think highly of it (CS)	5923	0.09 (0.03)	0.42 (0.06)
Someone who lost a purse or wallet around here would be likely to have it returned without anything missing (CS)	5923	0.20 (0.03)	-0.77 (0.06)
On your own, or with others, you can influence decisions affecting your local area (CS)	5923	0.21 (0.03)	0.63 (0.06)
Is it likely that someone would intervene if a group of youths were harassing someone in the local area? (CS)	5923	0.46 (0.03)	-0.47 (0.06)
To what extent do you agree that this neighbourhood is a place where people from different backgrounds get on well together? (CS)	5923	0.71 (0.03)	-0.82 (0.06)
To what extent do you feel that you belong to this neighbourhood? (CS)	5923	0.77 (0.03)	0.54 (0.06)
How safe would you feel walking alone in this neighbourhood after dark? (CS)	5923	0.73 (0.03)	-0.66 (0.06)
Buildings are visually interesting (varied in terms of design, scale, colours, textures) (EA)	5923	0.24 (0.03)	-0.92 (0.06)
Buildings are clean and fresh looking (EA)	5867	0.33 (0.03)	-0.60 (0.06)
Area in general is visually interesting (varied in terms of design, scale, colours, textures) (EA)	5438	0.11 (0.03)	0.49 (0.07)
Communal areas and public spaces are interesting and attractive (i.e. landscaped) (EA)	5860	-0.51 (0.03)	-1.39 (0.06)
Private gardens are interesting and attractive (EA)	3249	0.03 (0.04)	0.69 (0.09)
Walls, fences or hedges between properties are well-maintained (EA)	5903	0.87 (0.03)	0.96 (0.06)
Buildings are damaged and have signs of disrepair (EA)	5867	0.66 (0.03)	0.10 (0.06)
Private gardens, yards and driveways are tidy and well-maintained (EA)	3249	0.82 (0.04)	-0.52 (0.09)
Buildings are marked with graffiti or other signs of vandalism (EA)	5890	0.89 (0.03)	0.55 (0.06)
Communal areas and public spaces are tidy and well-maintained (EA)	5860	-0.04 (0.03)	1.39 (0.06)
Area in general is clean and fresh looking (EA)	5923	0.03 (0.03)	-0.24 (0.06)

[10] Items pertaining to private gardens had a smaller n than other items. I re-ran the PCA excluding these items and the same factor structure was obtained. Therefore, only results from the PCA including all items are presented.

4.4.3 Factor characteristics and descriptive statistics

The average communality was 0.63 and the sample size was >250, therefore it was appropriate to using Kaiser's criterion for factor extraction. The PCA extracted 7 factors with eigenvalues greater than 1 (**Table 4.3**). Examination of the scree plot also revealed that the point of inflexion lay at 8 factors, indicating that 7 factors should be retained (**Figure 4.1**). Together, the factors explained 63% of the variance in the 24 items included in the analysis. Rotated factor loadings are presented in the pattern matrix (**Table 4.3**) and structure matrix (**Table 4.4**). The matrices revealed the same combination of item loadings on the 7 factors. Three items had factor loadings of >0.4 on more than one factor. In these instances, the item was retained on the factor for which it had the highest loading. Cronbach's alpha for the factors ranged from 0.5 to 0.9, demonstrating adequate to excellent internal reliability for the factor scales.

Table 4.3 Pattern matrix of factor loadings for environment items (n=5,923)

Item	Rotated factor loadings						
	Social environment factors				Physical environment factors		
	'Social support'	'Social interaction'	'Trust & empowerment'	'Cohesion and safety'	'Aesthetics of built form'	'Cues of physical disorder'	'Aesthetics & maintenance of open space'
Buildings are visually interesting (varied in terms of design, scale, colours, textures) (EA)					**.921**		
Buildings are clean and fresh looking (EA)					**.791**	-.174	
Area in general is visually interesting (varied in terms of design, scale, colours, textures) (EA)					**.678**	.137	.445
Thinking about your relatives, friends and neighbourhoods outside your home, how many people could you ask to go to the shop for messages if you are unwell? (CS)	**-.892**						
Thinking about your relatives, friends and neighbourhoods outside your home, how many people could you ask to give you advice and support in a crisis? (CS)	**-.890**						
Thinking about your relatives, friends and neighbourhoods outside your home, how many people could you ask to lend you money to see you through the next few days? (CS)	**-.886**						
Not counting people you live with, how often do you meet up with friends? (CS)		**.858**					
How often do you speak to neighbours? (CS)		**.775**					
Not counting people you live with, how often do you meet up with relatives? (CS)		**.756**					
People who live in this neighbourhood think highly of it (CS)	-.136	-.139	**.664**	-.103	.148		
Someone who lost a purse or wallet around here would be likely to have it returned without anything missing (CS)			**.663**		.101		
On your own, or with others, you can influence decisions affecting your local			**.660**	-.103			

area (CS)							
Is it likely that someone would intervene if a group of youths were harassing someone in the local area? (CS)	.114	.115	**.621**				
Communal areas and public spaces are interesting and attractive (i.e. landscaped) (EA)						.134	**.793**
Private gardens are interesting and attractive (EA)						-.273	**.661**
Walls, fences or hedges between properties are well-maintained (EA)					.272	-.147	**.509**
To what extent do you agree that this neighbourhood is a place where people from different backgrounds get on well together? (CS)			-.247	**-.797**			
To what extent do you feel that you belong to this neighbourhood? (CS)			.116	**-.705**			
How safe would you feel walking alone in this neighbourhood after dark? (CS)			.196	**-.546**			
Buildings are damaged and have signs of disrepair (EA)						**.826**	.136
Private gardens, yards and driveways are tidy and well-maintained (EA)					-.168	**-.657**	.467
Buildings are marked with graffiti or other signs of vandalism (EA)					-.472	**.598**	.224
Communal areas and public spaces are tidy and well-maintained (EA)						**-.577**	.147
Area in general is clean and fresh looking (EA)					.499	**-.508**	.125
Eigenvalue	2.65	2.05	1.72	1.21	5.01	1.17	1.38
% of variance	11.0	8.6	7.2	5.0	20.9	4.9	5.7
Cronbach's alpha	0.9	0.7	0.6	0.5	0.8	0.8	0.6

Bold typeface indicates the highest factor loadings, specifying loading of each variable onto a factor. CS: community survey; EA: environmental audit.

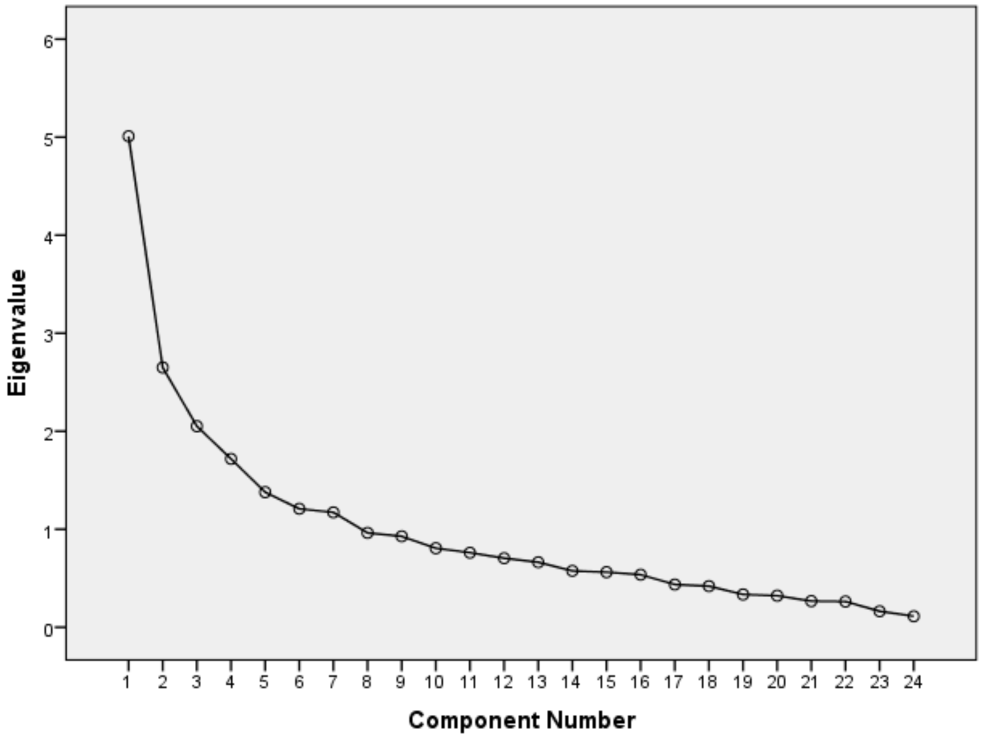
Table 4.4 Structure matrix of factor loadings for environment items (n=5,923)

Item	Rotated factor loadings						
	Social environment factors				Physical environment factors		
	'Social support'	'Social interaction'	'Trust & empowerment'	'Cohesion and safety'	'Aesthetics of built form'	'Cues of physical disorder'	'Aesthetics & maintenance of open space'
Buildings are visually interesting (varied in terms of design, scale, colours, textures) (EA)		-.134	-.110	.166	.919	-.286	.177
Buildings are clean and fresh looking (EA)	-.103	-.117	-.128	.131	.847	-.440	.186
Area in general is visually interesting (varied in terms of design, scale, colours, textures) (EA)		-.149			.729	-.174	.560
Thinking about your relatives, friends and neighbourhoods outside your home, how many people could you ask to go to the shop for messages if you are unwell? (CS)	-.890		-.179	.103		-.108	
Thinking about your relatives, friends and neighbourhoods outside your home, how many people could you ask to give you advice and support in a crisis? (CS)	-.895		-.181	.109		-.106	
Thinking about your relatives, friends and neighbourhoods outside your home, how many people could you ask to lend you money to see you through the next few days? (CS)	-.875		-.115				
Not counting people you live with, how often do you meet up with friends? (CS)		.850					
How often do you speak to neighbours? (CS)		.777		-.159			
Not counting people you live with, how often do you meet up with relatives? (CS)		.762		-.137	-.117		
People who live in this neighbourhood think highly of it (CS)			.656	-.190	-.157		
Someone who lost a purse or wallet around here would be likely to have it returned without anything missing (CS)		-.128	.647				
On your own, or with others, you can influence decisions affecting your local area (CS)	.193		.689	-.218	-.115	.105	
Is it likely that someone would intervene if a group of youths were harassing someone in the local area? (CS)	.232	.108	.629			.112	

Communal areas and public spaces are interesting and attractive (i.e. landscaped) (EA)			.106		.103		.759
Private gardens are interesting and attractive (EA)			-.144	.147	.291	-.462	.734
Walls, fences or hedges between properties are well-maintained (EA)				.152	.441	-.365	.602
To what extent do you agree that this neighbourhood is a place where people from different backgrounds get on well together? (CS)			-.134	-.743	-.111		
To what extent do you feel that you belong to this neighbourhood? (CS)	.179	.211	.247	-.748	-.132	.129	
How safe would you feel walking alone in this neighbourhood after dark? (CS)	.157	.142	.294	-.583			
Buildings are damaged and have signs of disrepair (EA)	.124	.139			-.266	.801	
Private gardens, yards and driveways are tidy and well-maintained (EA)			-.174	.142	.156	-.723	.581
Buildings are marked with graffiti or other signs of vandalism (EA)			.154	-.177	-.633	.713	
Communal areas and public spaces are tidy and well-maintained (EA)					.248	-.621	.283
Area in general is clean and fresh looking (EA)		-.120	-.125	.159	.697	-.705	.345

CS: community survey; EA: environmental audit.

Figure 4.1 Scree plot used for factor extraction



Descriptive statistics for the 7 factors are presented in **Table 4.5**. Absolute values for skewness and kurtosis indicate normal distribution for all factors other than 'social interaction' which had slight leptokurtic kurtosis.

Table 4.5 Descriptive and normality statistics for factors

Factor	N	Mean	SD	Skewness	Kurtosis
'Social support'	5923	0.65	0.19	-0.13	-0.34
'Social interaction'	5923	0.76	0.15	-0.78	1.21
'Trust and empowerment'	5923	0.63	0.12	-0.17	0.28
'Cohesion and safety'	5923	0.49	0.18	-0.77	0.42
'Aesthetics of the built form'	5923	0.64	0.19	0.31	-0.43
'Cues of physical disorder'	5923	0.70	0.15	-0.62	0.74
'Aesthetics and maintenance of open space'	5923	0.65	0.12	-0.02	-0.02

Higher score indicates more positive (better) environmental exposure.

4.4.4 Social environment and socio-demographics

Mean scores and statistically significant mean differences in social environment factors are shown in **Table 4.6**. There were no significant differences in social environment factors by sex, other than female participants reporting significantly lower levels of 'cohesion and safety' than male participants ($F(1,5913)=56.03$, $p<0.001$). Compared with British participants, non-British participants reported lower levels of 'social interaction' ($F(1,5913)=71.13$, $p<0.001$) and lower levels of 'cohesion and safety' ($F(1,5913)=63.07$, $p<0.001$), but there were no differences in 'social support' and 'trust and empowerment'. Participants in employment or retirement reported higher levels of 'trust and empowerment' than those out of employment ($F(2,5912)=6.18$, $p<0.01$), but there were no significant differences between the groups in the other social environment factors. Similarly, older participants scored significantly higher on 'trust and empowerment' than younger participants ($F(4,5910)=5.37$, $p<0.001$), although participants aged 16-24 years revealed higher levels of 'social interaction' than older participants ($F(4,5910)=5.79$, $p<0.001$). There were differences between participants living in rented accommodation compared with owner-occupied accommodation across all social environment factors: 'social support': $F(1,5913)=9.28$, $p<0.01$; 'social interaction': $F(1,5913)=26.07$, $p<0.001$; 'trust and empowerment': $F(1,5913)=17.21$, $p<0.001$; 'cohesion and safety': $F(1,5913)=48.47$, $p<0.001$.

Table 4.6 Mean scores for social environment factors by participant characteristics (n=5,923)

	'Social support'	'Social interaction'	'Trust & empowerment'	'Cohesion & safety'
Sex				
Male	.642	.751	.631	**.757**
Female	.655	.767	.629	**.728**
Age group				
16-24	.677	**.782**	**.622**	.730
25-39	.648	**.754**	**.614**	.716
40-54	.652	**.771**	**.629**	.749
55-64	.647	**.753**	**.639**	.755
65+	.642	**.754**	**.648**	.751
Citizenship				
British	.652	**.770**	.634	**.750**
Non-British	.637	**.705**	.605	**.677**
Employment				
Working	.667	.784	**.638**	.760
Not working	.646	.754	**.615**	.720
Retired	.642	.753	**.647**	.754
Household				
Adult	.646	.763	.627	.743
Family	.660	.763	.619	.725
Older	.643	.755	.647	.752
Tenure				
Own	**.670**	**.786**	**.656**	**.783**
Rent	**.643**	**.753**	**.622**	**.726**

Bold typeface indicates significant difference at p<0.01 level controlling for neighbourhood, distance to audit assessment site and remaining socio-demographic characteristics. Higher score indicates more positive (better) environmental exposure.

4.4.5 Quality of the physical environment and socio-demographics

Table 4.7 displays mean factor scores and significant differences in factor scores by socio-demographics. There were no statistically significant differences in factors measuring the quality of the physical environment by sex or household type. 'Aesthetics of the built form' was rated significantly lower for non-British participants than British participants ($F(1,5913)=203.88$, $p<0.001$), as was 'aesthetics and maintenance of open space' ($F(1,5913)=32.39$, $p<0.001$). Non-British participants also lived in areas with significantly more 'cues of physical disorder' than their British peers ($F(1,5913)=166.18$, $p<0.001$). A similar pattern was reported for participants living in rented accommodation compared with those in owner-occupied accommodation ('aesthetics of the built form': $F(1,5913)=148.91$, $p<0.001$; 'cues of physical disorder': $F(1,5913)=222.91$, $p<0.001$; 'aesthetics and maintenance of open space': $F(1,5913)=159.87$, $p<0.001$). Participants who were out of employment tended to live in areas which had lower ratings of ‘aesthetics of the built form’ (F(2,5912)=8.69, p<0.001) and more ‘cues of physical disorder’ (F(2,5912)=27.83, p<0.001); there was no difference in ‘aesthetics and maintenance of open space’. Older participants experienced fewer ‘cues of physical disorder’ (F(4,5910)=16.84, p<0.001) and more highly rated ‘aesthetics and maintenance of open space’ (F(4,5910)=6.32, p<0.001) than younger participants, although differences in the latter were starker than the former. Participants aged 16-24 years and 25-39 years lived in areas with poorer ‘aesthetics of the built form’ compared with those 40 years and over (F(4,5910)=10.94, p<0.001).

Table 4.7 Mean scores for physical environment factors by participant characteristics (n=5923)

	‘Aesthetics of built form’	‘Physical disorder’ (fewer cues)	‘Aesthetics & maintenance of open space’
Sex			
Male	.626	.706	.649
Female	.645	.705	.645
Age group			
16-24	**.606**	**.663**	**.629**
25-39	**.596**	**.673**	**.635**
40-54	**.653**	**.712**	**.646**
55-64	**.679**	**.724**	**.655**
65+	**.654**	**.737**	**.663**
Citizenship			
British	**.660**	**.719**	**.650**
Non-British	**.499**	**.618**	**.625**
Employment			
Working	**.673**	**.735**	.652
Not working	**.604**	**.669**	.634
Retired	**.661**	**.738**	.662
Household			
Adult	.636	.704	.648
Family	.621	.678	.633
Older	.657	.738	.661
Tenure			
Own	**.705**	**.768**	**.674**
Rent	**.617**	**.686**	**.639**

Bold typeface indicates mean difference at p<0.01 level, controlling for neighbourhood, distance to audit assessment site and remaining socio-demographic characteristics. Higher score indicates more positive (better) environmental exposure.

4.4.6 Bivariate associations between environment factor scores

Correlations between social and physical environment factors and within social factors were small (**Table 4.8**) (Cohen, 1992). Correlations within physical environment factors were medium to large. Most correlations were significant at p<0.01.

Table 4.8 Correlation matrix for environment factors (n=5,923)

	Correlation coefficient [a]						
	‘Social support’	‘Social interaction’	‘Trust and empowerment’	‘Cohesion and safety’	‘Aesthetics of built form’	‘Cues of physical disorder’	‘Aesthetics and maintenance of open space’
‘Social support’	-						
‘Social interaction’	0.01	-					
‘Trust and empowerment’	**0.19**	**-0.04**	-				
‘Cohesion and safety’	**0.15**	**0.13**	**0.26**	-			
‘Aesthetics of built form’	**0.08**	**0.15**	**0.09**	**0.17**	-		
‘Cues of physical disorder’	**0.12**	**0.07**	**0.16**	**0.26**	**0.59**	-	
‘Aesthetics and maintenance of open space’	0.02	**0.04**	0.02	**0.08**	**0.44**	**0.39**	-

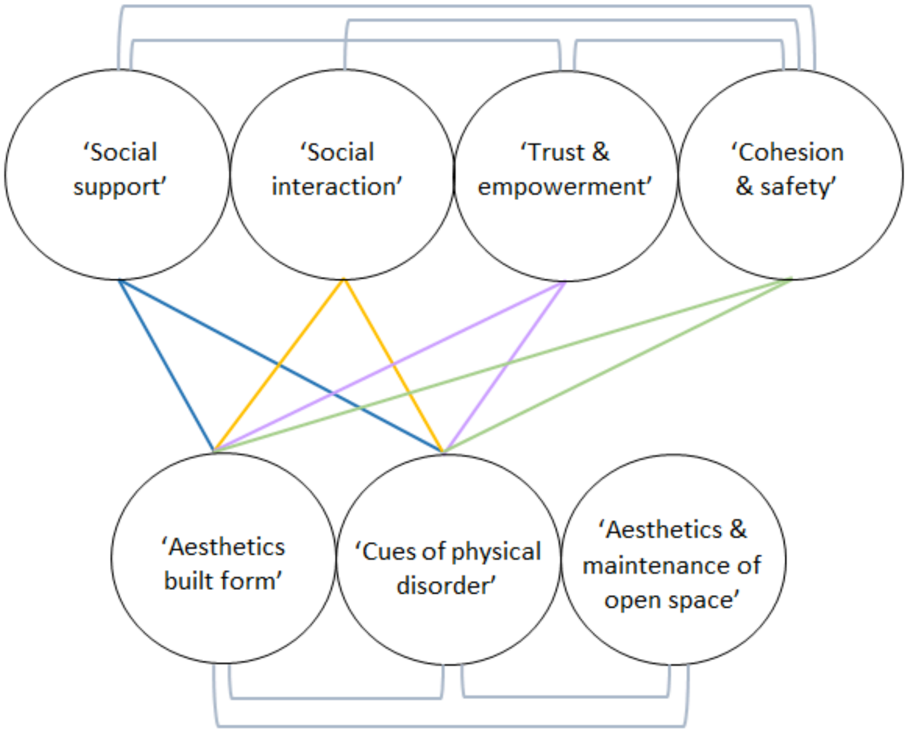
Bold typeface indicates significance at an alpha level of $p<0.01$. [a] Pearson’s product-moment coefficient presented for correlations for all factors other than ‘social interaction’, for which Spearman’s rank coefficient is presented due to non-normal distribution of data.

Significant associations between environment factors, obtained from chi-squared analyses, are presented in **Figure 4.2**. A significant association was revealed between 'aesthetics of the built form' and 'social support' ($X^2(1)=21.15$, $p<0.001$); 'social interaction' ($X^2(1)=62.68$, $p<0.001$); 'trust and empowerment' ($X^2(1)=15.02$, $p<0.001$); and 'cohesion and safety' ($X^2(1)=84.35$, $p<0.001$). Significant associations were also reported between 'cues of physical disorder' and 'social support' ($X^2(1)=6.95$, $p<0.01$); 'social interaction' ($X^2(1)=37.32$, $p<0.001$); 'trust and empowerment' ($X^2(1)=46.40$, $p<0.0010$); and 'cohesion and safety' ($X^2(1)=149.04$, $p<0.001$). 'Aesthetics and maintenance of open space' was not significantly associated with any social environment factors, although there was a trend towards a significant relationship with 'social interaction' ('social support' ($X^2(1)=0.46$, $p=0.50$); 'social interaction' ($X^2(1)=5.85$, $p=0.016$); 'trust and empowerment' ($X^2(1)=3.34$, $p=0.068$); 'cohesion and safety' ($X^2(1)=1.84$, $p=0.176$)).

'Aesthetics of built form' was associated with 'aesthetics and maintenance of open space' ($X^2(1)=68.78$, $p<0.001$) and 'cues of physical disorder' ($X^2(1)=759.04$, $p<0.001$). 'Aesthetics and maintenance of open space' and 'cues of physical disorder' were also significantly associated ($X^2(1)=313.33$, $p<0.001$).

There was a significant relationship between 'social support' and 'trust and empowerment' ($X^2(1)=49.01$, $p<0.001$) and 'cohesion and safety' ($X^2(1)=34.81$, $p<0.001$) but not between 'social support' and 'social interaction' ($X^2(1)=0.224$, $p=0.64$). 'Cohesion and safety' was related to all other social environment factors: 'social support' ($X^2(1)=34.81$, $p<0.001$), 'social interaction' ($X^2(1)=186.09$, $p<0.001$) and 'trust and empowerment' ($X^2(1)=135.66$, $p<0.001$). There was no association between 'social interaction' and 'trust and empowerment' ($X^2(1)=1.02$, $p=0.31$).

Figure 4.2 Significant associations (p<0.01) between factors measuring the social environment and quality of the physical environment (n=5,923)



4.4 Discussion

4.4.1 Summary of findings

In a sample of adults living in income-deprived neighbourhoods in Glasgow, UK, 4 factors emerged which measured the social environment: 'social support', 'trust and engagement', 'social interaction' and 'cohesion and safety'. The quality of the physical environment was operationalised in 3 underlying factors: 'aesthetics of the built form', 'cues of physical disorder' and 'aesthetics and maintenance of open space'. As hypothesised, significant associations between and within social and physical environment factors were revealed. There were several differences in mean factor scores by self-reported socio-demographics, suggesting exposure to or experience of the neighbourhood environment differed meaningfully between residents.

Findings presented here make an important contribution to the current understanding of the interplay between the quality of the social and physical neighbourhood environment in an income-deprived context in the UK. Systematic operationalisation of context-specific measures of the environment is valuable for future research and the factors presented exhibited good psychometric properties. Factors were deemed to have adequate internal reliability (Cronbach's alpha ≥0.5 for all factors). In addition, factors demonstrated negative associations between the quality of the residential environment and living in rented accommodation, as has been reported elsewhere using a similar sample, supporting the external reliability of factors (Hiscock *et al.*, 2003). The fact that the same factors were obtained in PCAs conducted separately for social and physical items further strengthens the obtained factor structure obtained in a single PCA, which confirmed that social and physical factors were stand-alone, not direct 'proxies' for each other (**Appendix 4.1**).

The loading of variables onto factors points towards the distinct nature of features of the physical and social environment. For example, there was not a general measure of neighbourhood aesthetics or neighbourhood maintenance in the operationalisation of measures of the quality of the physical environment, but separate factors pertaining to the built form, open space and physical disorder. These factors had differing relationships with factors underpinning the social environment; it is also possible they exert different effects on physical activity, potentially helping to elucidate previously observed inconsistency in the relationship between aesthetics and activity (Van Holle *et al.*, 2012). Together, composite scores were able to explain 63.3% of the variance in individual items. The composite scores (factors) reported here represent a valuable and warranted attempt to operationalise potential environmental correlates of physical activity using sensitive and context-specific measures.

There were significant associations between 'aesthetics of the built form' and 'cues of physical disorder' and all social environment factors. Due to the cross-sectional nature of current analyses, it is not possible to assess the direction of these associations. However, there are a number of feasible mechanisms through which one could speculate how the association operates. For example, aesthetically-pleasing physical environments could elevate residents' moods and their proclivity to interact with other residents (Leslie and Cerin, 2008). Alternatively, cues of physical disorder may undermine residents' trust in other residents or indicate that others do not abide by informal social rules about treatment of the shared environment (Ross and Jang, 2000; Medway, Parker and Roper, 2016). For example, Nettle found that first-time visitors to neighbourhoods were able to infer resident-reported levels of social trust and paranoia through assessment of physical characteristics alone (Nettle *et al.*, 2014). Finally, individuals could be less willing to engage in their community if the environment looks uninviting and is not cared for by its residents (the 'broken window' theory adopts this position, postulating that physical disorder creates norms that propagate anti-social behaviour; Sampson and Raudenbush, 1999). Drawing on qualitative research to understand the lived experience of individuals within the neighbourhoods would permit in-depth insight into potential mechanisms.

'Aesthetics and maintenance of open space' was not related to the social environment factors, although it was associated with the other physical environment factors. This is an unexpected finding in the context of previous research (Kuo *et al.*, 1998; Mehta, 2009). While it is also possible that this factor was underdetermined as only 3 items loaded onto the factor, significant associations with the other physical environment factors and socio-demographics suggest otherwise.

Finally, findings presented here suggest that demographic characteristics such as tenure and household structure are related to residents' experience of the social environment and quality of the physical environment in the neighbourhood. Socio-demographic variables must therefore be considered when exploring the impact of the environment on physical activity in deprived neighbourhoods. Results are supported by previous evidence from the UK that tenure is associated with health (Hiscock *et al.*, 2003; Macintyre *et al.*, 2003). In this sample, the overwhelming majority of participants living in rented accommodation rented from a social landlord (97% of renters). Such associations could emerge due to perceived or real differences in responsibility for the maintenance of the physical environment or more transitory renter populations, which could bring about deterioration in the social environment. However, it is also acknowledged that tenure might be acting as a proxy for income or wealth in analyses; unfortunately, income-related data were only available at the level of the neighbourhood.

4.4.2 Strengths and limitations

The collection of objective measures of the quality of the physical environment using trained environmental auditors constitutes a strength of the study. High levels of agreement between auditors reinforced the reliability of this method. However, it is important to note the potentially meaningful distinction between objective measurements and residents' perceptions of the physical environment when interpreting findings. Furthermore, because the social environment was measured by self-report, inconsistent definitions of the neighbourhood may have been employed for measurement of the physical environment (defined as the 100-metre area surrounding a postcode centroid) and social environment (defined by the participant as within a 5-10 minutes' walk of their residence). This might have resulted in a conservative estimate of the effect size of the association between physical and social environment factors.

Despite psychometric support for the factors drawn from the PCA, it is important to acknowledge PCA as an exploratory technique which can only reveal the factor structure of selected items measured within the studied sample. Therefore, composite scores identified here cannot be extrapolated to different populations without further research. Furthermore, PCA demands a certain amount of subjective interpretation in attaching conceptually meaningful labels to obtained factors; interpretation of the findings must be done with the nature of the clustered variables in mind. Factors derived from even more extensive measurement of the neighbourhood social and physical environment would be a fruitful endeavour for future research.

Finally, the use of cross-sectional data is a limitation as it does not permit insights into causality between associated factors. Longitudinal research will be important in determining the direction of relationships.

4.4.3 Implications for future research

Effect sizes of the correlations between social and physical factors were small but significant and in the expected direction. To account for the additional power from a large sample, the alpha level was reduced to $p<0.01$. Significant associations between social and physical environment factors add to evidence supporting the socioecological supposition of interactive environmental influences on physical activity which provides a rationale for future research in this area, as called for by other authors (Nelson *et al.*, 2008; Prins *et al.*, 2012; Gubbels *et al.*, 2014; Mama *et al.*, 2015).

Findings suggest that in addition to exploring and accounting for socio-demographic differences in environment factors, research examining independent effects of the social environment or quality of the physical environment on physical activity could increase its validity by fully accounting for associated environmental constructs, both through statistical analyses and methodological design. For example, investigation of the effect of relocation to a neighbourhood with a physical environment which has characteristics supportive of physical activity may also need to monitor changes in social environment constructs, and provide sufficient time for participants to be exposed to and engaged in social aspects of the new community in order to account for potential variance arising from this source (Giles-Corti and Donovan, 2002).

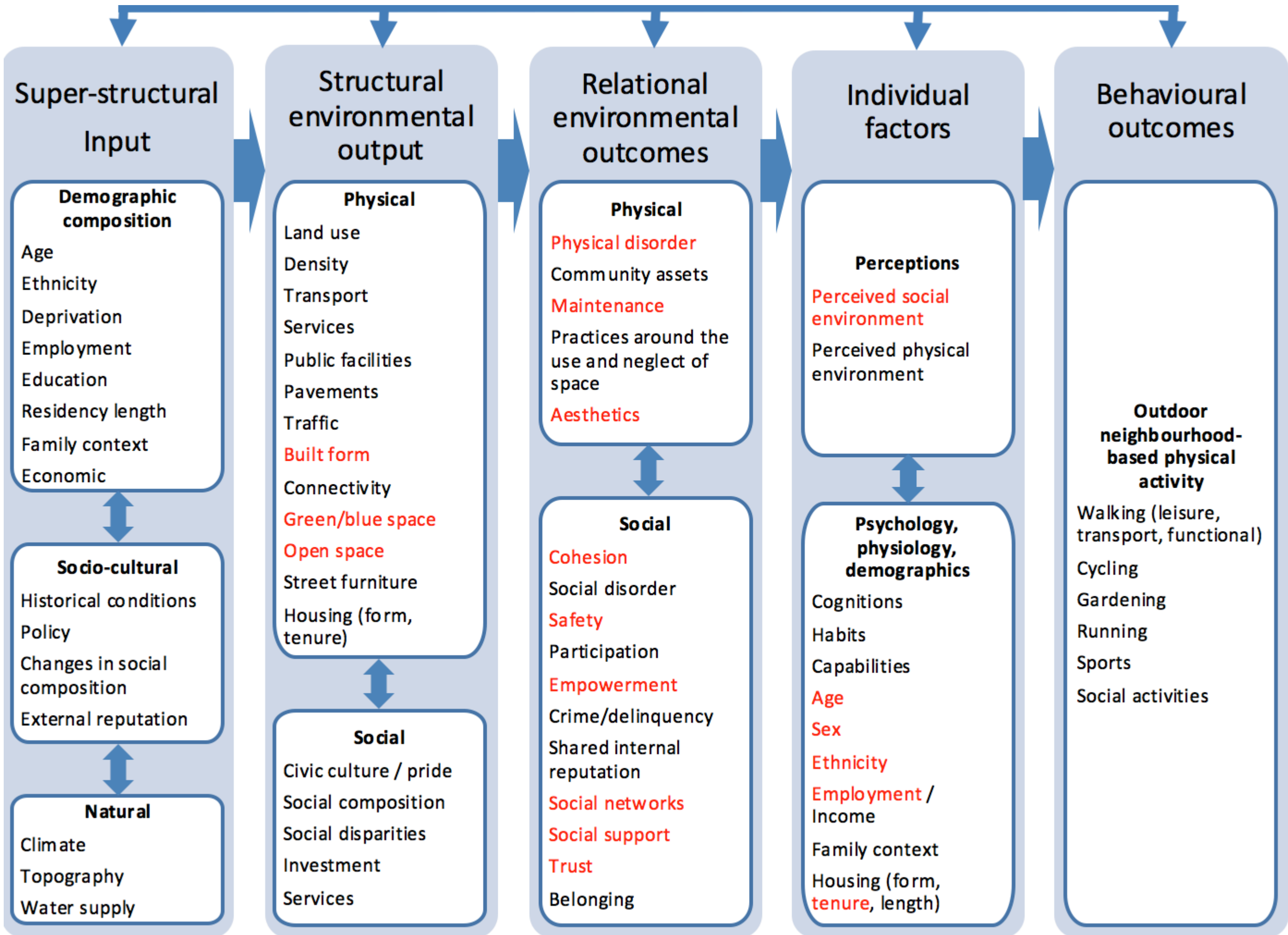
Findings provide a strong rationale for research exploring interactive effects of environment constructs on physical activity in deprived communities in the UK. An opportunity is also presented for further research to theoretically conceptualise factors operationalised in this study and elucidate the mechanisms through which factors might independently and interactively operate to exert hypothesised effects on physical activity.

4.4.4 Conclusions

Seven distinct factors were developed which reliably measured the social environment and quality of the physical environment in income-deprived neighbourhoods in Glasgow. Associations between environment factors were identified. These findings provide a rationale for investigation of interactive effects between the social and physical environment, as posited by socioecological models of physical activity. Reported socio-demographic differences in environmental factors, in particular the increased exposure to poor quality environments for participants living in rented accommodation compared with owner-occupied accommodation, demonstrate the importance of considering individual factors when examining the effect of environmental factors on physical activity.

Figure 4.3 presents the logic model presented in **Section 1.5**, with the constructs developed in this study demarcated in red text. The environmental factors lie across the categories of 'structural environmental output', 'relational environmental outcomes' and 'individual factors', reflecting the multiple environmental aspects underlying the construction of the developed factors. For example, 'aesthetics and maintenance of communal space' comprises both green space and open space ('structural environmental output') and aesthetics and maintenance ('relational environmental outcomes'). Likewise, 'cohesion and safety' incorporates 'cohesion' and 'safety' ('relational environment outcomes') and participants' individual perceptions of these aspects ('individual factors'). Socio-demographics were examined at the individual level and therefore lie within 'individual factors'. Further research should examine these factors in relation to neighbourhood-based physical activity.

Figure 4.3 Logic model of neighbourhood environmental influences on neighbourhood-based physical activity in deprived communities



Red text denotes factor developed in **Study 1**.

Chapter 5 Study 2: Cross-sectional interactions between quality of the physical and social environment and self-reported physical activity in income-deprived neighbourhoods[k]

5.1 Introduction

Despite a growing literature examining independent effects of the social and physical environment on physical activity (as presented in **Chapter 1**), there remains a shortage of context-specific research measuring environmental correlates in populations with particularly low levels of activity, such as residents of deprived neighbourhoods. In addition, the systematic review presented in **Section 1.4** highlighted the lack of evidence testing for interactive effects of physical and social environments on physical activity.

There is some emerging evidence of interactive effects, particularly in the USA. King's (2008) study of 645 older adults living in Denver, reported that perceived social cohesion mediated the association between neighbourhood-based physical activity and litter, and maintenance and presence of window bars. Crime was also reported to mediate the effect of garden maintenance on self-reported physical activity (King, 2008). Elsewhere in the USA, Bracy *et al.* (2014) found fewer interactive effects of perceptions of the physical environment and perceived safety on objectively-assessed MVPA. However, the authors did report that among adult participants who self-reported low levels of perceived safety, those living in neighbourhoods with low levels of walkability (e.g. low street connectivity, land-use mix and residential density, as assessed objectively using GIS) performed 91 minutes of MVPA less than those living in neighbourhoods with high levels of walkability. The difference in MVPA between participants in neighbourhoods with high and low levels of walkability was markedly less among participants who self-reported high levels of safety, supporting a hypothesis that perceived safety mitigates the impact of physical walkability factors.

[k] A version of this study has been published in *PLOS ONE* (Sawyer et al., 2017b).

Such evidence helps to elucidate pathways of association between the neighbourhood environment and physical activity, accounting for variance in the outcome which might otherwise contribute to inconsistent or contradictory results.

As previously noted, quality-related micro-features of the physical environment such as aesthetics and maintenance might be particularly salient in deprived populations (Neckerman *et al.*, 2009; Thornton *et al.*, 2016). In **Study 1**, seven factors were developed which assessed the quality of the neighbourhood social and physical environment. Associations were revealed between physical and social environmental factors in a sample of adults living in income-deprived neighbourhoods. However, independent and interactive relationships between environmental factors and physical activity were not tested. It is possible that these factors operate interactively to support or discourage physical activity by altering the use or perceptions of specific contexts. This could occur by the factors acting synergistically or one factor modifying the effect of another through moderation or mediation. For example, an individual with contacts in the neighbourhood may be more likely to walk to a friend's house or be active through socialising if the physical environment is well-maintained and aesthetically-pleasing, while an individual without contacts might be less exposed to the quality of the physical environment. To the best of my knowledge, no studies have simultaneously examined the independent and interactive effects of quality-related aspects of the neighbourhood social and physical environment on physical activity in deprived communities in the UK.

5.2 Study aim

In light of the gaps in the evidence base reviewed in **Chapter 1** and drawing on the results from **Study 1**, the aim of **Study 2** was to explore independent and interactive effects of extracted social and physical environmental factors on neighbourhood-based walking and MPA performed in a non-specific location ('non-specific MPA') in an income-deprived sample in the UK. I hypothesised that higher quality social and physical environments would be independently and interactively significantly associated with meeting physical activity guidelines through frequent neighbourhood-based walking and frequent MPA.

5.3 Methods

Methods for **Study 2** are described in more detail in **Section 3.1**.

5.3.1 Population

An adult sample (aged ≥16 years) was drawn from the first wave of data collection of the GoWell programme, with data from 14 neighbourhoods comprising 32 sub-areas. The sample was the same as the sample in **Study 1**.

5.3.2 Measures

Social and physical environmental factors developed in **Study 1** were used. They were: 'social support', 'trust and engagement', 'social interaction', 'cohesion and safety', 'aesthetics of the built form', 'cues of physical disorder' and 'aesthetics and maintenance of open space'. Environmental factors were dichotomised by mean score to create binary variables. Socio-demographics that were significantly associated with these factors were used as covariates in this study. Participant demographics and data on the neighbourhood social environment were collected using the GoWell community survey. Information on the quality of the physical environment was collected using the GoWell environmental audit.

Neighbourhood-based walking and non-specific MPA were measured using items from the GoWell community survey: '*In a typical week, on how many days do you go for a walk around your neighbourhood?*' and '*In a typical week, on how many days do you do 30 minutes of moderate physical exercise such as brisk walking, cleaning the house – it doesn't have to be 30 minutes all at once?*', respectively. Responses were collapsed into two binary variables using 5 days as a cut-off, reflecting national guidelines for adults to perform an amount of physical activity equivalent to walking or performing MPA on at least 5 days/week (Chief Medical Officer, no date).

5.3.3 Statistical analyses

A Pearson correlation coefficient was calculated to estimate the relationship between walking and MPA, ensuring the independence of the two outcome measures. Chi-squared analyses examined differences in walking or performing MPA on at least 5 days/week by socio-demographics. A series of binary logistic regression models were conducted to test environmental effects on i) walking and ii) MPA. First, models included a single environmental factor and adjusted for socio-demographic covariates (age, sex, citizenship, employment status, tenure, mobility-limiting illness, vehicle access, distance to audit assessment site and neighbourhood deprivation), accounting for nesting in participant sub-area (i.e. postcode) by fitting a random intercept in the multilevel model, as discussed in **Section 3.1.6.4** (Model 1). Second, a model for each physical activity outcome included all environmental factors and adjusted for socio-demographic covariates and sub-area (Model 2). Third, all pairwise interaction terms were entered into a full model (Model 3; including all environmental factors, covariates and adjusting for sub-area); insignificant interaction terms (alpha set at $p<0.05$) were progressively dropped starting with the interaction term with the largest p-value, until only significant terms were retained (Aiken and West, 1991). Significant interactions were explored with post-hoc testing by stratifying the analyses by a specified environmental factor (e.g. stratified into 'high' and 'low' groups) and estimating effects of the interacting environmental factor for each group. This approach has been adopted in previous examinations of interactive effects on physical activity and is described in further detail by Aiken and West (Aiken and West, 1991; Gubbels *et al.*, 2011). In light of the consistent differences in the experience of the social and physical environment by tenure reported in **Study 1**, logistic regression Models 1 and 2 were repeated, stratifying analyses by tenure, i.e. participants living in owner-occupied accommodation ('owners') and participants living in rented accommodation ('renters'). Results from full models including all main effects are presented.

Linear regression models for main effects were performed with continuous exposures (factor scores) and outcome variables (number of days/week) to ensure results did not substantially change when using dichotomised measures. Results for these analyses are presented in **Appendix 5.1**. Results for logistic regression analyses are presented and discussed here as there was little difference in direction and strength of effects, and results can be more easily interpreted in terms of probability of obtaining sufficient amounts of physical activity to obtain health benefits according to national guidelines (Chief Medical Officer, no date).

Analyses were conducted in STATA version 12. As in **Study 1**, a Bonferroni correction was applied and alpha was set at $p<0.01$.

5.4 Results

Participant characteristics for the full sample (n=5,923) are discussed in **Section 4.4.1** and presented in **Table 4.1.**

5.4.1. Physical activity characteristics

Number of days walking and performing MPA had a medium-large correlation ($r= 0.452$, $p<0.001$). **Figure 5.1** displays the proportion of participants walking or performing MPA by number of days. A total of 29% of participants (n=1,742) reported walking on at least 5 days/week on a typical week. A total of 24% (n=1,392) reported performing at least 30 minutes of MPA on at least 5 days/week on a typical week.

Figure 5.1 Percentage of participants walking or performing MPA on number of days over a typical week

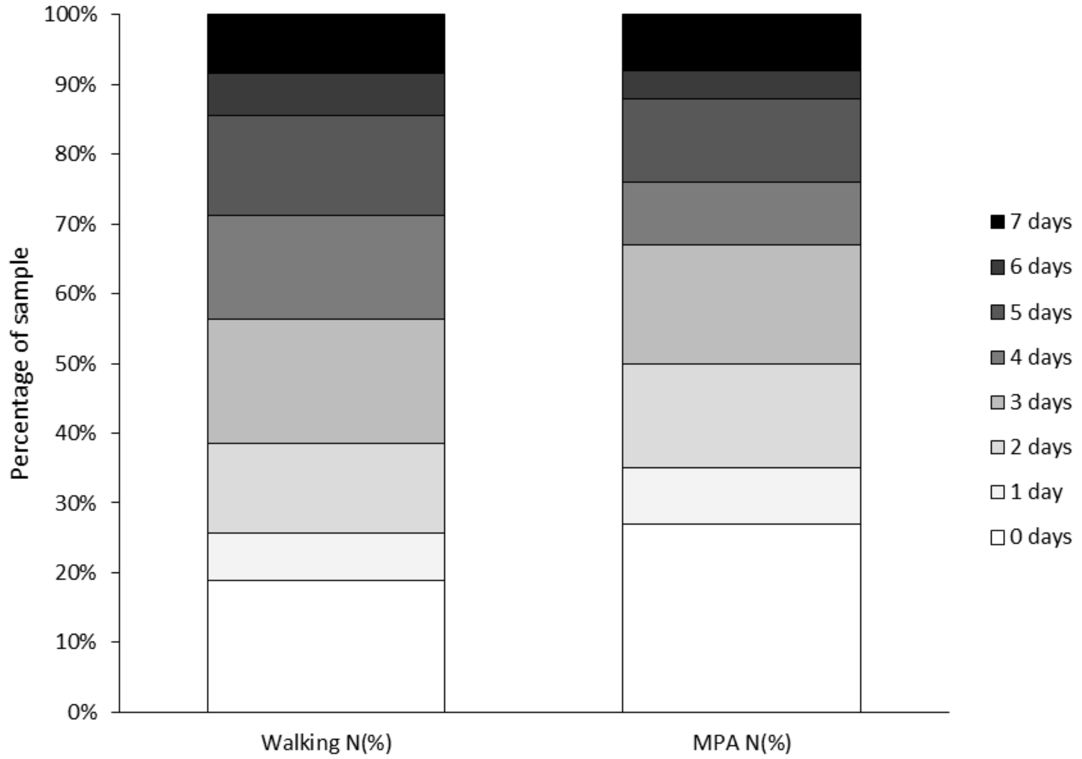


Table 5.1 presents differences in performing at least 5 days/week of walking and MPA by socio-demographics. Participants who were younger (16-24 year olds), non-retired, those not living in older household, home owners or those with regular access to a vehicle were significantly more likely to walk on at least 5 days/week. There were significant differences in all socio-demographics for regular participation in MPA, with females, 16-24 year olds, British participants, participants in employment, participants living in families, home owners or those with vehicle access being most likely to perform MPA on at least 5 days/week.

Table 5.1 Differences in walking and MPA on at least 5 days/week by socio-demographics

	Walk ≥5 days/week (n=1,742) N(%)	MPA ≥5 days/week (n=1,392) N(%)
Sex		
Male	729 (30.8)	**495 (20.9)**
Female	1013 (28.5)	**897 (25.2)**
Age group		
16-24	**191 (41.2)**	**141 (30.4)**
25-39	**528 (32.0)**	**415 (25.2)**
40-54	**482 (31.5)**	**399 (26.1)**
55-64	**239 (29.6)**	**178 (22.0)**
65+	**302 (20.5)**	**259 (17.6)**
Citizenship		
British	1512 (29.7)	**1276 (25.1)**
Non-British	230 (27.6)	**116 (13.9)**
Employment		
Working	**535 (30.7)**	**485 (34.9)**
Not working	**811 (29.2)**	**579 (20.9)**
Retired	**396 (22.5)**	**328 (18.6)**
Household		
Adult	**730 (30.9)**	**569 (24.1)**
Family	**647 (34.3)**	**501 (26.6)**
Older	**365 (21.8)**	**322 (19.2)**
Tenure		
Own	**491 (35.6)**	**401 (29.1)**
Rent	**1251 (27.5)**	**991 (21.8)**
Vehicle access		
Yes	**492 (33.9)**	**459 (31.6)**
No	**1250 (28.0)**	**933 (20.9)**

5.4.2 Independent effects of the social environment factors on physical activity

Results for models including main effects with walking on at least 5 days/week as the outcome are presented in **Table 5.2.** In models including single environmental factors and adjusting for covariates and participant sub-area (Model 1), an independent effect of each social environment factor was observed in the expected direction, i.e. more positive ratings of the social environment were associated with more frequent walking. In a multivariate model including all environmental factors, covariates and adjusting for participant sub-area (Model 2), there was a significant positive association between walking on at least 5 days/week and: ‘social support’ (OR:1.22, 95%CI=1.06-1.41, p<0.01), ‘social interaction’ (OR:1.25, 95%CI=1.10-1.42, p<0.01) and ‘cohesion and safety’ (OR:1.78, 95%CI=1.56-2.03, p<0.001). The association between ‘trust and empowerment’ and walking lost significance in Model 2.

Table 5.2 Independent effects of social and physical environmental factors on neighbourhood-based walking for at least 5 days/week (n=5,923)

Environmental factor	% walking ≥5 days	Model 1			Model 2		
		OR	95% CI	p	OR	95% CI	p
‘Social support’							
Lower	25.4	1.00			1.00		
Higher	30.9	1.27	1.11 – 1.47	**.001**	1.22	1.06 – 1.41	**.006**
‘Trust and empowerment’							
Lower	27.8	1.00			1.00		
Higher	30.9	1.21	1.07 – 1.37	**.003**	1.10	0.97 – 1.25	.141
‘Social interaction’							
Lower	25.0	1.00			1.00		
Higher	32.8	1.34	1.18 – 1.52	**.000**	1.25	1.10 – 1.42	**.001**
‘Cohesion and safety’							
Lower	21.3	1.00			1.00		
Higher	35.6	1.89	1.66 – 2.15	**.000**	1.78	1.56 – 2.03	**.000**
‘Aesthetics of built form’							
Poorer	25.7	1.00			1.00		
Better	33.2	1.60	1.35 – 1.90	**.000**	1.47	1.22 – 1.77	**.000**
‘Physical disorder’							
More cues of disorder	26.4	1.00			1.00		
Fewer cues of disorder	32.1	1.43	1.20 – 1.70	**.000**	1.13	0.94 – 1.36	.190
‘Aesthetics & maintenance of open space’							
Poorer	28.4	1.00			1.00		
Better	29.9	1.42	1.22 – 1.66	**.000**	1.32	1.13 – 1.54	**.001**

Model 1: Single social or physical environmental factor and socio-demographic covariates (age, sex, citizenship, employment status, tenure, vehicle access, mobility-limiting illness, distance to audit assessment site, neighbourhood deprivation), adjusted for participant sub-area. Model 2: All environmental factors and socio-demographic covariates, adjusted for participant sub-area. Tenure, age and limiting illness were the only significant covariates at p<0.01.

Results for models including main effects with MPA on least 5 days/week as the outcome are presented in **Table 5.3**. In Model 1, there was a significant positive association between MPA and: ‘social interaction’ (OR:6.68, 95%CI=5.59-7.97, $p<0.001$) and ‘cohesion and safety’ (OR:2.38, 95%CI=2.04-2.77, $p<0.001$). In Model 2, an independent effect was observed for: ‘social interaction’ (OR:6.16, 95%CI=5.14-7.37, $p<0.001$), ‘cohesion and safety’ (OR:1.93, 95%CI=1.65-2.27, $p<0.001$) and ‘social support’ which demonstrated a negative association with MPA (OR:0.79, 95%CI=0.67-0.94, $p<0.01$). There was no association between ‘trust and empowerment’ and MPA.

Table 5.3 Independent effects of social and physical environment factors on MPA on at least 5 days/week (n=5,923)

Environmental factor	% MPA ≥5 days	Model 1			Model 2		
		OR	95% CI	p	OR	95% CI	p
'Social support'							
Lower	22.8	1.00			1.00		
Higher	23.8	0.85	0.72 – 0.99	.034	0.79	0.67 – 0.94	**.007**
'Trust and empowerment'							
Lower	20.5	1.00			1.00		
Higher	26.3	1.14	0.99 – 1.31	.063	1.14	0.98 – 1.33	.087
'Social interaction'							
Lower	7.4	1.00			1.00		
Higher	35.6	6.68	5.59 – 7.97	**.000**	6.16	5.14 – 7.37	**.000**
'Cohesion and safety'							
Lower	13.0	1.00			1.00		
Higher	31.5	2.38	2.04 – 2.77	**.000**	1.93	1.65 – 2.27	**.000**
'Aesthetics of built form'							
Poorer	21.4	1.00			1.00		
Better	25.6	1.21	1.00 – 1.46	.050	1.02	0.82 – 1.27	.838
'Physical disorder'							
More cues of disorder	19.2	1.00			1.00		
Fewer cues of disorder	27.3	1.94	1.60 – 2.36	**.000**	1.63	1.31 – 2.03	**.000**
'Aesthetics & maintenance of open space'							
Poorer	25.4	1.00			1.00		
Better	22.5	1.32	1.11 – 1.56	**.001**	1.16	0.97 – 1.40	.107

Model 1: Single social or physical environmental factor and socio-demographic covariates (age, sex, citizenship, employment status, tenure, vehicle access, mobility-limiting illness, distance to audit assessment site and neighbourhood deprivation), adjusted for participant sub-area. Model 2: All environmental factors and socio-demographic covariates, adjusted for participant sub-area. Sex, employment, age and limiting illness were the only significant covariates at p<0.01.

5.4.3 Independent effects of the physical environment factors on physical activity

Table 5.2 presents independent effects of physical environmental factors on walking on at least 5 days/week. In Model 1, all physical environment factors were found to have significant positive associations with walking (i.e. more positive ratings of the physical environment were related to increased frequency of walking). Model 2 revealed a positive association between walking on at least 5 days/week and: ‘aesthetics of built form’ (OR:1.47, 95%CI=1.22-1.77, p<0.001) and ‘aesthetics and maintenance of open space’ (OR:1.32, 95%CI=1.13-1.54, p<0.01). An association between ‘physical disorder’ and walking was rendered non-significant in Model 2.

Associations between physical environmental factors and MPA on at least 5 days/week are reported in **Table 5.3**. In Model 1, there was an independent effect of ‘physical disorder’ and ‘aesthetics and maintenance of open space’ on MPA. In Model 2, only ‘physical disorder’ was associated with an increased likelihood of performing MPA on at least 5 days/week (OR:1.63, 95%CI=1.31-2.03, p<0.001). ‘Aesthetics of built form’ and ‘aesthetics and maintenance of open space’ had no effect on MPA in Model 2.

Tenure, age and limiting illness were significant covariates (p<0.01) in the full model for environmental effects on walking. In the full model with MPA as the outcome variable, sex, employment, age and limiting illness were significant covariates (p<0.01).

5.4.4 Interactive effects of the social and physical environment on physical activity

A final model for walking on at least 5 days/week included main effects and pairwise interaction terms between social and physical environmental factors and adjusted for covariates and participant sub-area (Model 3). This model revealed two significant interactive effects, between ‘trust and empowerment’ and ‘aesthetics and maintenance of open space’ (OR:2.05, 95%CI=1.56-2.69, p<0.001) and between ‘cohesion and safety’ and ‘physical disorder’ (OR:1.54, 95%CI=1.16-2.03, p<0.01). The model was estimated to explain 11% of the variance in the outcome when only fixed effects were included.

A final model with MPA on at least 5 days/week as the outcome included main effects and pairwise interaction terms and adjusted for socio-demographics and participant sub-area. Three significant interactions were revealed: between ‘trust and empowerment’ and ‘aesthetics and maintenance of open space’ (OR:1.53, 95%CI=1.12-2.09, p<0.01); between ‘cohesion and safety’ and ‘physical disorder’ (OR:1.66, 95%CI=1.20-2.31, p<0.01); and between ‘social interaction’ and ‘aesthetics of the built form’ (OR:2.19, 95%CI=1.51-3.19, p<0.001). The model was estimated to explain 29% of variance in the outcome when only fixed effects were included.

The ICC estimate for the null model for walking for the full sample reported that that 7% of the residual variance at level 2 in likelihood of walking on at least 5 days/week was due to sub-area effects. In the full model, sub-area effects explained 12% of the variance. The likelihood ratio test statistic showed a significant improvement in the explanatory power of the model when including a random intercept to account for sub-area effects (LR=233.31, p<0.001).

In a null model for MPA, the ICC suggested that 22% of the residual variance at level 2 was attributable to sub-area effects; the full model attributed 20% of the variance to sub-area. Inclusion of a random intercept for sub-area effects significantly improved the model (LR=410.75, p<0.001).

Results for post-hoc analyses are presented in **Table 5.4**. ‘Physical disorder’ was found to only have a significant influence on walking and MPA when a higher level of ‘cohesion and safety’ was reported (walking: OR=1.50, 95%CI=1.20-1.86, p<0.001; MPA: OR=1.94, 95%CI=1.53-2.47, p<0.001), suggesting ‘cohesion and safety’ might have moderated the effect of ‘physical disorder’. In contrast, there was a significant association between ‘cohesion and safety’ and physical activity outcomes regardless of the level of ‘physical disorder’.

Similarly, ‘social interaction’ appeared to moderate the association between ‘aesthetics of built form’ and MPA: there was only a significant effect of ‘aesthetics of built form’ on MPA when a higher level of ‘social interaction’ was reported (OR=1.40, 95%CI=1.10-1.77, $p<0.01$). ‘Social interaction’ was significantly associated with MPA at both levels of ‘aesthetics of built form’.

Post-hoc analyses supported a synergistic effect of ‘trust and empowerment’ and ‘aesthetics and maintenance of open space’ on physical activity outcomes. For both walking and MPA, there was a significant effect of ‘aesthetics and maintenance of open space’ when ‘trust and empowerment’ was reported at the higher level (walking: OR=2.12, 95%CI=1.70-2.64, $p<0.001$; MPA: OR=1.47, 95%CI=1.15-1.87, $p<0.01$), but not the lower level, and there was a significant effect of ‘trust and empowerment’ when ‘aesthetics and maintenance of open space’ was reported was at the higher level (walking: OR=1.52, 95%CI=1.30-1.77, $p<0.001$; MPA: OR=1.29, 95%CI=1.08-1.54, $p<0.01$), but not the lower level.

Table 5.4 Results for post-hoc tests examining effect of specified environmental factors on neighbourhood-based walking and MPA on at least 5 days/week

Stratification	N	Exposure factor	Walking			MPA		
			OR	95% CI	p	OR	95% CI	p
‘Trust and empowerment’ Lower	2,830	‘Aesthetics & maintenance of open space’ Lower Higher	 1.00 0.84	 0.68 – 1.04	 .109	 1.00 1.00	 0.78 – 1.27	 .984
‘Trust and empowerment’ Higher	3,093	‘Aesthetics & maintenance of open space’ Lower Higher	 1.00 2.12	 1.70 – 2.64	 **.000**	 1.00 1.47	 1.15 – 1.87	 **.002**
‘Aesthetics & maintenance of open space’ Poorer	1,995	‘Trust and empowerment’ Lower Higher	 1.00 0.76	 0.62 – 0.94	 .012	 1.00 0.88	 0.68 – 1.13	 .311
‘Aesthetics & maintenance of open space’ Better	3,928	‘Trust and empowerment’ Lower Higher	 1.00 1.52	 1.30 – 1.77	 **.000**	 1.00 1.29	 1.08 – 1.54	 **.004**
‘Cohesion and safety’ Lower	2,558	‘Physical disorder’ More cues of disorder Fewer cues of disorder	 1.00 1.10	 0.85 – 1.41	 .484	 1.00 1.10	 0.85 – 1.41	 .484
‘Cohesion and safety’ Higher	3,365	‘Physical disorder’ More cues of disorder Fewer cues of disorder	 1.00 1.50	 1.20 – 1.86	 **.000**	 1.00 1.50	 1.20 – 1.86	 **.000**
‘Physical disorder’ More cues of disorder	2,778	‘Cohesion and safety’ Lower Higher	 1.00 1.58	 1.31 – 1.91	 **.000**	 1.00 1.58	 1.31 – 1.91	 **.000**
‘Physical disorder’ Fewer cues of disorder	3,145	‘Cohesion and safety’ Lower Higher	 1.00 2.20	 1.83 – 2.65	 **.000**	 1.00 2.20	 1.83 – 2.65	 **.000**
‘Social interaction’ Lower	2,537	‘Aesthetics of built form’ Lower Higher	 -	 -	 **-**	 1.00 0.59	 0.39 – 0.91	 .016

‘Social interaction’ Higher	3,386	‘Aesthetics of built form’ Lower Higher	-	-	**-**	1.00 1.40	1.10 – 1.77	**.005**
‘Aesthetics of built form’ Poorer	3,017	‘Social interaction’ Lower Higher	-	-	**-**	1.00 4.93	3.93 – 6.18	**.000**
‘Aesthetics of built form’ Better	2,906	‘Social interaction’ Lower Higher	-	-	**-**	1.00 10.67	7.88 – 14.46	**.000**

Models were conducted by stratified group and included specified environmental factors and socio-demographic covariates (age, sex, citizenship, employment status, tenure, vehicle access, mobility-limiting illness, distance to audit assessment site and neighbourhood deprivation), adjusted for participant sub-area.

5.4.5 Stratified analyses for owners and renters

In stratified analyses for walking on at least 5 days/week presented in **Table 5.5**, the two significant physical environment factors for the full sample ('aesthetics of built form' and 'aesthetics and maintenance of open space') were non-significant in the owners group while significant social factors retained significance in this group. In contrast, two of the three significant social environment factors for the full sample ('social support' and 'social interaction') were rendered non-significant in the renters group while significant physical environment factors retained significance in this group. 'Cohesion and safety' retained significance for owners and renters, but the effect was attenuated in renters compared with owners (owners: OR:2.68, 95%CI=1.99-3.60, p<0.001; renters: OR:1.59, 95%CI=1.37-1.85, p<0.001).

Table 5.5 Independent effects of social and physical environment factors on walking on at least 5 days/week in stratified analysis

Environmental factor	Owners (n=1,379)			Renters (n=4,544)		
	OR	95% CI	p	OR	95% CI	p
'Social support'						
Lower	1.00			1.00		
Higher	1.63	1.19 – 2.24	**.003**	1.13	0.96 – 1.34	**.**135
'Trust and empowerment'						
Lower	1.00			1.00		
Higher	0.87	0.66 – 1.14	**.**307	1.18	1.02 – 1.36	.030
'Social interaction'						
Lower	1.00			1.00		
Higher	1.60	1.20 – 2.12	**.001**	1.18	1.02 – 1.37	**.**031
'Cohesion and safety'						
Lower	1.00			1.00		
Higher	2.68	1.99 – 3.60	**.000**	1.59	1.37 – 1.85	**.000**
'Aesthetics of built form'						
Poorer	1.00			1.00		
Better	1.11	0.80 – 1.54	**.**545	1.60	1.28 – 1.99	**.000**
'Physical disorder'						
More cues of disorder	1.00			1.00		
Fewer cues of disorder	0,78	0.53 – 1.15	**.**206	1.20	0.97 – 1.49	.088
'Aesthetics & maintenance of open space'						
Poorer	1.00			1.00		
Better	1.12	0.82 – 1.55	**.**473	1.33	1.11 – 1.60	**.002**

Results for stratified analyses for MPA on at least 5 days/week are presented in **Table 5.6**. In contrast to non-stratified results, 'social support' was non-significant for both groups in stratified analyses. 'Physical disorder' also became non-significant for the owners group. The effect of 'cohesion and safety' on MPA was significant for both groups, but markedly larger in the owners group (owners: OR:3.22, 95%CI=2.24-4.64, p<0.001; renters: OR=1.72, 95%CI=1.43–2.06, p<0.001).

Table 5.6 Independent effects of social and physical environment factors on MPA on at least 5 days/week in stratified analysis

Environmental factor	Owners (n=1,379)			Renters (n=4,544)		
	OR	95% CI	p	OR	95% CI	p
'Social support'						
Lower	1.00			1.00		
Higher	0.83	0.58 – 1.18	.292	0.77	0.64 – 0.94	**.010**
'Trust and empowerment'						
Lower	1.00			1.00		
Higher	1.08	0.78 – 1.48	.652	1.18	0.99 – 1.41	.071
'Social interaction'						
Lower	1.00			1.00		
Higher	6.67	4.51 – 9.87	**.000**	6.07	4.95 – 7.46	**.000**
'Cohesion and safety'						
Lower	1.00			1.00		
Higher	3.22	2.24 – 4.64	**.000**	1.72	1.43 – 2.06	**.000**
'Aesthetics of built form'						
Poorer	1.00			1.00		
Better	1.04	0.72 – 1.53	.813	0.99	0.76 – 1.29	.923
'Physical disorder'						
More cues of disorder	1.00			1.00		
Fewer cues of disorder	1.57	0.98 – 2.49	.058	1.68	1.31 – 2.16	**.000**
'Aesthetics & maintenance of open space'						
Poorer	1.00			1.00		
Better	1.18	0.81 – 1.72	.383	1.12	0.90 – 1.39	.305

5.5 Discussion

5.5.1 Summary of findings

Independent and interactive effects of the quality of the physical and social environment were observed on neighbourhood-based walking and participation in MPA in an adult population in income-deprived communities in Glasgow, UK. Effects were predominantly in the hypothesised direction, with better quality physical and social environments being associated with increased likelihood of typically performing walking or MPA on at least 5 days/week.

In models including single environmental factors (and adjusting for socio-demographic covariates and participant sub-area), all social environment factors ('social support', 'trust and empowerment', 'social interaction', 'cohesion and safety') and all physical environmental factors (‘aesthetics of built form’, ‘physical disorder’, ‘aesthetics and maintenance of open space’) were associated with frequent walking. The largest effect was observed for ‘cohesion and safety’ which predicted nearly a two-fold increase in the likelihood of frequent walking for participants reporting higher levels. In multivariate models for walking, including all environmental factors, ‘trust and empowerment’ and ‘physical disorder’ were rendered non-significant but all other factors retained significance.

For MPA, models including single environmental factors revealed a significant effect of ‘social interaction’, ‘cohesion and safety’, ‘physical disorder’ and ‘aesthetics and maintenance of open space’. A multivariate model found a significant independent effect of ‘social support’, ‘social interaction’, ‘cohesion and safety’ and ‘physical disorder’. There was a large effect of ‘social interaction’, with participants reporting higher levels of ‘social interaction’ being over 6 times more likely to perform >30 minutes of MPA on at least 5 days/week. Of the significant independent effects of social and physical environmental factors reported, only ‘social support’ and MPA had a negative association. This association was non-significant when only ‘social support’ and covariates were included in the model, but reached significance in a multivariate model including all environmental factors and covariates. Although the alpha level was reduced to $p<0.01$ to reduce the chance of a type 1 error, there remains a possibility that this is a spurious result. Alternatively, a third factor could be determining the association and might not have been sufficiently controlled for in analyses; for example, age, financial, family or health characteristics could determine a greater need for support from family, friends and neighbours and reduced participation in MPA. This could also be true for observed positive associations.

Stratified analyses for owners and renters suggest that the social environment might be more closely-associated with physical activity in individuals who own their accommodation, while the quality of the physical environment could be more important for individuals who are renting accommodation. **Study 1** showed that renters reported poorer physical and social environments, raising the possibility that physical environment factors might present an initial barrier to physical activity in this group. Findings from stratified analyses provide insight into the value of group-specific interrogation of the effect of the social and physical environment on physical activity, even when these groups live in the same sub-areas. The null effect of 'social support' on MPA in stratified analyses highlight the potential instability of a significant negative effect of social support on MPA, revealed in non-stratified analyses.

There was some evidence of an interactive effect between social and physical environmental factors on walking and MPA. In these cases, results suggested that when both social and physical environmental factors supported physical activity, participants were more likely to meet activity guidelines through regular walking or MPA than participants who experienced environments where only one aspect (social or physical) supported activity. In multivariate models including main effects and interaction terms, interactive effects on walking and MPA were revealed for 'trust and empowerment' and 'aesthetics and maintenance of open space', and for 'cohesion and safety' and 'physical disorder'. 'Social interaction' and 'aesthetics of the built form' had an interactive effect on MPA only. Post-hoc testing supported the hypothesis of a moderating effect of 'cohesion and safety' on the relationship between 'physical disorder' and walking and MPA, and a moderating effect of 'social interaction' on the association between 'aesthetics of the built form' on walking and MPA.

'Trust and empowerment' and 'aesthetics and maintenance of open space' appeared to operate synergistically on walking and MPA, with the effect of the social and physical environmental factors in combination being greater than when they acted independently. 'Trust and empowerment' only had an effect of activity when there were positive ratings of 'aesthetics and maintenance of open space', and vice versa, suggesting the two aspects of the environment reinforce one another. For example, residents with high levels of trust and empowerment may possess the motivation and capability to advocate and maintain high quality open space, prompting other residents to feel empowered to do the same. Interventions aiming to increase physical activity by minimising levels of physical disorder or improving other aspects of the physical environment might need to ensure relevant aspects of the social environment are also conducive to activity. In a sample of 380 adults living in Canada, neighbourhoods with the physical metrics of high walkability (structural and quality-related micro-scale features) and high levels of participant-reported cohesion and trust revealed the highest levels of transport-related and leisure-time walking, reflecting results reported here (Kaczynski and Glover, 2012). To my knowledge, this is the first time such results have been revealed in a UK sample.

Interactive effects of the social and physical environment on physical activity support a central tenant of socioecological models of physical activity. Findings build upon support emerging evidence from North America (e.g. King, 2008; Kaczynski and Glover, 2012; Bracy *et al.*, 2014), demonstrating independent and interactive effects on physical activity in new context.

There were some differences in results for neighbourhood-based walking and non-specific MPA. Notably, effects for ‘social interaction’ and ‘cohesion and safety’ were stronger for MPA than neighbourhood-based walking, and ‘physical disorder’ only had an effect on MPA (while effects of ‘aesthetics of the built form’ and ‘aesthetics and maintenance of open space’ were only revealed for neighbourhood-based walking). Additionally, a significant interactive effect of ‘aesthetics of built form’ and ‘social interaction’ was found for MPA, only. The stronger effects of the social environment contradict the assumption that neighbourhood exposures would be more closely related to neighbourhood-based activity than non-specific activity (Giles-Corti *et al.*, 2005). However, it is possible that although the MPA measure was non-specific, it captured activity that was predominantly performed in the neighbourhood. Indeed, Mason, Curl and Kearns (2016) suggest that the domain-specific measure of MPA used at wave 3 in the GoWell programme most often captured brisk walking, gardening, household chores and – perhaps importantly for the interactive effect of 'aesthetics of built form' and 'social interaction': use of local physical activity facilities. Future examination of environmental effects on different domains of physical activity performed in the neighbourhood would provide further insight into findings.

5.5.2 Strengths and limitations

A large, representative sample drawn from income-deprived neighbourhoods is a major strength of the study as it improves reliability and generalisability of the results to other individuals within the target population. However, it is important to note that extrapolation of findings to other contexts or populations is not possible: assessments of the social and physical environment in this study were relative and better aesthetics or higher levels of trust may not manifest in the same way in another context.

The large sample size presented a limitation in rendering objective physical activity measurement unfeasible and expensive. In addition, data were drawn from a broad research programme which did not have physical activity as a primary outcome but was concerned with measurement of the residential environment; the inclusion of more or less comprehensive measures reflect this and enforce pragmatic decision-making with regards to the use of the most valuable data for secondary analysis. In light of the available data, analyses were performed on comprehensive measures of the quality of the physical and social environment and self-report single-item measures of physical activity. As noted, these single-item measures have been previously used in routine data collection at a population level but their psychometric properties have not been tested. However, similar single-item measures of physical activity have been reported to have adequate criterion validity when compared with accelerometry and moderate validity and strong repeatability (internal reliability) against more comprehensive self-report measures (Milton and Bauman, 2011; Milton, Clemes and Bull, 2013). Furthermore, there is a valuable congruence in examining the likelihood of adherence to national physical activity guidelines (e.g. approximately 5 or more days of physical activity/week) using self-reported data, when such data were also used in the estimations of associated health benefits of physical activity to develop such guidelines (Troiano *et al.*, 2014; Kelly, Fitzsimons and Baker, 2016). Obtaining similar patterns of effect of the environment on two self-reported physical activity outcomes (walking, MPA) also supports the use of such measures. Nonetheless, it is important that future research is able to replicate reported results using more comprehensive self-report and objective physical activity measures, in addition to further examination of whether effects hold across different physical activity domains (e.g. transport-related, leisure-time). Further research using neighbourhood-based MPA - in addition to neighbourhood-based walking as used in this study - might increase the sensitivity to detect associations with the neighbourhood environment with this physical activity outcome. Lastly, it is important to interpret results while acknowledging that participants achieving less than 5 days of neighbourhood-based walking or MPA may have achieved recommended amounts of activity through a combination of neighbourhood-based walking or non-specific MPA and other types of activity. It was not possible to create a composite activity measure for this study. Nonetheless, in light of data which suggest walking is typically the largest contributor to meeting guidelines (National Institute for Health and Care Excellence, 2012), it was deemed meaningful to use 5 days as a cut-off for the walking and MPA outcomes.

The causal direction of reported associations cannot be assessed using a cross-sectional study design. It is possible that increased physical activity improves the quality of an environment by providing more opportunity to interact with neighbours or concern and action around the quality of the physical environment, or that a third factor directly influences both the quality of the environment and physical activity. In addition, it is possible that more active individuals select to live in areas with better quality physical and social environments in which to be active. This concern of neighbourhood self-selection has previously been partly addressed by capturing and statistically adjusting for participant-reported neighbourhood selection (e.g. McCormack *et al.*, 2017) and assessing individuals' physical activity levels before and after relocation to activity-supportive neighbourhoods to examine whether changes in activity correspond to pre-move levels (Vehige Calise *et al.*, 2013). In the current study, data on participant–reported neighbourhood selection were not available, however, the sample were predominantly living in socially-rented accommodation. At the time of data collection, choice-based letting (where tenants are able to directly bid for preferred properties) was not practiced by housing associations operating in the neighbourhoods (Shelter, 2005). It could therefore be speculated that self-selection into neighbourhoods is less problematic in this sample. However, selection into neighbourhoods was likely to be determined by other individual factors which could be associated with physical activity outcomes. While some of these characteristics are controlled for at an individual level in analyses, some residual confounding may still exist. Remaining variance which was unexplained in the full regression models suggests that other factors are important in determining physical activity behaviour.

Although neighbourhood deprivation was included as a covariate in regression models, it was not possible to control for income or deprivation at an individual level as data were not available (<25% of the sample provided data on income). Vehicle access and employment were used as proxy measures; however, it remains possible that effects of individual-level socioeconomic status on perceptions of the social environment or self-reported physical activity were not accounted for statistically. Because measures of the physical environment were objective rather than self-reported, it seems less probable that individual level socioeconomic status influenced any effect of the physical environment which would not be already captured by neighbourhood deprivation, unless individual income or deprivation is spatially clustered within neighbourhoods.

Structural physical environment constructs that are often incorporated in measures of walkability (e.g. density, connectivity and land-use mix) were not within the scope of this study (Cervero and Kockelman, 1997). Instead, the study aims addressed recent findings suggesting that improving the quality of the physical and social environment (e.g. maintenance, aesthetics, physical and social disorder) may be more practical and affordable intervention strategies to increase activity levels (Neckerman *et al.*, 2009; Kerr *et al.*, 2016; Thornton *et al.*, 2016). Furthermore, targeting features of the physical environment which may be disproportionately poorer in deprived neighbourhoods compared with non-deprived neighbourhoods may help to attenuate established health inequalities (Neckerman *et al.*, 2009; Thornton *et al.*, 2016). Nonetheless, it is necessary to acknowledge the potential additional influence of structural macro-scale elements of the physical environment on physical activity when interpreting the results presented here.

5.5.3 Implications for future research

Kerr *et al.* highlight micro-scale features of the physical environment, such as aesthetics and disorder, as potentially impactful low-cost intervention targets (Kerr *et al.*, 2016). Findings from the current study raise the possibility that intervening to increase physical activity through reduction of physical disorder or creation of more attractive and interesting built form might have the largest impact when relevant aspects of the social environment are also supportive of physical activity. Along with the results from analyses stratified by tenure, these findings suggest that policy employing active design principles to promote healthy environments should be informed by timely research that is, as far as possible, specific to the resident population and context.

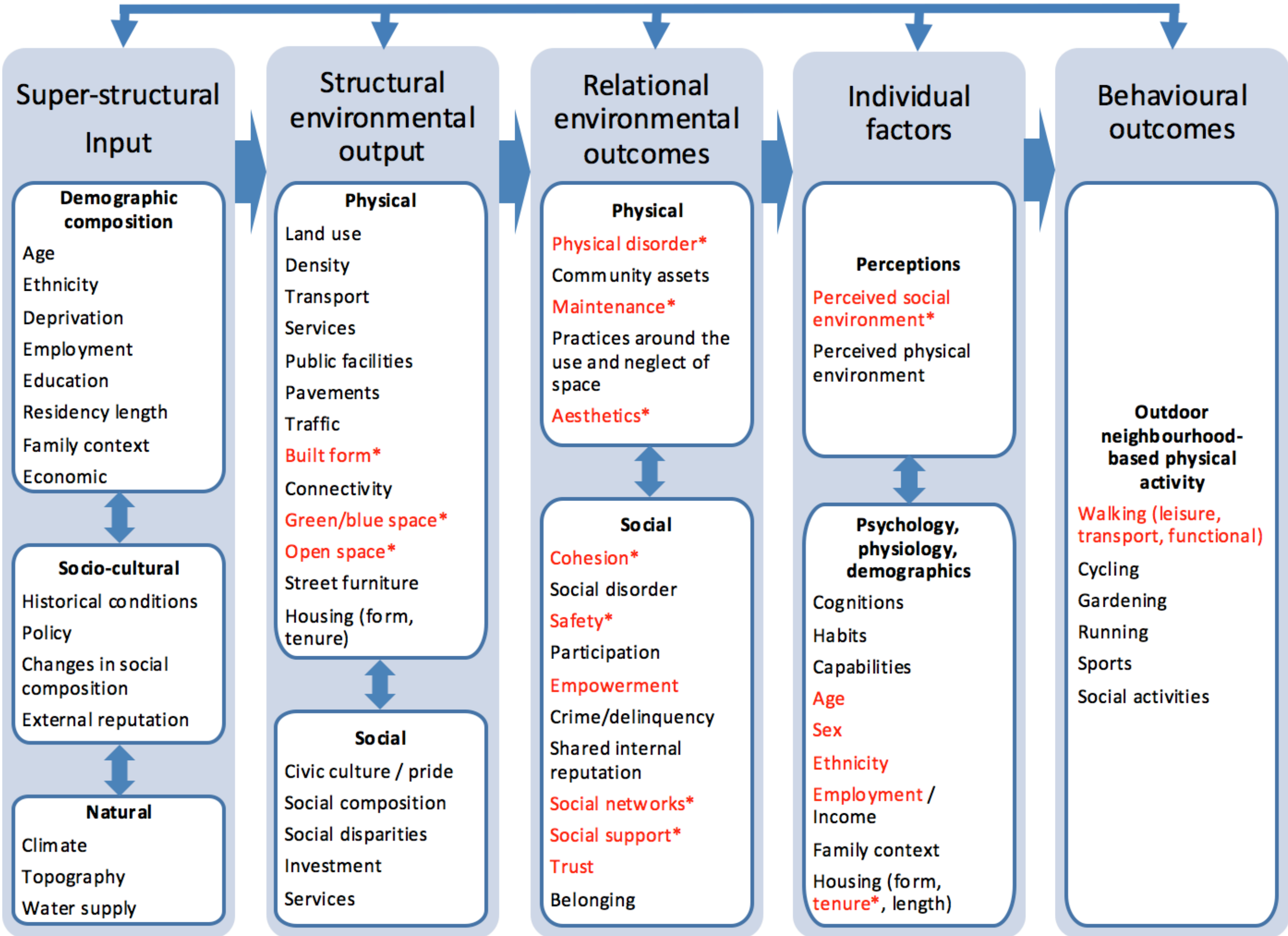
Longitudinal and quasi-experimental study designs will permit valuable insight into the direction of effects between the physical and social environment and physical activity. However, as noted in **Chapter 1**, the relationship between the environment and physical activity is likely to be complex (Rutter, Glonti and Lakerveld, 2016). Therefore, qualitative data is also likely to provide valuable insight into the direction of effects which inform conceptualisation of neighbourhood environmental effects on physical activity.

5.5.4 Conclusions

Independent and interactive effects of the quality of the neighbourhood physical and social environment on neighbourhood-based walking and non-specific MPA were reported. Findings from the systematic literature review reported in **Section 1.4** indicate that this was the first time independent and interactive effects of the social and physical environment were demonstrated in a sample of adults living in deprived neighbourhoods in the UK. Simultaneously targeting aspects of the social and physical environment might engender the largest impact on physical activity; however, further qualitative and longitudinal examination of key environmental correlates is required to conceptualise and test potential pathways between neighbourhood social and physical environments and physical activity in this population.

Figure 5.2 incorporates findings from **Study 2** into the logic model. Factors that were examined in relation to neighbourhood-based walking are demarcated in red; a significant independent effect on the outcome is denoted with an asterisk. The only socio-demographic variable examined in analyses with neighbourhood-based walking was tenure, therefore, other covariates are not demarcated in red text.

Figure 5.2 Logic model of neighbourhood environmental influences on neighbourhood-based physical activity in deprived communities



Red text denotes factor examined in **Study 2**. * Denotes significant association with physical activity.

Chapter 6 Study 3: A qualitative examination of supportive environments for physical activity in deprived neighbourhoods: Active Living in Glasgow's Neighbourhoods[12]

6.1 Introduction

As previously documented in this thesis, there is evidence that aspects of the social and physical neighbourhood environment influences physical activity. However, much of the current evidence is not context- or population-specific, potentially masking the real influence of the neighbourhood environment. **Studies 1 and 2** provided original empirical evidence of the interplay between social and physical environmental factors and their independent and interactive association with walking and MPA in a sample of adults living in an income-deprived context in the UK. However, the quantitative nature of these studies mean they are restricted in the insight they can provide into how and why such associations arise.

Through an investigation of descriptive narrative rather than numerical data, qualitative research is well-placed to acknowledge and explore the rich experiences influencing behaviour and to unpack some of the complex relationships operating between influences. For example, in Belon *et al.*'s study in Belfast, Northern Ireland, 14 focus groups aimed at examining factors that impeded or facilitated the use of local physical activity infrastructure revealed that participants didn't view physical activity participation as being determined by discrete facilitators and barriers but a 'complex web of concerns' including threats of violence, vandalism, actions of neighbours, weather and the wider political environment (Belon *et al.*, 2014). The findings advocate a broad socioecological perspective on environmental influences on activity. A meta-synthesis of qualitative studies published in 2016 extracted four themes that were recurrently observed as neighbourhood influences on walking in adults which also pertained to physical and social aspects; they were: 'environmental aesthetics', 'convenience and efficient', 'social relations' and 'safety and security' (Dadpour, Pakzad and Khankeh,

[12] A version of this study has been published in *Social Science & Medicine* (Sawyer et al., 2018)

2016). However, of the 10 studies included in the review, only Burgoyne, Coleman and Perry's (2007) study with a sample from Ireland was conducted in a deprived context. In this study, focus groups comprising 53 adults aimed to explore the null effect behind an intervention to increase neighbourhood physical activity through provision of a new walking route with signage. The authors reported that barriers, including perceived neglect of the environment by local authorities and anti-social behaviour of local residents, mitigated the intended impact of improvements in the physical environment. Although not included in the meta-synthesis, a focus group study of 27 adults living in deprived neighbourhoods in the USA identified social connectedness and crime prevention as important targets for increasing physical activity (Griffin *et al.*, 2008).

A complex interplay between social and physical factors was evident in Seaman, Jones and Ellaway's (2010) study of neighbourhood greenspace usage in a deprived context in Glasgow, UK. As in Burgoyne, Coleman and Perry's (2007) study, this research was specific to usage of a particular amenity, although in this instance, physical activity was not the primary focus and it was not included in Dadpour, Pakzad and Khankeh's (2016) meta-synthesis. The authors reported that social integration and cohesion within the neighbourhood played an important role in residents perceiving the greenspace as accessible by assuaging the impact of barriers including anti-social behaviour. Elsewhere within the UK, Hanson, Guell and Jones' (2016) study of indicators for participation in organised walking groups in deprived communities included interview questions about settings for independent walking (i.e. not in groups), identifying physical influences such as ‘car parking’, ‘aesthetics’ and ‘seating’.

Despite insight into the simultaneous roles of social and physical aspects of the environment on facility usage and physical activity offered in previous research, there remains a paucity of evidence on mechanisms through which the wider neighbourhood environment supports or discourages physical activity in a deprived context in the UK.

6.2 Aims

The aim of **Study 3** was to examine social and physical environmental factors that were perceived by residents to support physical activity in a deprived context in the UK. This investigation aimed to further understand residents' experience and use of neighbourhood environments and how environmental factors manifest and elicit influence over activity. Findings will further inform the logic model of neighbourhood environmental influences on physical activity, discussed in **Section 1.5** by providing preliminary insight into the potential causal mechanisms operating between factors.

6.3 Methods

6.3.1 Study design

Semi-structured photo-elicitation interviews were conducted with individual participants, using individual participants' photography. Photo-elicitation interviews were used as they are advantageous in encouraging the participant to assume a more active role in the research process and re-balancing the power between researcher and participant (Wang and Burris, 1997). This is achieved by the participant taking photographs of aspects of the environment they perceive as salient to the research question (i.e. acting as the observer) and then using their photographs to guide the interview.

6.3.2 Population

Methods are described in detail in **Section 3.2**. In brief, participants were adults (aged ≥16 years) who had resided in two GoWell neighbourhoods, Drumchapel and Govan, for a minimum of 12 months.

Studies 1 and 2 revealed that living in rented accommodation was associated with poorer quality social and physical environments and differential relationships between the neighbourhood environment and physical activity. Therefore, this study focused on individuals living in rented accommodation. Privately-rented accommodation comprised only 2% of rented accommodation in GoWell at wave 1, therefore only participants living in socially-rented accommodation were invited to participate.

6.3.3 Photo elicitation process and interview framework

More details on the photo-elicitation process and semi-structured framework are presented in **Section 3.2.3**. In brief, participants were provided with a 27-exposure disposable camera and asked to take photographs of their neighbourhood according to a briefing over a 7-day period. Participants were allowed to self-define the boundaries of their neighbourhood. Two participants were allowed to use their personal digital camera rather than the offered disposable camera, due to an expressed preference. The briefing was purposefully loose but asked participants to consider social and physical factors in the environment which influenced being active in the neighbourhood. Physical activity could be any unstructured or structured activity performed indoors or outdoors. Relevant concepts including the social environment, physical environment and physical activity were verbally described to participants at an initial meeting. Photographs were developed and used in semi-structured, face-to-face photo-elicitation interviews. Participants were encouraged to use the photographs to support their responses and photographs were used to guide and direct interview questions.

6.3.4 Approach to analysis

More details on analyses are provided in **Section 3.2.4**. Interviews were digitally recorded, transferred and stored on a secure computer and then deleted from the digital recording device. Hard copies of photographs were stored securely and scanned to enable digital storage.

Thematic analysis was used to derive themes from the interview data (Braun and Clarke, 2008). As noted in **Section 3.2.4**, framework analysis was not considered a feasible option as at the time of analysis there was no established conceptual or causal framework which specifically describes environmental effects on neighbourhood-based physical activity in income-deprived communities. Therefore, inductive, data-driven thematic analysis was performed, which protected against potentially disregarding important aspects of the relationship between social and physical environments and physical activity. Inter-coder agreement between myself and my supervisor (AF) was assessed for a random selection of 3 interviews to ratify extracted themes. Agreement was deemed to be excellent at >99% agreement of codes following discussion. A coding hierarchy was developed which comprised 95 first-level codes nested within 18 second-level codes which were nested within 5 thematic codes; the hierarchy of second-level and thematic codes is displayed in **Appendix 6.1**.

6.4 Results

6.4.1 Participant characteristics

A total of 23 participants provided neighbourhood photographs and participated in semi-structured interviews lasting between 45-90 minutes. Participant characteristics are presented in **Table 6.1**. Participants were relatively evenly distributed across neighbourhoods (Govan: n=12; Drumchapel: n=11), sex (male: n=10; female: n=13), and age (16-24 years: n=5; 25-39 years: n=6; 40-60 years: n=7; >60 years: n=5), which ranged from 16-77 years old. Only 2 of the 23 participants were non-British and most participants resided in single-person households (single-person: n=9, adult only: n=5, family: n=7, no answer: n=2).

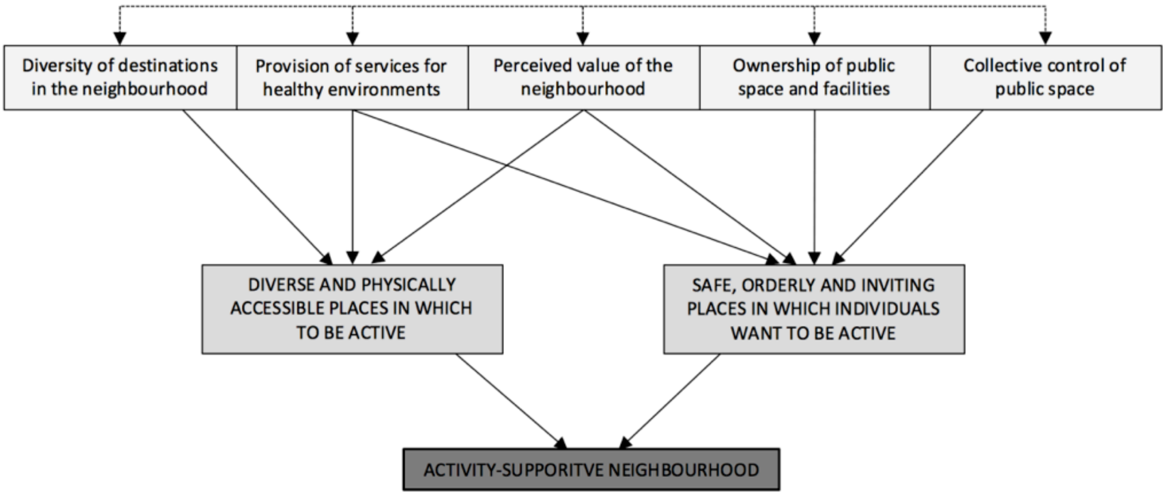
Table 6.1 Participant characteristics

Characteristic	Total N (%)	Govan N (%)	Drumchapel N (%)
Sex			
Male	10 (43.5)	7 (58.3)	3 (27.3)
Female	13 (56.5)	5 (41.7)	8 (72.7)
Age category			
16-24	5 (21.7)	2 (16.7)	3 (27.3)
25-39	6 (26.1)	3 (25.0)	3 (27.3)
40-60	7 (30.4)	3 (25.0)	4 (36.4)
>60	5 (21.7)	4 (33.3)	1 (9.1)
Ethnicity			
British	21 (91.3)	10 (83.3)	11 (100.0)
Non-British	2 (8.7)	2 (16.7)	0 (0.0)
Household			
Single-person	9 (39.1)	7 (58.3)	2 (18.2)
Adult only	5 (21.7)	1 (8.3)	4 (36.4)
Family	7 (30.4)	3 (25.0)	4 (36.4)
No answer	2 (8.7)	1 (8.3)	1 (9.1)

6.4.2 Identified themes

Physical activity was discussed by participants as a broad construct encompassing structured activity (i.e. exercise) and unstructured activity, predominantly performed outdoors in the neighbourhood environment. Interview data tended to describe upstream environmental factors which influenced physical activity by constructing a social and physical environment that was supportive, or unsupportive, of activity. As displayed in **Figure 6.1**, themes coalesced around two aspects which were identified as central to an activity-supportive environment within this context: environments needed to be diverse and physically accessible to provide the opportunity to perform activity; and safe, orderly and inviting so individuals have motivation and capability to perform activity.

Figure 6.1 Relationship of reported themes to two central aspects of activity-supportive environments identified by participants



Arrows indicate the cross-cutting influence of themes on central aspects of an activity-supportive neighbourhood environment and the interplay between themes.

Five themes emerged from the data as contributing to the central aspects of a supportive neighbourhood environment for physical activity (**Figure 6.1**). They were named: 'diversity of destinations in the neighbourhood'; 'provision of services to support healthy environments'; 'ownership of public space and facilities'; 'collective control of public space to prevent disorder'; and 'perceived value of the neighbourhood'. Participants frequently discussed the dependency and interplay between themes.

6.4.2.1 Diversity of destinations in the neighbourhood

Environments provided an opportunity for individuals to be active by offering a diversity of destinations to visit. This was discussed at a smaller geographical scale in terms of a neighbourhood high street, but also at a broader scale encompassing the whole neighbourhood and the provision of diverse destinations for errands and indoor and outdoor facilities for leisure, such as greenspace. Social and economic deprivation in the local area was thought to have reduced the diversity and number of local destinations, creating a barrier to activity in the two neighbourhoods.

> *"Long ago… Everything you needed was in Govan. There was numerous fish shops, butchers, fruit shops, shoe shops, various fashion shops, furniture shops, everything... You could come down to Govan on a Saturday and spend the afternoon in Govan. You can't now. Ten minutes and [claps] you've seen it."* Female, >60 years, Govan.

Diversity of destinations was characterised by inclusivity through a diversity in: function (e.g. functional, recreational); operating hours (e.g. night-time and day-time); users (e.g. by age or need); and ordained or structured use (e.g. specified and non-specified functions). By not fulfilling these criteria, environments could manifest as mono-functional and exclude groups by making them feel unsafe or unwelcome, discouraging activity.

> *"I think it probably does impact on some people's behaviour because like they don't want to be going out until late at night... I don't think it's good that it's only pubs that are open at night and that creates like a different atmosphere about the place. It feels like a really safe place to be during the day."* Male, 25-39 years, Govan.

Participants recognised that the residential populations had needs which should be addressed through the provision of specific types of destination. For example, economic factors produced a demand for physical activity facilities which were low-cost or free to use, especially for young people.

> *"Before [the children would] all climb over the fence, so we created a pay-a-pound for a walk-on ticket and they get their ticket and they go on [the football pitch], in a safe environment and not climbing fences"* Female, 40-60 years, Drumchapel.

In addition, perceived growing immigrant populations necessitated destinations which promoted integration and social cohesion between different resident groups. Furthermore, due to the high proportion of social housing in the neighbourhoods, particular housing stock was perceived as being allocated to individuals with greater needs due to alcohol or drug-related issues. These factors impacted upon the provision of destinations in the local area.

> *"[The reason there are no seating areas in cafes] is probably just because the people who would tend to sit in would be the undesirables I would imagine, during the day aye, it's the people that are not workin' will be the people that they don't really want in your business*." Male, 25-39 years, Drumchapel.

However, participants also noted that even when desirable destinations were available to local community, individual factors could still impede their use: destinations were therefore perceived as necessary but not sufficient in creating an activity-supportive neighbourhood environment.

> *"When I've gone up there with the dogs I've never ever bumped into anybody and I think this is beautiful here and they just don't use it, I feel like chappin' [knocking] on doors 'come on, come on out running in the fields!'"* Female, 25-39 years, Drumchapel (**Figure 6.2**).

Figure 6.2 Participant photograph of greenspace in Drumchapel

6.4.2.2 Provision of services to support healthy environments

The provision of efficient and affordable public and private services was recognised as vital in i) making destinations in the neighbourhood and beyond physically accessible to residents and ii) ensuring environments were maintained with acceptably low levels of social and physical disorder. Street lighting, punctual bin collection, adequate roads and paths and extensive, reliable and affordable public transport were reported as key services which supported physical activity by allowing individuals to use local destinations and making them pleasant and inviting places in which to be active.

> *"They've put a lot of thought into the new kind of [housing] scheme there, they've got this like thoroughfare right the way through it and it's also a cycle path as well. It takes you from the library right into Govan. It's pretty nice and you're just away from traffic and stuff."* Male, 25-39 years, Govan.

> *"I think the ferry is only ever on free during the school holidays and then it goes off. So to go on the underground to go to that it's quite costly... So I think the ferry and that should be free… it cannae cost that much [to fund]!"* Female, >60 years, Govan (**Figure 6.3**).

Figure 6.3 Participant photograph of the summer ferry in Govan

Community organisations were noted as valuable service-providers by providing destinations for activity (by getting individuals out of their home, or performing activity at the destination) and strengthening social networks and cohesion in the community. Community organisations included craft or hobby groups, support groups (e.g. mental health support, woman's groups), well-being hubs with community gardens or allotments and charitable organisations.

> *"I think a lot of people stay in the house a lot. 'Cause like the weather's so bad though. And they just like sit and watch telly too much but that's because there isn't much to do, even as adults. That's why people should get to this place [community garden and hub] because I come here nearly every day, it gets me out of the house."* Female, 16-24 years, Govan.

> *"Unity had a bike workshop down, just very close to Govan Cross. And like it's free to sort of like go in and just work on your bike."* Male, 25-39 years, Govan.

6.4.2.3 Ownership of public space and facilities

Perceived ownership of shared space and facilities supported activity, by creating an inclusive environment which invited all residents to use the space, and by discouraging disorder to ensure the space and facilities were well-maintained and functional for use. Participants reported that there currently existed an imbalance in the perceived ownership of space, whereby certain groups such as young people had a sense of territoriality over certain areas. It was felt that this could lead to social and physical disorder which further eroded a sense of ownership. Breaking this cycle by sharing space and facilities and engendering pride in the local area was seen as crucial in creating a collective sense of ownership and responsibility for the shared neighbourhood environment, which would support physical activity.

> *"It's only the river Clyde but I mean it's quite a nice… it also lets you go out and walk wi' the pram and meet people and sit and have a gab 'cause they've got all these wee seatin'. We don't want it to be somewhere fae young people to go doon and drink. So if we don't keep walkin' along these, that's what's going to happen because it's going to be a place where young people can hide."* Female, >60 years, Govan.

> *"Young people who don't have much respect [kept damaging the polytunnel in the community garden] but people who work there, they just keep patching it up… [The gardener] was like 'oh, come on in', he was just being inviting to like make [the young people] feel welcome… it hasn't happened since so I think it has worked. Because the main thing is that it is for everybody, it's for the community."* Female, 16-24 years, Govan (**Figure 6.4**).

Figure 6.4 Participant photograph of a greenhouse in a community garden in Govan

Housing associations were identified as actors with the capability of bestowing a collective sense of ownership over residential properties and land. This reflected the sample who exclusively lived in accommodation rented from housing associations. In order to achieve this sense of ownership and reduce cues of territoriality or a lack of pride in the area, it was suggested that associations might fund tenants to update or repair their accommodation. This could also help to address acknowledged resident attitudes towards living in rented accommodation whereby a resident might relinquish responsibility for the upkeep of their accommodation or surrounding area to other residents or the housing association. Finally, participants also noted that the local social and economic environment could influence the appearance and use of neighbourhood public space and facilities.

> *"If you own it, you want to keep it clean, if you're just renting, you don't pay for anything like that, a lot of them just think someone else will do it... they should take some sort of responsibility and keep their own area clean."* Male, >60 years, Govan.

> *"The housing situation, y'know, if you're not happy in your surroundings, I think you wouldn't bother with the outside."* Female, 40-60 years, Govan.

6.4.2.4 Collective control of public space to prevent disorder

Collective informal control of public space to reduce disorder supported physical activity. Participants believed that management of social disorder could strengthen perceptions of safety. Furthermore, collectively enforcing norms around the disapproval of physical disorder could create more orderly, attractive places in which to be active. Linked to perceived ownership of space, within the two neighbourhoods certain places were identified as being perceived to be controlled by specific groups who would use the space to loiter and drink alcohol. This behaviour engendered a hostile, unsafe environment which other groups could not overcome and therefore acted as a barrier to excluded groups, preventing physical activity.

> *"There's a drinking culture down there... Elderpark, it's a beautiful park, during the day it's well-used with people walking their dogs, doing bits and pieces… everything starts to change as the young ones come out of school, they've gone into the park, they're running about with this gang, and then it becomes eh, not safe… They've spent this money putting a nice play park in and a nice wee kind of gymnasium for people to do things, you know what I mean, but if you're scared or intimidated to go to these places then you tend just to stay away."* Male, 40-60 years, Govan (**Figure 6.5**).

Figure 6.5 Participant photograph of physical cues of drinking culture in Elderpark in Govan

Formal policing was not seen as the solution to combat disorder as the disorderly or intimidating behaviour was often not criminal; rather, participants saw a role for collective control wielded by the wider community which could enforce norms for behaviour and reclaim the space.

> *"When you'll have other people sticking together to stand up against these ones that are causing all the hassle and they'll get ousted… If they cannae get away with it there, they'll want to go somewhere else."* Male, 40-60 years, Govan.

Collective control, or a perceived lack of it, could go beyond resolving particular instances of social or physical order, by creating an atmosphere which precipitated (dis)order. For example, cues of social disorder (e.g. **Figure 6.5**), poor street lighting and a negative reputation of the area were sufficient to deter activity in certain places when there was a perceived lack of collective control. Cues of collective control, born from strong social networks, support and cohesion, could rectify this. For example, informal social interactions on the street or collective supervision of children were thought to mitigate cues of disorder and create an environment which felt safe.

> *"I mean obviously Govan has a bad reputation for that kind of thing but I do feel quite safe. Yeah I guess when you see people chatting to each other on the street you kind of feel a sense of people look out for each other."* Male, 25-39 years, Govan.

Certain aspects of this social contract were seen as specific to the context, and collective control as being constructed from local economic, cultural and political factors. For example, social norms and cohesion arose from close-knit communities of individuals who socialised within the neighbourhood and lived close-by to neighbours in tenement buildings (apartment blocks) with shared stairwells or who had shared cultural heritage and value.

> *"[Housing association] schemes are the only place you'll find toddlers running about. Where's the adults? 'Cause nothing ever happens to the kids, they trust them and they trust people to look after them. You never see it anywhere else… that's a scheme thing."* Female, 40-60 years, Drumchapel.

A lack of social integration prevented the dissemination and informal enforcement of social norms. Participants cited integration as an important issue in changing residential populations which they believed to have experienced outward migration due to lack of employment opportunities, and inward migration due to foreign immigration.

6.4.2.5 Perceived value of the neighbourhood

Perceived value of the neighbourhood supported physical activity by creating destinations for activity, and ensuring such places were inviting and orderly. Valuation of the neighbourhood was important both in terms of the perceived value held by those external to the neighbourhood (i.e. landowners, service-providers and non-residents), and perceived value held by those internal to the neighbourhood (i.e. residential community).

Poorly maintained and derelict public space and facilities and a shortage of inward investment elicited perceptions that those in authority, such as landowners and service-providers, did not value the neighbourhood. These features of the environment were also believed to inform negative external reputations of the neighbourhood. Other features of the physical environment were reported as symptomatic of a negative internal reputation held by residents; these included litter, dog foul, fly-tipping and vandalism. External valuations of the neighbourhood manifested through the environment were thought to reinforce internal valuations, and vice versa.

> *"I think that influences on how Drumchapel is looked at on a whole, 'cause they see all the run-down buildings like the old police station, all of our waste land and think oh it must be a bad, dingy place to live when it's not, we just need a new face."* Female, 16-24 years, Drumchapel.

> *"If [residents] do care, they should be like showing some respect, listening to other people, tidying up after themselves but I think none of them cares about it… they don't care about the place 'cause it's already dirty, it's already damaged."* Male, 16-24 years, Govan.

Conversely, positive cues including well-maintained gardens indicated residents' pride in their local area. Participants understood these negative or positive cues and residents' behaviour as operating reciprocally by sanctioning norms around social interaction and physical disorder.

> *"Because if you've got a broken-down area, you'll have broken-down people, simple as that. Have a nice area, have nice people. I'll give you an example: yesterday morning, stood out in my back garden have a cup of coffee and a cigarette and this guy walks up to me… he says 'it's nice to see somebody's taking pride in their area'. I said 'ah, I worked on it [participant's garden], I like doing it, I don't just do it for myself'."* Male, >60 years, Govan (**Figure 6.6**).

Figure 6.6 Participant photograph of own garden in Govan

Evidence of investment in the neighbourhood through improvement to the physical environment also prevented disorder by instilling a sense of pride in residents and influencing behaviour.

> *"That whole street has had like a facelift… Before [the shops] were sort of like a bit tatty or just a bit crap really. I mean, it's just a really nice street now. And it is just like an aesthetic thing but it makes a big difference, that street's really pleasant to walk down and it's like, suddenly there's less dog shit on the street and stuff, people don't want to ruin it… It lifts people's like pride in the place if they see stuff like that going on."* Male, 25-39 years, Govan.

> *"What happens is there's less anti-social behaviour. Err, like, if someone's littering, y'know, years ago, away back before the [housing] improvement works happened, they wouldn't think nothing of just dropping their papers on the ground. Where's now, you know, they feel slightly guilty about it...'Oh, I shouldn't have done that'."* Male, 16-24 years, Drumchapel (**Figure 6.7**).

Figure 6.7 Participant photograph of housing improvements in Drumchapel

Neighbourhoods were not considered as isolated areas within the city and comparisons with other neighbourhoods were used to emphasise and evidence perceived valuations. These comparisons highlighted the influence of the wider context and local economic factors and were used to illustrate how negative external reputations could be formed by the quality of the physical environment.

> *"If this was in a different housing area they'd be a bin there. But the vandals come down… they think it's funny just to get your bins off. That was like that for I don't know how long before a new bin goes on... If this was in a different place like Bearsden [affluent neighbourhood] you wouldn't get that."* Female, 40-60 years, Drumchapel (**Figure 6.8**).

Figure 6.8 Participant photograph of a dog waste bin in Drumchapel

"In another area that [path] would be all trimmed and all cut back and quite a nice wee walk, but because of where it is in Drumchapel, they just leave it… It should be nice and clean and tidy to encourage people to walk up it but a lot of folk won't walk up there because it's litter, it smells, you don't know what you're gonna encounter up there." Female, 40-60 years, Drumchapel (**Figure 6.9**).

Figure 6.9 Participant photograph of a walking path in Drumchapel

Participants noted that the salience of cues of the neighbourhoods' perceived value increased when the place or feature of the environment was culturally or physically prominent. In such instances, neglect or poor condition could be symbolic of the valuation of the community as being neglected, for example, due to post-industrial deprivation begetting unmet economic and social needs.

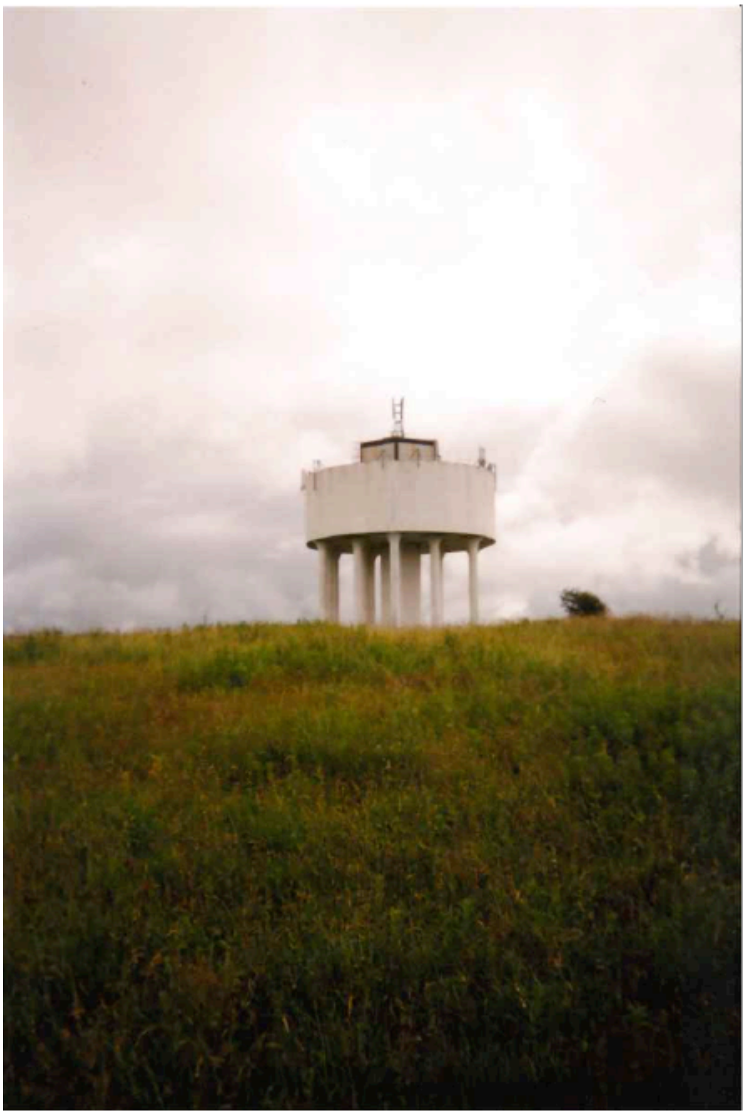
> *"North of the city they seem to get the money to do things easier than here… And what's around here is the graving docks, the dry docks… it's all weed-infested. So, there's nothing there… to me that is a perfect site for a shipping museum dedicated to the shipbuilding. I mean you saw the pictures… I mean it's all there ready to be built. Up north, if you see the buildings that have been refurbished over there. The Transport Museum and that building over there has been refurbished, that's the north of the city. You could do exactly the same with this… I certainly think changing this area, making the dry docks into something, that change would be magnificent."* Male, >60 years, Govan (**Figure 6.10**).

Figure 6.10 Participant photograph of the historic dry docks in Govan

Participants noted that these symbolic features of the local environment presented an opportunity to foster a sense of place and pride in the neighbourhood, creating attractive places in which to be active.

> *"You know you're in Drumchapel when you see the water tower. It's part of it, it's like the finishing cran, or it's like sort of the Eiffel tower."* Female, 40-60 years, Drumchapel (**Figure 6.11**).

Figure 6.11 Participant photograph of the water tower in Drumchapel



6.4.3 Brief case studies demonstrating interplay between themes

Themes were seldom discussed in isolation; they were perceived as interrelated and acting simultaneously upon the neighbourhood environment to support or discourage physical activity. **Figure 6.1** illustrates the interdependency between themes and how they were perceived as collectively fostering an activity-supportive neighbourhood environment. To demonstrate this interplay, a case study from each neighbourhood is considered. These case studies were discussed in depth by nearly all participants from the respective neighbourhood.

6.4.3.1 Drumchapel shopping centre

The shopping centre in Drumchapel (**Figure 6.12**) is the largest collection of shops in the neighbourhood and is situated nearby other amenities including the library, health centre, public transport hubs and greenspace. It was built in the 1960-70s and is a pedestrianised, uncovered shopping precinct.

Figure 6.12 Participant photograph of the shopping centre in Drumchapel

Although the provision of functional destinations could have supported physical activity, participants identified the shopping centre as an unsupportive environment due to a number of contributing factors. Firstly, while the destinations in the shopping centre were not mono-functional - including a job centre, an off-licence and a public house, participants suggested that destinations predominantly served a single user-group. A number of empty units and the lack of recreational and shopping destinations were thought to compel residents to visit these types of destinations outside of the neighbourhood removing these users from the area. Secondly, because the destinations were thought to serve a single user-group, participants held the perception that this group had ownership of the space. As a result, emergent patterns of intimidating territorial behaviour such as loitering outside of the public house were not contested by collective informal control; the police station situated nearby was perceived to be equally unsuccessful in combatting this behaviour.

> *"I don't feel safe, because there's so many people that just walk out of it just look at you as if... 'What the hell are you doing here?' 'You don't... you're not supposed to be here. You're not a regular member of [the public house]'…It's quite a hostile environment."* Female, 16-24 years, Drumchapel.

> *"They need a bomb on it! It's horrible! They've no' got enough shops. The shops are closing down, I think it's the rates and everything are too high now. And how it used to be was marvellous but that'll no' come back 'cause with everything else they've no' got the money. You don't want to go down to the shopping centre 'cause there's always alcoholics or somebody passing 'have you got a fag? have you got a fag? 50 pence?'."* Female, >60 years, Drumchapel.

> *"The problem with the shopping centre is you've got the off-sales obviously, then you've got the chemists, the job centre so they're the 3 places where they're gravitating towards.…You see if there were more shops you'd probably find an increase in people going, not just the alcoholics or the addicts."* Male, 16-24 years, Drumchapel.

Empty and neglected buildings were reported as indicating that landowners and service-providers did not perceive the shopping centre and local community as valuable. In combination with issues around perceived territoriality, these physical features informed perceived negative external reputations held by visitors and others living outside of the neighbourhood which could otherwise support physical activity and be a local asset.

> *"They want to leave it to rot so they can knock it down... they're not doing any repair works on it, which they really should do. Repair works to make it look more welcoming because then it'll make a nicer image of Drumchapel."* Female, 40-60 years, Drumchapel.

These factors acted simultaneously to create an unsupportive environment for functional or recreational physical activity.

6.4.3.2 The Lyceum in Govan

The Lyceum (**Figure 6.13**) was first opened in 1898 as a music hall and then in 1938 as a cinema seating over 2,000 patrons. Most recently in 1974, it became a cinema and bingo hall, which closed in 2006; the building has been vacant since and is currently reported to be privately-owned and in a state of some disrepair. The large building is situated on the main thoroughfare through Govan.

Figure 6.13 Participant photograph of The Lyceum building in Govan

The Lyceum was identified as an environmental feature which did not support physical activity by all but one of the participants in Govan, citing the fact that it no longer provided a destination for physical activity and created an unattractive streetscape for activity. Importantly, the neglect of an historically important cultural building was perceived as indicative of authorities and investors not valuing and investing in the community. There was a strong sense of attachment to The Lyceum because it physically represented the industrial heyday of Govan when the neighbourhood was thriving. The building was perceived as a community resource which should serve multiple user-groups in the community, rather than create divisions between groups or be used for financial gain through housing development.

> *"And it's a shame it's lying there rotting… it's such a massive resource and it's been sittin'. They paid £8000 for that banner… to hide [that] it's derelict; it's really bad, smashed windows. It was all art deco windows I think, they're all smashed. So this was to make Govan look good? I went 'why didn't you add another couple of noughts and actually just clean the building. Rather than a bandage, put a bandage over it'... If I won the lottery I would have loved to have made that a big social building for every age."* Female, >60 years, Govan.

> *"If anything I can see a developer going in, just some big cats with money gonna go in and make even more money. We don't need more houses there; we need more things for people to do… They're not going outside, they've not*

got any education… I'm actually quite a wee bit passionate about it." Male, 40-60 years, Govan.

6.4.4 Photographic content analysis

In total, 463 photographs were taken by participants. Not all participants completed the 27 photograph exposures on the camera, therefore the number of photographs varied between participants. **Table 6.2** presents the prevalence of photograph content. The content of the vast majority of photographs was an aspect of the physical environment, possibly reflecting the nature of the format. The most popular subjects were: community organisations (e.g. inside the building from which the organisation operates) or community centres (n=51), green space (n=50), roads (n=51), walking paths or pavements (n=42) and friends (n=45).

Table 6.2 Analysis of photograph content

Content category	Photograph content	N*
Destinations	Community organisation/centre	51
	Library, museum	34
	Housing	24
	Local business and industry	19
	Leisure facility, sports facility, play area	18
	Place of worship	17
	Shop(s)	14
	Restaurant, fast food takeaway, café	13
	Pub/bar	8
	Local service buildings, council offices	6
	School	4
	Bingo, betting shop, pawnbrokers	3
	Health centre	2
	Public toilets	1
Destinations: open space	Green space (park)	50
	Blue space (pond, river)	14
	Planting, flowers, leaves, trees	27
	Communal garden	22
	Railings, fencing	13
	Open space	7
	Private garden	7
	Seating	6
Services	Bins	6
	Police station	3
	Street lighting	2
Services: transport and accessibility	Road(s) (incl. signs, works, crossing)	51
	Walking, walking paths, pavements	42
	Public transport	26
	Parking	12
	Cycling	3
Physical disorder	Litter/rubbish, fly tipping	21
	Run down/derelict building/place	17
	Graffiti, vandalism	4
	Political flag	3
	Dog mess	2
Social aspects	Friends	45
	Local history	10
	Cultural event	10
	Family	9
	Community	4
Built form	Landmark, architectural feature	26
	Building(s)	7
	Construction, regeneration, refurbishment	5
Views	Long shots of area	7
	View from window or balcony	4

*Some photos feature more than one subject so are listed multiple times.

Two photograph themes: ‘destinations’ and ‘services’ can be mapped directly onto interview themes: ‘diversity of destinations in the neighbourhood’ and ’provision of services to support healthy environments’, respectively. Assigning other photograph themes to the remaining interview themes (‘ownership of public space and facilities’, ‘collective control of public space to prevent disorder’ and ‘perceived value of the neighbourhood’) is more ambiguous since these themes are constructed from multiple physical and social aspects and require a degree of interpretation when depicted in photography (e.g. to state that a neglected building represents a perceived lack of value).

6.5 Discussion

6.5.1 Summary of findings

Five themes underpinning activity-supportive neighbourhoods were extracted from photo-elicitation interviews with 23 participants from two communities with high levels of deprivation in Glasgow, UK. Themes largely drew on upstream influences and were named: ‘diversity of destinations in the neighbourhood’, ‘provision of services to support healthy environments’, ‘ownership of public space and facilities’, ‘collective control of public space to prevent disorder’ and ‘perceived value of the neighbourhood’. Participants discussed these themes as operating simultaneously to create an environment in which they have the motivation and capability to perform outdoor, predominantly unstructured, physical activity. Unfortunately, neighbourhood environments considered in this study were largely unsupportive of physical activity in this deprived context, where influence of economic factors was salient. Two brief case studies illustrated the complex pathways of interplay and reciprocity between identified themes which underpinned their manifestation in two environments unsupportive of physical activity. To the best of my knowledge, this study was novel in using qualitative methods to examine features of the social and physical environment in the wider neighbourhood which acted specifically to support or discourage physical activity in adults, in a deprived context in the UK.

Local economic factors were pervasive and influenced the expression and construction of themes. This highlighted the point that environmental influences on physical activity are closely entwined with the local context and revealed the necessity of context-specific examination of the relationship between the social and physical environment and physical activity. For example, within this context, weak local economies and the declining historical industry in the area (i.e. shipbuilding in Govan) teamed with a perceived lack of investment were substantial barriers to diversity of destinations and lowered the perceived value of the neighbourhood. Restricted employment opportunities and individual issues arising from unmet social and economic needs were also used by participants to explain features of the physical environment such as the restriction of seating in cafes, designed to deter individuals from loitering but inadvertently deterring individuals from lingering and using the recreational facility.

There are two considerations that should be acknowledged in the interpretation of these findings. Firstly, both neighbourhoods had experienced some recent regeneration activities. While the GoWell regeneration programme targeted physical and social aspects of the neighbourhood, the physical environment had received substantially higher levels of investment (Egan *et al.*, 2016), potentially inducing participants to focus on barriers in the social environment. This may limit the generalisability of findings to populations in similar contexts who have also experienced recent change in their neighbourhood. Research within the GoWell programme documents residents' diverse positive and adverse experiences of relocation from housing which has been demolished in regeneration activities and the pathways through which such experiences impact on health (Egan *et al.*, 2015). In line with the current study, the authors noted the salience of social determinants underpinning socioeconomic deprivation and their importance to the health of residents. A participant inclusion criterion for the current study was at least 12 months' residence in the neighbourhood and, to my knowledge, no participants had been recently obliged to relocate due to regeneration activities. However, living in deprived neighbourhoods undergoing change remains a potentially important characteristic of the sample.

Secondly, findings pertain to participants' perceptions of their local neighbourhood. In **Studies 1 and 2**, the physical environment was measured objectively by non-resident auditors. There are established differences in the relationship between objectively-measured and perceived aspects of the neighbourhood environment and physical activity. A recent systematic review of 85 studies concluded that objectively-measured and perceived neighbourhood environments are empirically related but distinct constructs, each explaining unique variance in physical activity behaviour (Orstad *et al.*, 2016). The manifestation of the themes reported here might be understood and documented differently by individuals outside of the neighbourhood, for example, those designing interventions; this distinction should therefore be acknowledged.

6.5.2 Strengths and limitations

The use of participant-produced photography in photo-elicitation interviews strengthened the findings of this study. As previously noted, visual data can enrich verbal interviews by conveying insider perspectives to the researcher and providing a common vantage point between the researcher and participant (Wang and Burris, 1997; Guell and Ogilvie, 2015). Owing to the study methods, participants came to the interview having thought about the research questions during the 7-day photography period, often having created a strong narrative around their photography. This permitted a depth to the discussion and participant ownership of the narrative that may not have been achievable had the photography not taken place. Participatory techniques help to redress the usual power imbalance between the researcher and participant - enabling the participant to inform the interview process with considered personal data and insights - and have been emphasised by proponents of visual qualitative techniques (Wang and Burris, 1997). Such methods reflect a growing appreciation of engaging participants to be key collaborators in the research process, for example, adopting the role of 'citizen scientists' to inform scientific enquiry (Rosas *et al.*, 2016; Winter *et al.*, 2016). Practically, the photographs acted as a memory aid for participants and allowed me to manage the timely progress of the interview, using progressions to the next photograph to pace the interview.

There were also possible limitations associated with photo-elicitation interviewing. The need to act as an observer in your own neighbourhood may have deterred some individuals, particularly vulnerable individuals, from participating in the study, as they might have felt conspicuous or uncomfortable in this role. For example, members of a woman's group approached during recruitment felt it would be unsafe or inappropriate to take photographs in the neighbourhood, especially in areas where they felt unsafe or exposed. This may limit the generalisability of findings to particular groups in the neighbourhood.

Similarly, this technique had the potential to restrict data collection to physically observable constructs (as is reflected in the photographic analysis) or certain environments or conditions in the neighbourhood. For example, one participant reported that the environment partly dictated which visual data were recorded:

> *"It's not very nice down there… I was going to take the camera down with me but I didn't want to take it down in case somebody tried to steal it".* Female, 25-39 years, Drumchapel

In addition, while participants discussed different experiences of the neighbourhood during day-time and night-time, all photographs were taken during the daytime. This could be attributed to the use of disposable cameras with relatively low specifications for night-time photography or because participants rarely went out in the neighbourhood at night-time. There were no apparent differences in the photographs taken by the two participants using digital cameras compared with other participants, suggesting an equivalence of using the two types of equipment and that use of disposable cameras may not have driven this feature of the photographic data. Lastly, the study was conducted over summer months (June - October), potentially introducing bias into the results due to seasonal differences in the experience of the neighbourhood, in terms of weather and hours of daylight. The interview was used to interrogate these possible limitations by asking whether, and why, certain aspects of the neighbourhood were not captured in the photographs and whether the season influenced the participant's experience of being active in the neighbourhood, but it remains important to consider these potential limitations in the interpretation of the findings.

6.5.3 Reflexivity

When undertaking qualitative research, it is valuable for the researcher to reflect upon how their preconceptions of a context or population may shape the interview process, analysis and interpretation of findings. Being an 'outsider' to the study context can be advantageous in circumventing more entrenched preconceptions born from familiarity but it also might create a potential division between researcher and participant.

The use of visual methods was beneficial in two ways. Firstly, visual imagery can facilitate an understanding of a context and the priorities of the participant in a complementary way to narrative description. In a context which may already be labelled as having particular characteristics (e.g. social and economic deprivation), such strategies can suspend preconceptions and enable a focused, shared viewpoint between the researcher and participant. Secondly, the practicalities of the method extended participant involvement in the study process, both in time commitment and data collection. This aspect nurtured a rapport between the researcher and the participant which was consequential in encouraging participants to be candid in their interview responses and have the confidence to help guide the interview.

6.5.4 Implications for future research

Findings reveal the importance of upstream physical and social features of the neighbourhood environment on physical activity, notably documenting the interplay between these factors in creating supportive environments for physical activity. Future research should go further in elucidating and measuring the impact of upstream factors in deprived and non-deprived neighbourhood environments, across populations.

Themes extracted in this study inform the operationalisation of composite factors developed in **Study 1** and the conceptualisation of their relationship with physical activity as examined in **Study 2**. The complex interplay between social and physical factors existing within these upstream themes provides insight into the expression of interactive effects. For example, how and why the interactive effect of 'cohesion and safety' and 'physical disorder' on walking and MPA might arise can be elucidated in the theme around collective control. The reciprocal pathway from a cohesive community that can monitor and control disorder, and the way perceived maintenance and order can feed into better social relations is described in the current study.

Together with results from **Studies 1 and 2**, findings presented here suggest that change in extracted themes capturing physical and social aspects of the environment would have a causal effect on physical activity. However, it is possible that barriers persist even when such factors are targeted. Quasi-experimental study designs, with longitudinal measurement of neighbourhood environments and physical activity, are needed to estimate the impact of change in these factors on physical activity.

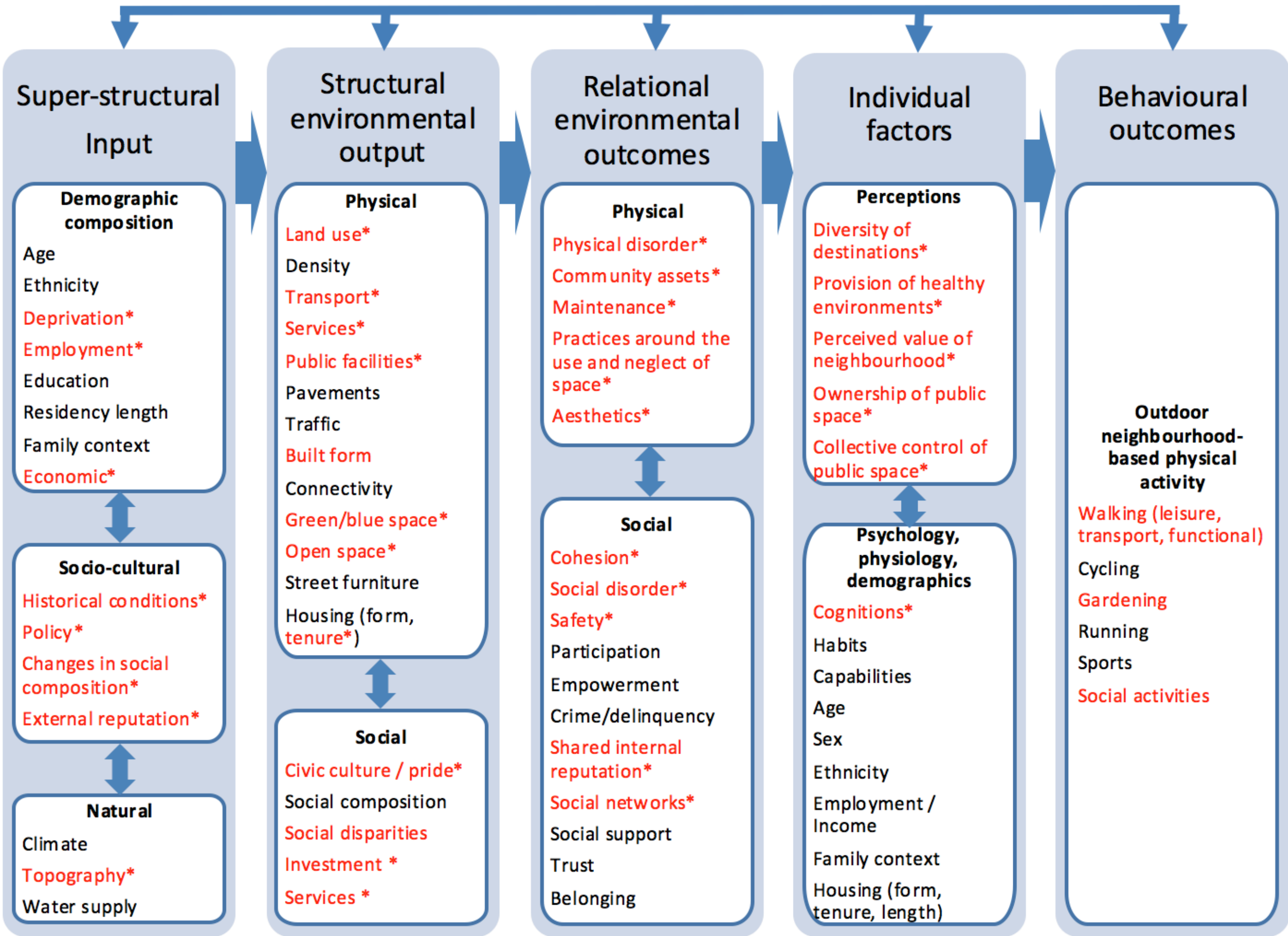
The use of this method could stimulate participatory research within a community context, acknowledging the interest community groups expressed in using a photographic method to serve their own interests. Members of community groups believed it would be an effective method to audit the local area for opportunities for physical activity to facilitate signposting of these community assets (Personal Communication). Engaging methods such as this could add to existing participatory approaches which encourage residents to audit and monitor their neighbourhood environments and present communities with new tools to co-design activity-supportive environments (e.g. Pawlowski *et al.*, 2017).

6.5.5 Conclusions

Themes identified in this study describe the upstream social and physical aspects of the neighbourhood which can contribute to an activity-supportive environment. These themes were perceived to operate simultaneously to bear substantive influence on neighbourhood-based physical activity in a deprived context in the UK. The overarching discussion of the role of the local economic environment in the manifestation and salience of themes emphasises the value of examining the relationship between the neighbourhood environment and physical activity in a way that is sensitive and specific to context.

Figure 6.14 presents the logic model developed in respect to findings from the current study. Factors that were examined in qualitative analyses are highlighted in red text; those that were discussed as being associated with neighbourhood-based physical activity (walking, gardening or social activities) are demarcated with an asterisk. Perceptions of the environment were more clearly defined in this study than in **Studies 1 and 2** and have therefore been defined in the logic model. These perceptions are constructed of factors from upstream categories in the model. For example, ‘perceived diversity of destinations’ incorporates multiple super-structural factors (e.g. historical conditions or economic factors) which contribute to level of ‘investment’ into the area and ‘land-use’ mix (‘structural environmental output’) which influences ‘practices around the use and neglect of space’ (‘relational environmental outcome’), leading to perceived diversity of destinations (‘individual factor’) which is thought to influence physical activity. The feedback loop is evident across categories, with perceptions reinforcing and modifying individuals’ relationship with the environment and more upstream factors such as external reputations (‘super-structural input’) and ‘services’ or ‘investment’ (‘structural environment output’). For example, residents’ perceived ownership of the communal garden led to increased maintenance and reduced social disorder within that space; investment into these community services was maintained and there was a sense of pride in the area generated through this (social and physical) community asset. Future research could further explore causality of pathways of influence of social and physical environmental factors on physical activity in the neighbourhood.

Figure 6.14 Logic model of neighbourhood environmental influences on neighbourhood-based physical activity in deprived communities



Red text denotes factor examined in **Study 3**. * Denotes significant association with physical activity.

Chapter 7 Study 4: Change in the quality of the neighbourhood physical and social environment and self-reported walking over a 7-year period

7.1 Introduction

Findings from cross-sectional analyses in **Study 2** suggest that the quality of the neighbourhood physical and social environment is associated with self-reported walking and MPA in adults living in income-deprived communities in Glasgow, UK. In addition, results revealed some significant interactive effects suggesting that intervening to improve the quality of both the physical and social environment (i.e. a synergistic effect of ‘trust and empowerment’ and ‘aesthetics and maintenance of open space’ on activity), or ensuring the social environment is conducive to activity before intervening in the physical environment may be more effective at increasing physical activity (i.e. a moderating effect of ‘social interaction’ on the relationship between ‘aesthetics of built form’ and activity and a moderating effect of ‘cohesion and safety’ on the relationship between ‘physical disorder’ and activity). However, it is difficult to unpick the direction of effects in cross-sectional analyses due to temporality. Qualitative research in **Study 3**, suggested a causal link between upstream social and physical environmental factors and neighbourhood-based activity; however, qualitative insights have been criticised for not being able to provide estimates of real-world effect sizes which can be replicated in future studies (as discussed in Smith, 2018). However, it can be argued that their value lies in generating hypotheses of complex mechanisms operating within associations, which can be examined in future qualitative and quantitative research to generate evidence of a generalisable pathway of influence (Egan *et al.*, 2015; Smith, 2018).

Longitudinal or quasi-experimental evidence has the characteristics which enable further insight into the direction of the association. Previously, longitudinal and quasi-experimental studies examining the impact of area-based initiatives on health have provided equivocal evidence of positive impact of area-based initiatives including urban regeneration on health outcomes (Thomson *et al.*, 2006; Thomson, 2008).

Studying outcomes which feasibly have more proximal relationships with environmental change, such as physical activity, could be valuable in identifying effects and unpacking potential mechanisms by examining the impact of change in specific features of the environment, rather than broader evaluations of large-scale interventions (Thomson, 2008), which may disproportionately target certain features of the environment (Kearns *et al.*, 2013; Ruijsbroek *et al.*, 2017). However, a programme of urban regeneration targeting deprived communities in the Netherlands found no difference between intervention and control neighbourhoods in physical activity 6.5 years after the start of the intervention period using difference-in-difference analysis (Ruijsbroek *et al.*, 2017), despite small but significant differences in leisure-time physical activity apparent at 3.5 years (Kramer *et al.*, 2014).

In non-deprived samples, in a natural experiment in Australia, participants' relocation to activity-supportive neighbourhoods (e.g. increased land-use mix, traffic calming and street connectivity) had no effect on self-reported walking after 3 years when compared with participants who relocated to neighbourhoods without these physical features (Christian *et al.*, 2013). In the Netherlands, positive changes in perceived social cohesion, social and physical disorder and green space were prospectively related to self-reported physical activity and sports participation in national survey data (Jongeneel-Grimen *et al.*, 2014). However, targeted modification of the environment has had positive effects: increased connectivity of the pedestrian network was related to increased self-reported walking distance in a longitudinal cohort of 146 participants in Hong Kong (Sun, Oreskovic and Lin, 2014).

7.2 Aims

This study aimed to assess change in the environmental factors developed in **Study 1** and thereby assess the relationship between change in the quality of the neighbourhood physical and social environment and change in self-reported walking, over a 7-year period in 12 income-deprived neighbourhoods in Glasgow, UK. Change in the environment occurred in income-deprived neighbourhoods as a result of a programme of urban regeneration (GoWell, 2017). This regeneration programme was monitored and assessed by the GoWell research and learning programme (details of which are provided in **Section 3.1**).

It was hypothesised that positive change in perceived and objective physical environmental factors and change in perceived social environmental factors would be associated with positive change in days walking. In line with the focus on this thesis, a secondary aim of this study was to further understand interactive effects reported in **Study 2**, where possible, using longitudinal data.

7.3 Methods

More details on methods are provided in **Section 3.1**.

7.3.2 Population

A longitudinal sample of participants who had remained in the same sub-area between 2008 and 2015 was drawn from waves 2 and 4 of the GoWell study. Participants from 3 neighbourhoods were excluded (Birness Drive, Shawbridge and Sighthill); reasons for this are discussed in **Section 3.1.3**. A sample drawn from 12 neighbourhoods comprising 27 sub-areas was used in analyses.

7.3.3 Measures

Measurements of the social environment, perceived physical environment, physical activity and socio-demographics were taken at two time points, using wave 2 data collected in 2008 (time point 1) and wave 4 data collected in 2015 (time point 2). Objective measures of the physical environment were drawn from wave 1 data (2006) and wave 4 data (2015), as the environmental audit was only conducted twice. More details on the creation of the ‘change’ variables are discussed in **Section 3.1.6.3**.

7.3.3.1 Social environment

Social factors developed in **Study 1** were created for each time point. They were: 'social support', 'trust and engagement', 'social interaction' and 'cohesion and safety'; items comprising these factors are listed in **Table 4.3**. Absolute change in each factor between time point 1 and time point 2 was calculated for longitudinal analyses.

7.3.3.2 Objective physical environment

Audited physical disorder was assessed using environmental audit data from waves 1 and 4. Other physical environment factors developed in **Study 1** ('aesthetics of built form' and 'aesthetics and maintenance of open space') were not used due to many items not being repeated in the audit at wave 4. In order to create the 'physical disorder' variable, PCA conducted in **Study 1** was repeated on wave 1 data excluding the item '*Private gardens, yards and driveways are tidy and well-maintained'* which was originally included in the 'physical disorder' factor but was not available at wave 4. The same factor structure was obtained for all environmental factors. Therefore, a 'physical disorder' factor for time point 1 and time point 2 was constructed using the 4 available items. This factor retained excellent internal consistency (Cronbach's alpha = 0.8). As in **Study 2**, this variable was scored using standardised variables which were reverse coded by adding 1 to the maximum value and subtracting the observed value for each participant. Therefore, higher values on this factor indicated fewer cues of physical disorder. Absolute change in 'physical disorder' between time point 1 and 2 was calculated for longitudinal analyses.

7.3.3.3 Perceived physical environment

Five categorical items pertained to the perceived quality of the physical environment: quality of the environment, buildings and parks or open spaces and vandalism and litter as a problem in the neighbourhood. Responses for items measuring vandalism and litter were reverse-coded. For longitudinal analyses, changes in the quality of the environment, buildings and parks or open space were measured using the following categories: ‘consistently poorer’, ‘declined’, ‘improved’ and ‘consistently better’. Changes in litter and vandalism were measured using the following categories: ‘constantly a problem’, ‘becoming a problem’, ‘no longer a problem’, ‘constantly not a problem’.

7.3.3.4 Walking

Number of days walking for ≥10 minutes in a non-specific location (‘non-specific walking’) was self-reported using the IPAQ-SF. Number of days walking for ≥20 minutes within the neighbourhood (‘neighbourhood-based walking’) was self-reported using a single item. Absolute change between time points 1 and 2 was calculated for longitudinal analyses.

7.3.3.5 Covariates

Socio-demographics that were associated with social environment and objective physical environment exposure variables in **Study 1** were included as covariates in statistical models. They were: sex, citizenship, age group, tenure, working status, vehicle access, mobility-limiting condition and neighbourhood deprivation. Area intervention type was included as a covariate as it was likely to be related to change in environmental measures and could also relate to other individual factors associated with activity, such as individual socioeconomic status. Intervention types were defined by the GoWell team.[13] It was not possible to adjust analyses for distance to the audit assessment site as done in **Study 2** as these data were unavailable; however, this was not deemed necessary because audit data were aggregated across neighbouring assessment sites to the level of sub-area for these analyses.

Covariates were used from time point 1 as they were either expected to remain relatively fixed between time points (e.g. sex, citizenship), or, should they have been

[13] Intervention types: transformational regeneration area (TRA; substantial neighbourhood regeneration including demolition and new housing), housing improvement area (HIA; homes receiving housing improvements), local regeneration area (LRA; substantial regeneration activities targeted at smaller areas of disadvantage), peripheral estate (PE; neighbourhoods targeted by multiple housing organisations for new housing) and wider surrounding area (WSA; neighbourhoods surrounding TRAs and LRAs, often also receiving housing improvements).

more likely to change, this change might have been related to changes in the social or physical environment (e.g. regular access to a vehicle being more likely if 'social support' increased, or changes in working status being related to changes in 'social interaction').[14] Within-participant differences in covariates between time point 1 and time point 2 were tested, using McNemar's test for dichotomous variables and Wilcoxon signed-rank test for categorical variables.

7.3.4 Statistical analysis

Participant characteristics were produced using descriptive statistics. Characteristics of the final sample were compared with: i) the longitudinal sample for whom longitudinal audit data were not available and ii) the cross-sectional sample at wave 1, using chi-squared analyses to test for significant changes in the composition of the sample. Normality was examined for linear exposures assessing absolute change in the physical and social environment and walking outcomes. Correlation between days of non-specific walking for ≥10minutes/day and neighbourhood-based walking for ≥20 minutes/day was assessed using a Pearson product-moment correlation coefficient.

A series of linear regression models were performed with absolute change in number of days of non-specific walking as the outcome, accounting for covariates and potential nesting in sub-area. The same series of linear regression models were repeated with neighbourhood-based walking as the outcome.

Study 2 revealed an interactive cross-sectional effect between 'cohesion and safety' and 'physical disorder' on neighbourhood-based walking. Post-hoc tests suggested that 'physical disorder' was moderated by 'cohesion and safety': only when levels of 'cohesion and safety' were high, did 'physical disorder' have an effect on walking. Therefore, additional linear regression models were performed using absolute change in 'physical disorder' as an exposure and absolute change in non-specific and

[14] Models were also run using covariates from time point 2 to check there were no differences in results. Results were the same, so only models using covariates from time point 1 are presented.

neighbourhood-based walking as outcomes, stratified by ‘cohesion and safety’ levels at time point 1. ‘Cohesion and safety’ levels at time point 1 were used instead of at time point 2, as a causal relationship would assume the effect of ‘cohesion and safety’ to be prospective. ‘Cohesion and safety’ at time point 1 was calculated as a binary variable, using a mean cut-off, with values above being ‘high’ levels and values below being ‘low’ levels (as in **Study 2**).

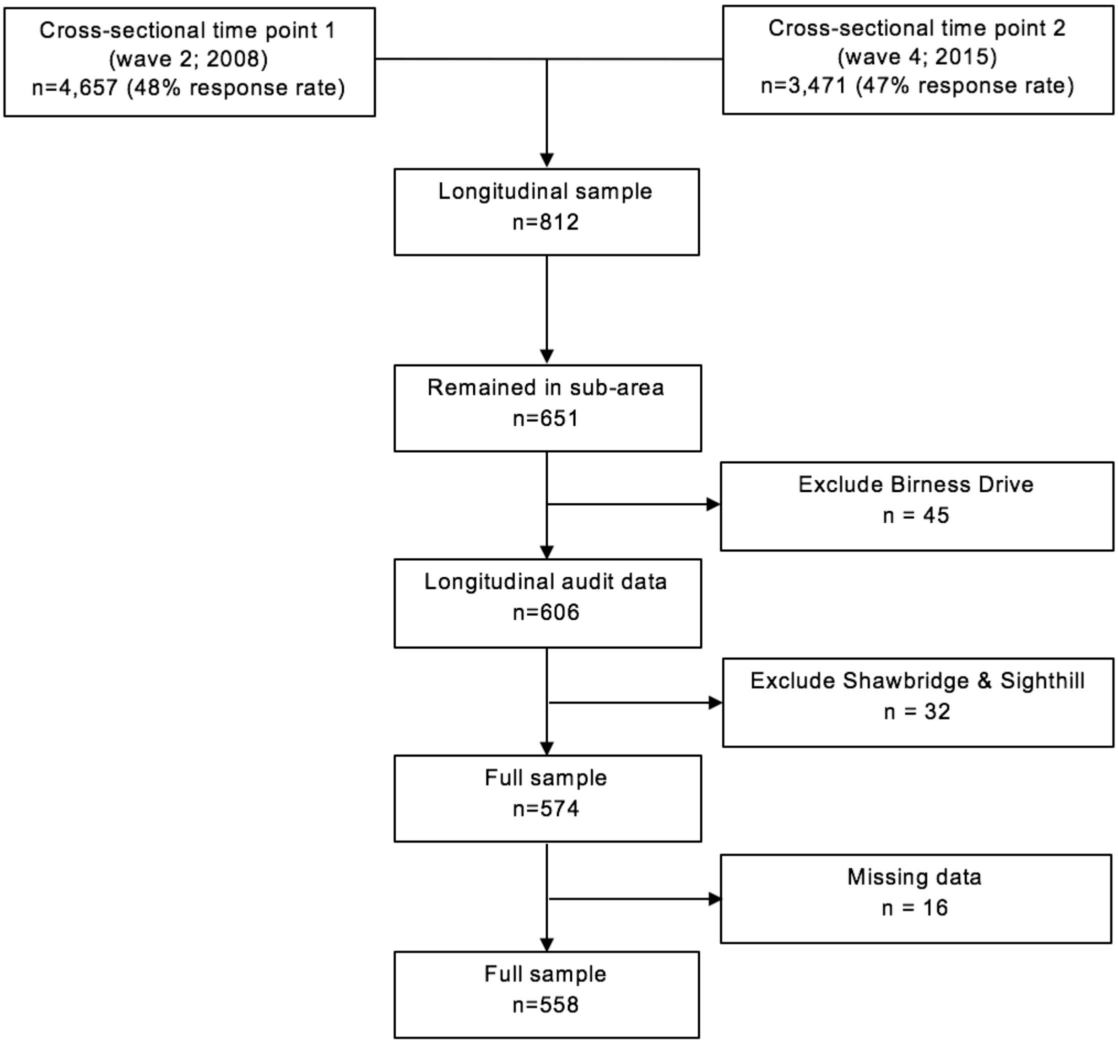
Cross-sectional analyses were conducted on the final sample using cross-sectional data from time point 2. Cross-sectional analyses were conducted in the same way as longitudinal analyses, using a series of linear regression models. These analyses were conducted to test that there was sufficient power in this smaller sample to replicate cross-sectional associations observed in **Study 2**.

7.4 Results

7.4.1 Participant characteristics

A total of 558 participants were included in analyses. The selection of the final sample is presented in **Figure 7.1**.

Figure 7.1 Selection of longitudinal sample



Participant characteristics are presented in **Table 7.1** (number of participants per sub-area is presented in **Appendix 4.2**). There were more participants who were female (63%), aged over 40 years (84%), British (97%), not working or retired (76%), living in rented accommodation (75%), or did not have access to a vehicle (72%). Participants predominantly came from neighbourhoods receiving housing improvements, wider surrounding area or peripheral estates. Compared with participants at baseline (i.e. wave 1, characteristics presented in **Table 7.1**), participants in this longitudinal sample were significantly older ($X^2(5) = 210.88$, $p<0.001$), British ($X^2(1) = 57.31$, $p<0.001$) and retired ($X^2(2) = 27.12$, $p<0.001$); there was no difference in sex, tenure and vehicle access.

Table 7.1 Participant characteristics at time point 1 (n=558)

Characteristic	N (%)
Sex	
Male	206 (36.9)
Female	352 (63.1)
Age group	
16-24	**13 (2.3)**
25-39	**78 (14.0)**
40-54	**159 (28.5)**
55-64	**132 (23.7)**
65+	**176 (31.5)**
Citizenship	
British	**543 (97.0)**
Non-British	**15 (2.7)**
Employment	
Working	**134 (24.0)**
Not working	**202 (36.2)**
Retired	**222 (39.8)**
Tenure	
Own	**137 (24.6)**
Rent	**421 (75.4)**
Vehicle access	
Yes	156 (28.0)
No	402 (72.0)
Intervention area type	
TRA	9 (1.6)
LRA	81 (14.5)
WSA	134 (24.0)
HIA	185 (33.2)
PE	149 (26.7)

Bold typeface indicates significant difference between time point 1 and time point 2 at p<0.01. TRA: transformational regeneration area; HIA: housing improvement area; LRA: local regeneration area; PE: peripheral estate; WSA: wider surrounding area.

Compared with participants excluded from analyses as they lived in neighbourhoods without appropriate longitudinal audit data, participants included in analyses were more often British ($X^2(1)=12.05$, $p<0.01$), living in owner-occupied accommodation ($X^2(1)=16.04$, $p<0.001$) and had access to a vehicle ($X^2(1)=7.65$, $p<0.01$). These differences are expected due to differences in housing type and area for participants living in areas excluded from the final sample, i.e. both Shawbridge and Sighthill were TRAs including multi-storey flats (≥5 storeys). There were no significant differences in sex, age or working status.

There were expected significant differences in certain characteristics between time point 1 and time point 2: at the later time point there were more participants who were older ($Z=-14.09$, $p<0.001$), retired ($Z=-5.63$, $p<0.001$). There was no difference in tenure (p=0.627) or citizenship (p=0.754) between time points. Sex and vehicle access was only reported at time point 1.

7.4.2 Change in environmental exposures

Table 7.2 presents environmental factors at time points 1 and 2. Mean change in social environmental factors and ‘physical disorder’ was positive for all factors except ‘social interaction’, for which the mean factor score remained constant between time points 1 and 2. ‘Physical disorder’ and ‘social support’ had the largest difference in mean score between time points. There was a significant increase in scores between time point 1 and time point 2 for: ‘physical disorder’ (t(557)=-24.67, p<0.001); ‘social support’ (t(557)=-4.16, p<0.001); and ‘cohesion and safety’ (t(557)=-5.44, p<0.001). There was no difference between time points for: ‘social interaction’ (t(557)=0.48, p=0.631); and ‘trust and empowerment’ (t(557)=-1.88, p=0.061).

Table 7.2 Change in environmental exposure across time points

	Time point 1 Mean (SD)	Time point 2 Mean (SD)	Mean absolute change (SD)	Range in absolute change
‘Physical disorder’	**0.73 (0.09)**	**0.85 (0.09)**	0.42 (0.11)	-0.14 – 0.42
‘Social support’	**0.66 (0.22)**	**0.72 (0.20)**	0.05 (0.29)	-0.67 – 0.67
‘Social interaction’	0.77 (0.18)	0.77 (0.15)	0.00 (0.22)	-0.60 – 0.73
‘Trust and empowerment’	0.65 (0.14)	0.66 (0.13)	0.01 (0.18)	-0.65 – 0.50
‘Cohesion and safety’	**0.73 (0.16)**	**0.77 (0.15)**	0.04 (0.17)	-0.49 – 0.49

Bold typeface indicate significant difference at p<0.01. Mean scores: higher score indicates more positive (better) environmental exposure.

Variables assessing absolute change in social environmental factor scores and ‘physical disorder’ factor score were deemed to be normally-distributed (‘absolute change in physical disorder’: skewness: 0.63, kurtosis: 0.71; ‘absolute change in social support’: skewness: 0.01, kurtosis: -0.33; ‘absolute change in social interaction’: skewness: 0.34, kurtosis: 0.42; ‘absolute change in trust and empowerment: skewness: -0.07, kurtosis: -0.05; ‘absolute change in cohesion and safety’: skewness: -0.17, kurtosis: 0.07). The following percentage of participants had no change in environmental scores: ‘physical disorder’: 7%; ‘social support’: 20%; social interaction’: 16%; ‘trust and empowerment’: 12%; and ‘cohesion and safety’: 21%.

Table 7.3 shows perceived environmental exposures across time points 1 and 2. There was a significant difference in perceptions between time points for 'perceived quality of parks' ($Z=-2.95$, $p<0.01$), 'perceived attractiveness of the environment' ($Z=-6.68$, $p<0.001$); 'perceived attractive of buildings' ($Z=-6.10$, $p<0.001$); and 'perceived vandalism' ($Z=-9.53$, $p<0.001$), but a non-significant difference for 'perceived litter' ($Z=-1.20$, $p=0.229$).

Table 7.3 Perceived environmental exposure across time points

	Time point 1 N (%)	Time point 2 N (%)
'Perceived quality of parks'		
Very good	**73 (13.1)**	**105 (18.8)**
Fairly good	**299 (53.5)**	**310 (55.6)**
Neither good nor poor	**80 (14.3)**	**63 (11.3)**
Fairly poor	**48 (8.6)**	**35 (6.3)**
Very poor	**23 (4.1)**	**22 (3.9)**
Don't know	**35 (6.3)**	**23 (4.1)**
'Perceived attractiveness of environment'		
Very good	**86 (15.4)**	**100 (17.9)**
Fairly good	**262 (47.0)**	**347 (62.2)**
Neither good nor poor	**122 (21.9)**	**63 (11.3)**
Fairly poor	**59 (10.6)**	**33 (5.9)**
Very poor	**23 (4.1)**	**12 (2.2)**
Don't know	**6 (1.1)**	**3 (0.5)**
'Perceived attractiveness of buildings'		
Very good	**80 (14.3)**	**97 (17.4)**
Fairly good	**263 (47.1)**	**342 (61.3)**
Neither good nor poor	**122 (21.9)**	**65 (11.6)**
Fairly poor	**62 (11.1)**	**41 (7.3)**
Very poor	**24 (4.3)**	**12 (2.2)**
Don't know	**7 (1.3)**	**1 (0.2)**
'Perceived vandalism'		
Serious problem	**94 (16.8)**	**15 (2.7)**
Slight problem	**147 (26.3)**	**83 (14.9)**
Not a problem	**306 (54.8)**	**453 (81.2)**
Don't know	**11 (2.0)**	**7 (1.3)**
'Perceived litter'		
Serious problem	80 (14.3)	63 (11.3)
Slight problem	152 (27.2)	151 (27.1)
Not a problem	321 (57.5)	344 (61.6)
Don't know	5 (0.9)	0 (0.0)

Bold typeface indicate significant difference at $p<0.01$.

7.4.3 Change in walking outcomes

The variable assessing change in days of non-specific walking was deemed to be normally distributed (skewness: -0.00, kurtosis: -0.42) as was the variable assessing change in days of neighbourhood-based walking (skewness: 0.03, kurtosis: -0.29). These variables were highly correlated (r=0.60, p<0.001).

At time point 1, 31% participants performed non-specific walking for ≥10 minutes on no days of the week (**Table 7.4**), similar to national Scottish estimates of doing very low amounts of physical activity in 2016 (<30minutes MVPA/week) in the most deprived quartile for SIMD (29%) (ScotCen Social Research, 2017). The mean number of days of non-specific walking was 3.4 days/week (SD=2.93). At time point 2, 22% participants performed non-specific walking for ≥10 minutes on no days of the week; the mean number of days spent walking was 3.9 days (SD=2.87). The mean absolute change in number of days of non-specific walking was 0.5 days. There was a significant difference in number of days of non-specific walking between time points (t(557)=-3.09, p<0.01).

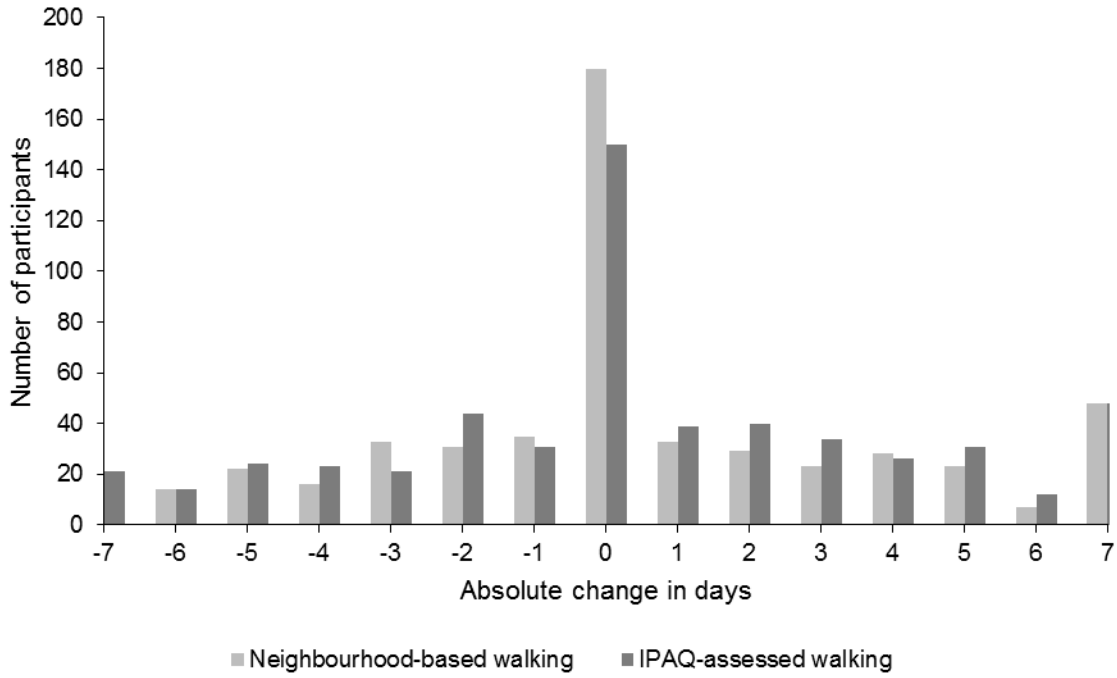
Table 7.4 Number of days walking across time points

Variable	Time point 1 N (%)	Time point 2 N (%)
Days of non-specific walking ≥10 minutes		
None	**173 (31.0)**	**125 (22.4)**
1	**30 (5.4)**	**39 (7.0)**
2	**58 (10.4)**	**55 (9.9)**
3	**38 (6.8)**	**45 (8.1)**
4	**34 (6.1)**	**33 (5.9)**
5	**31 (5.6)**	**36 (6.5)**
6	**19 (3.4)**	**18 (3.2)**
7	**175 (31.4)**	**207 (37.1)**
Days neighbourhood-based walking ≥20 minutes		
None	205 (36.7)	198 (35.5)
1	33 (5.9)	40 (7.2)
2	42 (7.5)	39 (7.0)
3	48 (8.6)	33 (5.9)
4	25 (4.5)	26 (4.7)
5	28 (5.0)	38 (6.8)
6	18 (3.2)	18 (3.2)
7	159 (28.5)	166 (29.7)

Bold typeface indicates significant difference at p<0.01.

Neighbourhood-based walking for ≥20 minutes was similar: 37% of participants did no days of neighbourhood-based walking for ≥20 minutes at time point 1 and 36% of participants did no days of neighbourhood-walking at time point 2 (**Table 7.4**). The mean number of days of neighbourhood-based walking per week was 4.1 days at time point 1 and 4.2 days at time point 2. Mean absolute change in number of days of neighbourhood-based walking was 0.1 days. However, there was a non-significant difference in days of neighbourhood-based walking between time points (t(557)=-0.68, p=0.497). Absolute change in walking is presented in **Figure 7.1**.

Figure 7.2 Frequencies of absolute change in neighbourhood-based walking



7.4.4 Associations between change in environment and change in walking

Results for change in non-specific walking for Models 1-3 are shown in **Table 7.5**. There was a significant association between change in number of days of non-specific walking and 'social support' after controlling for other environmental factors, covariates and potential nesting in sub-area (Model 3: B=2.08, SE=0.55, 95%CI=0.99-3.16, p<0.001). Every positive unit change in 'social support' was related to 2 more days of non-specific walking between time point 1 and 2. Change in other social environmental factors, audited 'physical disorder' or perceived quality of the physical environment did not have an effect on change in non-specific walking. There were no significant associations between change in environmental variables and change in days of neighbourhood-based walking except for a negative association between change in walking between participants who perceived that the quality of local parks and open space has declined compared with those who perceived parks and open space to be consistently poor (**Table 7.6**).

Table 7.5 Associations between absolute change of environmental factors and absolute change in number of days of non-specific walking for ≥10 minutes per week (n=558)

Environmental factor (absolute change)	Model 1			Model 2			Model 3		
	B (SE)	95% CI	p	B (SE)	95% CI	p	B (SE)	95% CI	p
‘Physical disorder’	-1.87 (1.37)	-4.55 – 0.81	0.171	-3.03 (1.65)	-6.27 – 0.21	0.067	-2.45 (1.75)	-5.89 – 0.99	0.163
‘Social support’	2.00 (0.52)	0.98 – 0.67	**0.000**	2.01 (0.55)	0.94 – 3.08	**0.000**	2.08 (0.55)	0.99 – 3.16	**0.000**
‘Trust and empowerment	-0.53 (0.87)	-2.23 – 1.17	0.544	-0.45 (0.87)	-2.15 – 1.25	0.604	-0.52 (0.91)	-2.30 – 1.26	0.568
‘Social interaction’	1.35 (0.70)	-0.03 – 2.73	0.055	1.30 (0.77)	-0.21 – 2.81	0.092	0.71 (0.74)	-0.73 – 2.15	0.336
‘Cohesion and safety’	0.82 (0.93)	-1.00 – 2.64	0.378	0.85 (0.86)	-0.83 – 2.53	0.323	0.64 (0.87)	-1.07 – 2.34	0.464
‘Perceived attractiveness of buildings’									
Constantly poorer (ref)									
Declined	-0.07 (0.66)	-1.32 – 1.18	0.914	0.09 (0.62)	-1.14 – 1.31	0.892	0.43 (0.67)	-0.89 – 1.74	0.526
Improved	0.25 (0.57)	-0.81 – 1.31	0.658	0.71 (0.54)	-0.36 – 1.77	0.193	1.32 (0.60)	0.14 – 2.51	0.028
Constantly better	0.15 (0.54)	-0.86 – 1.16	0.781	0.54 (0.52)	-0.47 – 1.55	0.299	1.18 (0.61)	-0.00 – 2.37	0.051
‘Perceived quality of parks/open space’									
Constantly poorer (ref)									
Declined	-1.47 (0.61)	-2.70 - -0.23	0.016	-1.40 (0.63)	-2.63 - -0.17	0.026	-1.20 (0.62)	-2.43 – 0.02	0.053
Improved	-0.87 (0.56)	-1.20 – 0.25	0.119	-0.61 (0.59)	-1.76 – 0.55	0.305	-0.52 (0.59)	-1.68 – 0.65	0.382
Constantly better	-0.89 (0.51)	-1.92 – 0.14	0.078	-0.68 (0.53)	-1.72 – 0.35	0.196	-0.54 (0.54)	-1.59 – 0.52	0.319
‘Perceived attractiveness of environment’									
Constantly poorer (ref)									
Declined	-0.24 (0.69)	-1.54 – 1.05	0.722	0.04 (0.67)	-1.27 – 1.35	0.955	-0.17 (0.68)	-1.51 – 1.18	0.809
Improved	-0.51 (0.58)	-1.68 – 0.65	0.375	-0.03 (0.61)	-1.22 – 1.16	0.961	-0.75 (0.64)	-2.00 – 0.50	0.239
Constantly better	-0.61 (0.55)	-1.73 – 0.50	0.262	-0.10 (0.59)	-1.26 – 1.06	0.866	-0.82 (0.64)	-2.08 – 0.44	0.204
‘Vandalism’ (reversed)									
Constantly problem (ref)									
Become problem	0.20 (0.74)	-1.09 – 1.48	0.791	0.06 (0.65)	-1.22 – 1.34	0.933	0.51 (0.68)	-0.82 – 1.84	0.454
No longer a problem	-0.76 (0.54)	-1.79 – 0.28	0.165	-0.61 (0.53)	-1.64 – 0.42	0.270	-0.48 (0.53)	-1.52 – 0.57	0.371
Constantly not a problem	-0.59 (0.52)	-1.59 – 0.40	0.256	-0.31 (0.52)	-1.32 – 0.71	0.576	-0.19 (0.58)	-1.33 – 0.95	0.745
‘Perceived litter’ (reversed)									
Constantly problem (ref)									
Become problem	-0.72 (0.49)	-1.70 – 0.26	0.143	-0.77 (0.49)	-1.73 – 0.18	0.112	-0.94 (0.53)	-1.97 – 0.09	0.075
No longer a problem	-0.87 (0.47)	-1.78 – 0.03	0.064	-0.75 (0.47)	-1.67 – 0.17	0.111	-0.71 (0.48)	-1.65 – 0.24	0.145
Constantly not a problem	-0.45 (0.42)	-1.24 – 0.34	0.283	-0.20 (0.40)	-0.98 – 0.58	0.621	-0.33 (0.46)	-1.24 – 0.58	0.479

Model 1: model including single environmental exposure; Model 2: model including single environmental exposure and covariates (sex, citizenship, age group, tenure, working status, vehicle access, mobility-limiting condition, neighbourhood deprivation and area intervention type), adjusted for potential nesting in sub-area; Model 3: model including all environmental exposures and adjusted for covariates and potential nesting in sub-area. Bold typeface indicates significance at $p<0.01$. No significant covariates in Model 3. Model 1 with 'social support' as the outcome was significant: $F(1)=14.75$, $p<0.001$; explaining 3% of variance. SE: robust standard error.

Table 7.6 Associations between absolute change in environmental factors and absolute change in number of days of neighbourhood-based walking for ≥20 minutes per week (n=558)

Environmental factor (absolute change)	Model 1			Model 2			Model 3		
	B (SE)	95% CI	p	B (SE)	95% CI	p	B (SE)	95% CI	p
‘Physical disorder’	-0.27 (1.39)	-2.46 – 3.00	0.847	-0.61 (1.58)	-3.71 – 2.49	0.699	-0.25 (1.72)	-3.62 – 3.12	0.884
‘Social support’	0.57 (0.54)	-0.49 – 1.62	0.290	0.50 (0.54)	-0.56 – 1.56	.356	0.34 (0.54)	-0.71 – 1.39	0.527
‘Trust and empowerment’	-1.50 (0.88)	-3.22 – 0.23	0.089	-1.38 (0.88)	-3.11 – 0.35	0.117	-2.12 (0.86)	-3.81 - -0.43	0.014
‘Social interaction’	1.36 (0.71)	-0.04 – 2.76	0.057	1.30 (0.77)	-0.22 – 2.82	0.093	0.91 (0.72)	-0.50 – 2.33	0.207
‘Cohesion and safety’	1.55 (0.94)	-0.29 – 3.40	0.099	1.55 (0.92)	-0.26 – 3.36	0.094	1.29 (0.90)	-0.47 – 3.06	0.151
‘Perceived attractiveness of buildings’									
Constantly poorer (ref)									
Declined	-0.33 (0.67)	-1.69 – 1.04	0.628	-0.19 (0.70)	-1.56 – 1.17	0.784	0.74 (0.76)	-0.74 – 2.22	0.329
Improved	0.19 (0.58)	-0.93 – 1.32	0.736	0.63 (0.58)	-0.51 – 1.77	0.277	1.09 (0.69)	-0.26 – 2.44	0.113
Constantly better	-0.23 (0.54)	-1.32 – 0.86	0.669	0.25 (0.56)	-0.85 – 1.36	0.652	1.04 (0.68)	-0.30 – 2.38	0.129
‘Perceived quality of parks/open space’									
Constantly poorer (ref)									
Declined	-2.30 (0.61)	-3.53 - -1.08	**0.000**	-2.15 (0.63)	-3.38 - -0.93	**0.001**	-2.18 (0.61)	-3.38 – 0.98	**0.000**
Improved	-0.82 (0.56)	-1.94 – 0.29	0.145	-0.46 (0.58)	-1.60 – 0.69	0.432	-0.65 (0.58)	-1.79 – 0.50	0.267
Constantly better	-1.35 (0.51)	-2.37 - -0.32	**0.001**	-1.03 (0.53)	-2.06 – 0.01	0.052	-1.17 (0.54)	-2.22 - -0.11	0.030
‘Perceived attractiveness of environment’									
Constantly poorer (ref)									
Declined	-0.79 (0.70)	-2.25 – 0.68	0.259	-0.51 (0.76)	-2.01 – 0.99	0.502	-0.78 (0.78)	-2.32 – 0.76	0.319
Improved	-0.28 (0.59)	-1.49 – 0.94	0.637	0.25 (0.63)	-0.99 – 1.49	0.696	-0.06 (0.71)	-1.45 – 1.33	0.930
Constantly better	-0.81 (0.56)	-1.98 – 0.37	0.146	-0.16 (0.62)	-1.37 – 1.05	0.797	-0.55 (0.67)	-1.87 – 0.76	0.410
‘Perceived vandalism’ (reversed)									
Constantly problem (ref)									
Become problem	0.24 (0.75)	-1.29 – 1.77	0.745	-0.16 (0.79)	-1.38 – 1.71	0.835	0.91 (0.82)	-0.70 – 2.51	0.268
No longer a problem	-0.46 (0.55)	-1.59 – 0.66	0.403	-0.18 (0.56)	-1.27 – 0.92	0.755	-0.06 (0.56)	-1.17 – 1.04	0.911
Constantly not a problem	-0.65 (0.53)	-1.71 – 0.42	0.223	-0.16 (0.55)	-1.24 – 0.92	0.771	-0.01 (0.61)	-1.18 – 1.19	0.994
‘Perceived litter’ (reversed)									
Constantly problem (ref)									
Become problem	-1.15 (0.50)	-2.14 - -0.16	0.022	-1.17 (0.51)	-2.16 - -0.18	0.021	-1.14 (0.54)	-2.20 - -0.09	0.034
No longer a problem	-0.40 (0.48)	-1.36 – 0.57	0.408	-0.23 (0.49)	-1.19 – 0.73	0.640	-0.21 (0.48)	-1.15 – 0.74	0.665
Constantly not a problem	-0.23 (0.42)	-1.04 – 0.57	0.586	0.06 (0.40)	-0.73 – 0.85	0.882	0.13 (0.45)	-0.75 – 1.01	0.777

Model 1: model including single environmental exposure; Model 2: model including single environmental exposure and covariates (sex, citizenship, age group, tenure, working status, vehicle access, mobility-limiting condition, neighbourhood deprivation and area intervention type), adjusted for potential nesting in sub-area; Model 3: model including all environmental exposures and adjusted for covariates and potential nesting in sub-area. Bold typeface indicates significance at $p<0.01$. No significant covariates in Model 3. SE: robust standard error.

7.4.4.1 Associations between change in physical disorder and change in walking, stratified by baseline levels of safety and cohesion

Absolute change in ‘physical disorder’ was not associated with absolute change in days of non-specific walking (**Table 7.7**) or absolute change in days of neighbourhood-based walking (**Table 7.8**) when stratified by levels of ‘cohesion and safety’ at time point 1.

Table 7.7 Association between absolute change in 'physical disorder' and absolute change in non-specific walking, stratified by 'cohesion and safety' (n=558)

Environmental factor	Model 1			Model 2		
	B (SE)	95% CI	p	B (SE)	95% CI	p
'Change in 'physical disorder'						
High 'cohesion and safety'	-1.52 (1.83)	-5.13 – 2.08	0.407	-1.31 (2.44)	-6.10 – 3.48	0.592
Low 'cohesion and safety'	-2.69 (2.05)	-6.73 – 1.35	0.191	-4.04 (2.49)	-8.92 – 0.85	0.105

Model 1: model including single environmental exposure; Model 2: model including single environmental exposure and covariates (sex, citizenship, age group, tenure, working status, vehicle access, mobility-limiting condition, neighbourhood deprivation and area intervention type), adjusted for potential nesting in sub-area. Significance was tested at p<0.01. SE: robust standard error.

Table 7.8 Association between absolute change in 'physical disorder' and absolute change in neighbourhood-based walking, stratified by 'cohesion and safety' (n=558)

Environmental factor	Model 1			Model 2		
	B (SE)	95% CI	p	B (SE)	95% CI	p
Change in 'physical disorder'						
High 'cohesion & safety'	-1.01 (1.81)	-4.57 – 2.55	0.577	0.79 (2.06)	-3.24 – 4.83	0.700
Low 'cohesion & safety'	1.68 (2.17)	-2.60 – 5.96	0.440	-1.01 (2.68)	-6.26 – 4.24	0.707

Model 1: model including single environmental exposure; Model 2: model including single environmental exposure and covariates (sex, citizenship, age group, tenure, working status, vehicle access, mobility-limiting condition, neighbourhood deprivation and area intervention type), adjusted for potential nesting in sub-area. Significance was tested at p<0.01. SE: robust standard error.

7.4.5 Cross-sectional associations between environment and walking

Table 7.9 presents cross-sectional associations between social and physical environmental variables and number of days of non-specific walking for ≥ 10 minutes (all measured at time point 2). Model 1 revealed significant positive associations between self-reported ‘social interaction’ (B=3.51, SE=0.79, p<0.001) and ‘cohesion and safety’ (B=2.59, SE= 0.79, p<0.01). The association between ‘social interaction’ and walking retained significance upon inclusion of other environmental variables and adjustment of covariates and sub-area; the association between ‘cohesion and safety’ lost significance upon adjustment. Similarly, results were found for cross-sectional analyses with number of days of neighbourhood-based walking for ≥20 minutes, although these effects were slightly stronger (Model 1: ‘social interaction’: B=3.71 SE=0.82, p<0.001; ‘cohesion and safety’: B=3.62, SE=0.82, p<0.001) and the effect of ‘cohesion and safety’ persisted after adjustment for other environmental variables, covariates and non-independence of participant data (**Table 7.10**).

Table 7.9 Cross-sectional associations between environmental exposures and number of days of non-specific walking for ≥10 minutes (n=558)

Environmental factor	Model 1			Model 2			Model 3		
	B (SE)	95% CI	p	B (SE)	95% CI	p	B (SE)	95% CI	p
‘Physical disorder’*	-1.76 (1.38)	-4.47 – 0.96	0.204	-1.40 (1.60)	-4.54 – 1.74	0.383	-0.75 (1.69)	-4.05 – 2.55	0.656
‘Social support’*	0.47 (0.61)	-0.72 – 1.66	0.438	0.70 (0.61)	-0.49 – 1.88	0.250	0.20 (0.64)	-1.06 – 1.47	0.754
‘Trust and empowerment’*	-0.56 (0.90)	-2.32 – 1.21	0.537	-0.87 (0.89)	0.88 – 0.95	0.330	-1.69 (0.94)	-3.53 – 0.14	0.071
‘Social interaction’*	3.51 (0.79)	1.96 – 5.06	**0.000**	2.71 (0.76)	1.23 – 4.20	**0.000**	2.31 (0.85)	0.64 – 3.97	**0.007**
‘Cohesion and safety’*	2.59 (0.79)	1.03 – 4.15	**0.001**	1.49 (0.76)	0.01 – 2.97	0.055	1.13 (0.80)	-0.45 – 2.70	0.161
‘Perceived attractiveness of buildings’									
Fairly poor/neither good nor bad (ref)									
Fairly/very good	-0.43 (0.30)	-1.01 – 0.15	0.147	-0.00 (0.28)	-0.56 – 0.56	0.995	0.08 (0.33)	-0.57 – 0.73	0.812
‘Perceived quality of parks/open space’									
Fairly poor/neither good nor bad (ref)									
Fairly/very good	0.07 (0.30)	-0.52 – 0.65	0.826	-0.37 (0.29)	-0.93 – 0.20	0.209	0.38 (0.30)	-0.21 – 0.97	0.207
‘Perceived attractiveness of environment’									
Fairly poor/neither good nor bad (ref)									
Fairly/very good	-0.60 (0.31)	-1.20 – 0.00	0.051	-0.04 (0.29)	-0.53 – 0.61	0.882	-0.07 (0.34)	-0.74 – 0.61	0.850
‘Perceived vandalism’ (reversed)									
Slight/serious problem (ref)									
Not a problem	-0.51 (0.32)	-1.13 – 0.12	0.113	-0.05 (0.31)	-0.55 – 0.66	0.860	-0.06 (0.32)	-0.56 – 0.69	0.847
‘Perceived litter’ (reversed)									
Slight/serious problem (ref)									
Not a problem	-0.41 (0.25)	-0.90 – 0.08	0.099	-0.19 (0.24)	-0.27 – 0.66	0.416	-0.22 (0.26)	-0.72 – 0.29	0.399

Model 1: model including single environmental exposure; Model 2: model including single environmental exposure and covariates (sex, citizenship, age group, tenure, working status, vehicle access, mobility-limiting condition, neighbourhood deprivation and area intervention type), adjusted for potential nesting in sub-area; Model 3: model including all environmental exposures and adjusted for covariates and potential nesting in sub-area. Bold typeface indicates significance at p<0.01. SE: robust standard error. * Higher score indicates more positive (better) environmental exposure.

Table 7.10 Cross-sectional associations between environmental exposures and number of days of neighbourhood-based walking for ≥20 minutes (n=558)

Environmental factor	Model 1			Model 2			Model 3		
	B (SE)	95% CI	p	B (SE)	95% CI	p	B (SE)	95% CI	p
‘Physical disorder’*	-1.64 (1.44)	-4.47 – 1.18	0.254	-0.93 (1.68)	-4.23 – 2.37	0.577	-0.43 (1.73)	-3.83 – 2.97	0.805
‘Social support’*	0.19 (0.62)	-1.05 – 1.43	0.760	0.35 (0.62)	-0.86 – 1.57	0.569	-0.31 (0.66)	-1.60 – 0.98	0.636
‘Trust and empowerment’*	-0.32 (0.94)	-2.16 – 1.53	0.736	-0.26 (0.95)	-2.11 – 1.60	0.786	-1.55 (0.97)	-3.45 – 0.36	0.112
‘Social interaction’*	3.71 (0.82)	2.11 – 5.33	**0.000**	3.06 (0.79)	1.51 – 4.60	**0.000**	2.51 (0.88)	0.79 – 4.23	**0.004**
‘Cohesion and safety’*	3.62 (0.82)	2.02 – 5.23	**0.000**	3.09 (0.83)	1.45 – 4.72	**0.000**	2.69 (0.88)	0.96 – 4.42	**0.002**
‘Perceived attractiveness of buildings’									
Fairly poor/neither good nor bad (ref)									
Fairly/very good	0.10 (0.31)	-0.71 – 0.50	0.736	-0.28 (0.31)	-0.89 – 0.34	0.376	0.15 (0.37)	-0.57 – 0.87	0.688
‘Perceived quality of parks/open space’									
Fairly poor/neither good nor bad (ref)									
Fairly/very good	0.19 (0.31)	-0.42 – 0.80	0.536	-0.53 (0.31)	-1.15 – 0.09	0.091	0.40 (0.33)	-0.24 – 1.04	0.218
‘Perceived attractiveness of environment’									
Fairly poor/neither good nor bad (ref)									
Fairly/very good	-0.19 (0.32)	-0.81 – 0.44	0.562	-0.37 (0.33)	-1.02 – 0.28	0.261	0.35 (0.39)	-0.42 – 1.13	0.374
‘Perceived vandalism’ (reversed)									
Slight/serious problem (ref)									
Not a problem	-0.41 (0.33)	-1.06 – 0.24	0.216	-0.11 (0.35)	-0.78 – 0.57	0.761	0.12 (0.36)	-0.58 – 0.82	0.731
‘Perceived litter’ (reversed)									
Slight/serious problem (ref)									
Not a problem	-0.14 (0.26)	-0.65 – 0.37	0.601	-0.07 (0.25)	-0.57 – 0.43	0.781	-0.16 (0.27)	-0.69 – 0.37	0.558

Model 1: model including single environmental exposure; Model 2: model including single environmental exposure and covariates (sex, citizenship, age group, tenure, working status, vehicle access, mobility-limiting condition, neighbourhood deprivation and area intervention type), adjusted for potential nesting in sub-area; Model 3: model including all environmental exposures and adjusted for covariates and potential nesting in sub-area. Bold typeface indicates significance at p<0.01. SE: robust standard error. * Higher score indicates more positive (better) environmental exposure.

7.5 Discussion

7.5.1 Summary of findings

This study examined the relationship between change in the quality of the neighbourhood social and physical environment and days of walking over a 7-year period in income-deprived neighbourhoods in Glasgow. Environmental factors developed in **Study 1** all displayed some degree of change in the expected direction (i.e. positive change between time point 1 and time point 2). A positive change in 'social support' over time was related to a positive change in number of days/week of non-specific walking for ≥10 minutes; there was no relationship with change in days/week of neighbourhood-based walking for ≥20 minutes. Change in other quality-related aspects of the objective and perceived neighbourhood social and physical environment did not predict change in walking patterns of participants. Findings therefore do not support a relationship between change in context-specific and non-specific walking and change in: 'physical disorder', 'social interaction'; 'trust and empowerment'; 'cohesion and safety'; 'perceived attractiveness of buildings'; 'perceived attractiveness of environment'; 'perceived quality of parks and open space'; 'perceived vandalism'; and 'perceived litter'.

A significant relationship between change in 'social support' and non-specific walking suggests a prospective link between these two constructs. While the literature provides strong evidence for a relationship between physical activity and social support specific to physical activity (i.e. encouragement to perform in exercise), there is more limited evidence for general social support (Lindsay Smith *et al.*, 2017). No studies using a simultaneous assessment of general social support and physical environment factors on activity were identified in the systematic review presented in **Section 1.4**.

Null findings are not necessarily evidence for no effect of environmental factors on physical activity and there may be several contributing factors to a lack of an observed effect. Firstly, there might have been insufficient change in the environmental exposures to detect an effect on change in walking outcomes. There was a 16% increase in mean ratings of fewer cues of physical disorder but only a 0-8% mean increase in the perceived social environment (‘social support’: 8%; ‘social interaction’: 0%; ‘trust and empowerment’: 3%; ‘cohesion and safety’: 6%). More substantial change in environmental exposures may be required to predict co-occurring change in context-specific and non-specific walking behaviour. A lack of substantial change in exposures may be partly due to changing priorities of stakeholders over the intervention period and the varying intensity and reach of regeneration activities across studied neighbourhoods (Bond *et al.*, 2013).

Secondly, and relatedly, effects of small changes might be expected to operate over an extended latency period. While time points were 7 years apart, it is not possible to know the time at which change in the environment occurred. This could impact upon a possible latency period for the effects of change in the environment to influence physical activity behaviour. This element of the study design may therefore have limited the opportunity to detect an effect.

Thirdly, it is possible that null effects reflect an absence of a *direct* effect between the quality of the neighbourhood physical and social environment and walking. This could be true for either direction of effect or that a system of influences with feedback and adaptive relationships between variables may not be detectable using these analyses. In such a case, extraneous factors could be contributing to observed cross-sectional relationships. It is possible that more proximal individual factors could independently influence both exposure and outcome, driving cross-sectional relationships; for example, age could influence perceptions of the social environment and treatment of the physical environment while having a separate influence on frequency of walking. Individual factors could also be intervening in a relationship between environment and activity: it might be necessary to simultaneously target cognitions such as motivation in order to promote walking in environments which are increasingly supportive of activity.

Cross-sectional associations between walking and 'social interaction' and 'cohesion and safety' replicate findings from **Study 2**, using a validated measure of days of non-specific walking as the outcome. Although change in self-reported 'social support' was related to change in self-reported non-specific walking, it was not related to change in specifically neighbourhood-based walking, nor did it have a cross-sectional association with frequency of non-specific or neighbourhood-based walking. A significant cross-sectional relationship between 'social support' and activity in **Study 2** was somewhat unstable with the significance being lost in analyses stratified by tenure, therefore a lack of effect in cross-sectional analyses in the current study is not surprising.

7.5.2 Strengths and limitations

A strength of this study was a longitudinal sample of adults who remained in the same neighbourhood over a 7-year period and were exposed to some - albeit limited - change in the physical and social environment. The use of a longitudinal sample rather than a repeat cross-sectional sample means that findings cannot be attributed to compositional change in the sample arising from inward or outward migration of residents over time. The use of a validated measure of non-specific walking behaviour was also a strength of the study, as was a measure of context-specific walking. Although the psychometric properties of this single-item measure of neighbourhood-based walking have not been evaluated, its use is advantageous in terms of providing a degree of geographical consistency between exposure and outcome, as encouraged by Giles-Corti *et al.* (2005) and the findings from the systematic review presented in **Section 1.4.1**.

The use of data from a real-world intervention also brings several limitations. Because change in the environment does not occur under laboratory conditions, it is necessary to interpret findings in relation to the wider context. There were also no control areas used for analyses. This is less problematic than it would be in an evaluation of an intervention; within the current study sub-areas exposed to no change in the environmental measures could be conceived as pragmatic controls. Nonetheless, these sub-areas may have experienced change in different aspects, such as increased employment opportunities or quality of housing, which could have driven observed mean increases in walking. Moreover, sub-areas are likely to have been exposed to different patterns of change in the environmental exposures; therefore, this persists as a limitation.

Identifying controls for such a study is difficult (Thomson, 2008). Cities are fluid and are constantly experiencing directed (through intervention) or undirected change, owing to wider ecological factors such as the international economic crisis in 2008 or new housing standards introduced in Scotland during the measurement period (Scottish Government, 2011). Likewise, change in the study neighbourhoods cannot be attributed only to the effects of regeneration activities, nor can the first time point be conceived as a ‘baseline’, before which the environmental conditions were unchanging. Therefore, it is possible that confounding factors were introduced during the period of regeneration. These challenges are common in research examining the impact of environmental change in real-world conditions and are known to be extremely difficult to address (Thomson, 2008).

Change in only one aspect of the physical environment was objectively measured: longitudinal audit data were not available for ‘aesthetics of built form’ and ‘aesthetics and maintenance of open space’. Previous research highlights distinct relationships between the perceived and objective physical environment and physical activity (Orstad *et al.*, 2016), therefore null associations between change in the perceived physical environment cannot be extrapolated to these aspects of the objective physical environment. Moreover, objective data on ‘physical disorder’ was collected in 2006 while perceptions of the physical environment were collected in 2008. While neighbourhoods which were expected to have undergone substantial change between 2006 and 2008 due to regeneration activities were excluded, there remains a possibility that change in the objective environment prior to collection of walking data in included neighbourhoods was undetected, obscuring a possible association between change in physical disorder and change in walking. Finally, although the same rigorous protocol was followed, environmental audit data were collected by separate auditors in 2006 and 2015, potentially raising issues around subjectivity and inconsistency of evaluation across time. This should be acknowledged when interpreting the null effects.

Although the sample was substantially smaller than the cross-sectional sample used in **Study 2**, an a-priori power calculation suggested that the sample size was sufficiently powered to detect small and medium effects. Cross-sectional associations reported in **Study 2** were also replicated using the smaller longitudinal sample, attesting to the power to detect effects. There were no unexpected differences in participant characteristics: participants were older, more likely to be retired and own their house than participants in the cross-sectional sample used in **Study 2**. It is frequently reported that attrition from longitudinal sample is higher in lower-SES and younger groups (Parry *et al.*, 2001; Booker, Harding and Benzeval, 2011). Differences may also be due to the selection of participants who remained in the same sub-area over the 7-year period. It is likely that individuals who are older, retired and own their home are less transient than other groups. To some extent, this limits the generalisability of findings to the wider population living in income-deprived neighbourhood in Glasgow and beyond.

Finally, physical activity outcomes were self-reported. As such, levels of physical activity might have been overestimated (Health and Social Care Information Centre, 2009). In addition, items assessing neighbourhood-based and non-specific walking used different cut-offs (>20 minute sessions and >10 minute sessions, respectively). Interpretation of results should acknowledge that differential cut-offs might have influenced results.

7.5.3 Implications for future research

Findings suggest that a wider systems-based approach should inform future research examining potentially indirect relationships between the neighbourhood environment and non-specific and neighbourhood-based walking. Interrogating pathways of influence through a system would aid interpretation of the null findings presented in this study. As discussed, it is possible individual cognition or recursive, adaptive relationships in the environment has obscured the detection of longitudinal associations which are shown in cross-sectional analyses. Future research would also be strengthened by detailed observation of timelines of change in environmental exposure so that potential latency periods could be accounted for in analyses and study design. In order to do this, a realistic but complex systems approach is required, to examine context, outcomes and mechanisms driving any associations. This reflects a broader shift to complex systems approaches in physical activity research, which acknowledge the complexity of system influences on behaviour rather than attempting to isolate cause-and-effect relationships in which to intervene (Rutter, Glonti and Lakerveld, 2016; Rutter *et al.*, 2017).

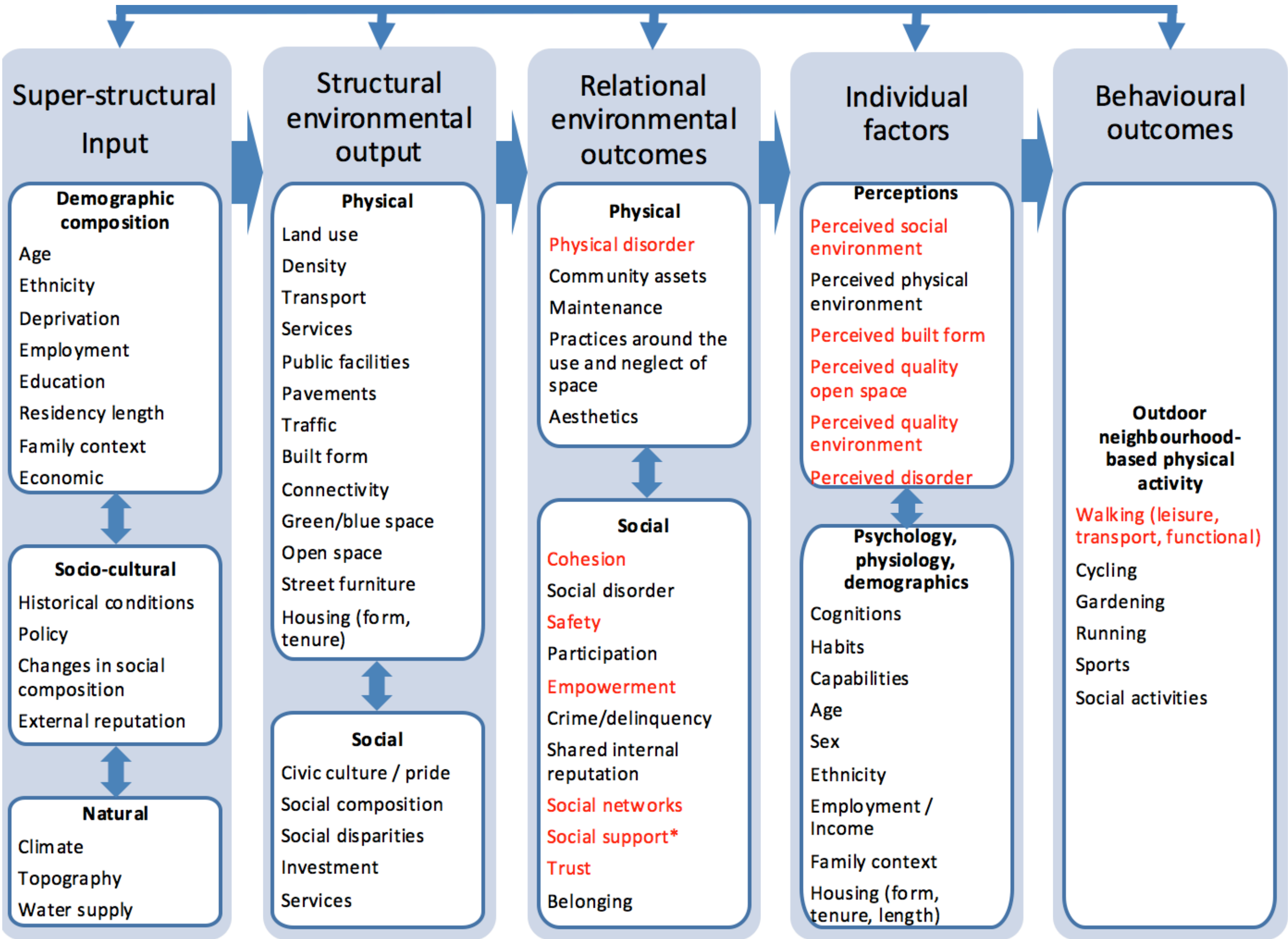
Over a 7-year period of measurement, there was limited change in the perceived social environment in this sample. Lack of reported association between change in exposures and change in outcome should be further interrogated. Future research could aim to induce larger changes in the environment, potentially by selecting areas undergoing high-intensity interventions, or identifying select areas using data on environmental change to ensure sufficient variation to examine associations. Targeting the social environment more intensively in urban regeneration programmes would enable such research. Current evidence of successful approaches to intervention in the social environment should be drawn upon to inform interventions (Moore, Salsberg and Leroux, 2013; Coll-Planas *et al.*, 2017), especially evidence based on deprived populations.

7.5.4. Conclusions

Overall, there was little evidence that change in the quality of the neighbourhood social or physical environment were associated with change in self-reported walking. ‘Social support’ was an exception, with positive 1 unit change in social support from friends, family and neighbours being related to an additional 2 days/week of non-specific walking for ≥10 minutes; this relationship was not observed for days/week of neighbourhood-based walking for ≥20 minutes. There are several reasons for a potential lack of associations: i) a causal relationship may not exist, ii) change in environmental exposures was not sufficient to detect an effect, or iii) causal pathways are complex and operating through a system of environment and individual factors which were not captured in this study. Adoption of systems approaches and assessment of the impact of more substantial changes in the neighbourhood environment are recommended in order to further interrogate the direction of observed cross-sectional associations.

Figure 7.3 displays the logic model developed for **Study 4**. Factors examined in relation to neighbourhood-based walking in ‘change’ analyses are displayed in red text; an asterisk denotes a positive association with change in neighbourhood-based walking.

Figure 7.3 Logic model of neighbourhood environmental influences on neighbourhood-based physical activity in deprived communities



Red text denotes factor examined in **Study 4**. * Denotes significant association with physical activity.

Chapter 8 Discussion: Environmental influences on physical activity in adults in income-deprived neighbourhoods

8.1 Rationale for the thesis

There is growing evidence of independent effects of the neighbourhood social and physical environment on physical activity, leading to 'active design' approaches gaining traction in policy as an inclusive, sustainable method to support healthy lifestyles (Kleinert and Horton, 2016). The quality, or condition, of aspects of neighbourhood social and physical environment might explain observed differences in physical activity by neighbourhood deprivation (Giles-Corti and Donovan, 2002; Van Lenthe, Brug and Mackenbach, 2005; Kamphuis *et al.*, 2008; UK Active, 2014; Bardsley *et al.*, 2017).

The systematic review presented in **Section 1.4** suggested that research adopting a socioecological approach to simultaneously examine social and physical environmental influences on activity was limited, and provided an inconsistent evidence base for putative independent effects. Moreover, only 1 in 8 of the studies included in the review explored interactive effects – a central tenant of socioecological models of activity. Studies which did examine interactive effects afforded preliminary insight into the potential complexity of the pathways through which the neighbourhood environment might influence physical activity. Alongside calls from other researchers (Nelson *et al.*, 2008; Gubbels *et al.*, 2014; Rutter, Glonti and Lakerveld, 2016), this review identified the interrogation of a central tenant of socioecological models - that multiple, interactive influences of the environment operate on physical activity – as a priority for future research.

As such, this thesis drew on a review of empirical and theoretical evidence to generate novel research, measuring environmental correlates of physical activity in a population with typically low levels of activity: residents of deprived neighbourhoods, acknowledging a need to move individuals from inactivity to some level of activity in order to obtain health benefits. The design of this research responded to recommendations developed from the review.

Firstly, the research aimed to be sensitive and specific. Neighbourhood-based physical activity was a primary outcome, increasing sensitivity to detect hypothesised environmental effects. Theoretically and analytically coherent composite scores of the neighbourhood environment were operationalised, condensing large amounts of information on environmental exposures for use in quantitative research. This responded to an observed heterogeneity in environmental variables within the literature (Feng *et al.*, 2010). A context- and group-specific examination of environmental influences on activity was adopted, acknowledging that the salience, direction and strength of environmental correlates are likely to differ across socioeconomic and geographical contexts (Macintyre, Ellaway and Cummins, 2002).

Secondly, the research aimed to further conceptualise the interdependency between neighbourhood environmental influences on physical activity in order to test a central tenant of socioecological models: interaction between levels of influence. Such research offers insight into pathways of influence; for example, how actions within one domain of the physical or social environment might influence physical activity opportunities directly or indirectly through effects on other aspects of the environment.

8.2 Associations between the quality of the social and physical environment and physical activity

In **Study 1**, in a sample of adults living in income-deprived neighbourhoods in Glasgow, UK, 4 factors assessing the quality and quality of the neighbourhood physical and social environment were extracted from self-reported survey data and an objective environmental audit. The factors demonstrated good psychometric properties and were named: ‘social support’; ‘trust and engagement’; ‘social interaction’; ‘cohesion and safety’; ‘aesthetics of the built form’; ‘cues of physical disorder’; and ‘aesthetics and maintenance of open space’.

Significant associations were observed between 'aesthetics of the built form' and 'cues of physical disorder' and all social environment factors. Effect sizes were small but were in the expected direction and substantiated by previous literature. There were several differences in mean factor scores by socio-demographics, suggesting exposure to or experience of the neighbourhood environment differed meaningfully between residents, with participants in rented accommodation being especially exposed to poorer quality social and physical conditions.

Associations between 'aesthetics of the built form' and 'cues of physical disorder' and social environment factors are substantiated by previous literature outside of the UK. For example, in a study of 335 adults residing in 3 suburbs in Australia, neighbourhood upkeep (unkempt gardens, fences, houses, playgrounds or open spaces, dumping or littering, poor street-lighting) was associated with perceived safety and levels of social capital (comprising measures of reciprocity, engagement, social networks and trust) (Wood *et al.*, 2008). In addition, Foster, Giles-Corti and Knuiman (2011) posit that streets are increasingly inviting and safe for pedestrians when there are fewer cues of territoriality in the physical environment.

A lack of an association between 'aesthetics and maintenance of open space' and social environment factors was unexpected and contrasts with previous studies. For example, a study with 145 adults living in social housing in Chicago, USA, found that landscaped shared open space increased interactions and social ties between residents (Kuo *et al.*, 1998). The authors note the importance of quality open spaces in areas with high residential density as social withdrawal has previously been linked to living in such conditions (Baum and Valins, 1979; Kuo *et al.*, 1998). However, there were differences in the significance of effects for 'building greenness' (vegetation in shared spaces around building) and 'apartment greenness' (view of vegetation from participants' apartments), with only 'apartment greenness' showing significant relationships with socialising, knowing nearby neighbours and sense of local community. Moreover, use of shared spaces was a significant mediator in the relationship between ‘apartment greenness’ and social ties (Kuo *et al.*, 1998). In the present study, our measure of the condition of open space was broader, encompassing multiple aspects of aesthetics and maintenance beyond landscaping and was at a larger scale than the building level. Discrepancies with previous research might therefore be attributable to the ‘variety of scales’ at which context can be examined, experienced and exert an effect, as noted by Bronfenbrenner (1979), and the potential individual differences in the use of local open spaces.

Systematic operationalisation of analytically coherent measures of the quality of the environment in an income-deprived context pointed to separate underlying dimensions of the environment, which were differentially related to one another and socio-demographics, and therefore, hypothetically, differentially associated with physical activity. **Study 1** developed robust measures of the quality of the social environment in deprived settings in the UK, which enable context-specific examination of environment effects on physical activity, as recommended in the systematic review presented in **Section 1.4**.

Study 2 examined the independent and interactive effects of social and physical environmental factors, identified in **Study 1**, on self-reported neighbourhood-based walking and non-context-specific moderate physical activity. As in **Study 1**, associations were explored in a large sample of adults living in 14 income-deprived neighbourhoods in Glasgow. Testing of interactive effects of social and physical environmental factors was data-driven, using statistical approaches advised for exploratory analyses (Aiken and West, 1991), although theoretical and empirical evidence from sociology and public health underpinned the selection variables in **Study 1** and their hypothesised interactive effect on physical activity in this context and population. Furthermore, results from **Study 1** suggested interplay between the variables, pointing towards possible interplay in their influence on meeting physical activity guidelines through walking or MPA.

Multilevel logistic regression models found independent effects of: 'social support'; 'social interaction'; 'cohesion and safety'; 'aesthetics of built form'; and 'aesthetics and maintenance of open space' on neighbourhood-based walking on at least 5 days/week. Most impressive was a 1.78 increased odds of walking around the neighbourhood on at least 5 days/week for those reporting a stronger sense of neighbourhood safety cohesion. 'Social interaction' and 'cohesion and safety' were positively associated with MPA on at least 5 days/week while 'social support' unexpectedly had a negative effect on MPA. Participants reporting higher levels of 'social interaction' were more than 6 times more likely to meet activity guidelines through frequent MPA. There was no effect of 'trust and empowerment' on either walking or MPA and 'physical disorder' was the only physical environment factor significantly associated with performing MPA on at least 5 days/week.

Post-hoc testing of interactive effects suggested that 'trust and empowerment' and 'aesthetics and maintenance of open space' operated synergistically on walking and MPA while 'cohesion and safety' moderated an effect of 'physical disorder' on activity outcomes. 'Social interaction' also appear to moderate a significant effect of 'aesthetics of the built form' on MPA.

Stratified analyses provided insight into the possible role of individual factors in environmental influences on activity, revealing larger effects of the social environment for participants in owner-occupied accommodation and heightened importance of the quality of the physical environment for those in (predominantly socially-) rented accommodation.

Previous findings from the GoWell sample, using single measures (rather than composite factors) of the social environment, broadly supported these results, reporting a significant association between neighbourhood-based walking and perceived: safety after dark; belonging to the neighbourhoods; cohesion between residents of different backgrounds; and likelihood of intervention in harassment (Mason, Kearns and Bond, 2011). However, there were a small number of differences. It is likely that the construction of the multivariate model including social environment and physical environment factors and the use of single measures rather than composite scores (i.e. factors), had a bearing on any differences. For example, a measure of 'trust and empowerment' will capture something different to a single item assessing trust in terms of the likelihood of a lost wallet being returned without anything missing – perhaps explaining a lack of effect on neighbourhood-based walking in the results presented here, and a negative effect in Mason, Kearns and Bond (2011).

Findings from other populations also support those reported in **Study 2**. For example, in a study with 1,112 adults living in low-income neighbourhood in the USA, Shelton *et al.* (2011) reported a positive association between social network size and physical activity measured by pedometer. A positive effect of perceived neighbourhood aesthetics on self-reported transport-related walking for at least 150 minutes/week (equivalent to meeting physical activity guidelines) was revealed in the IPEN study of 17 cities across 12 countries (Kerr *et al.*, 2016). This finding reflects the reported relationships between meeting national physical activity guidelines through frequent walking and both audited 'aesthetics of the built form' and 'aesthetics and maintenance of open space' in the GoWell sample.

Previous research permits elaboration on why some interactive effects were significant while others were not and how interactive effects might manifest. An association between cues of physical disorder and anti-social disorder has been reported elsewhere (Sampson and Raudenbush, 1999; Keizer, Lindenberg and Steg, 2013), generating the hypothesis that signs of neglect or purposeful vandalism create the perception that, because implicit social rules around maintenance are flouted, individuals are more likely to commit criminal or anti-social behaviour (Lorenc *et al.*, 2013). Results from the current study suggest that when perceived 'cohesion and safety' was low, there was no effect of 'physical disorder' on activity, possibly because any indirect cues of safety or cohesion, usually extracted from physical disorder, were overridden. However, when perceived 'cohesion and safety' was high, 'physical disorder' had a significant effect on activity; 'physical disorder' might have been nullified as a cue of safety but absence of disorder could still create a more inviting and pleasant environment in which to be active.

Additionally, from an interactive effect of 'aesthetics of the built form' and 'social interaction' on MPA, it could be speculated that aesthetically-pleasing built environments only encourage MPA in situations where an individual is able to use these attractive buildings and environments (e.g. green space or a leisure centre) for group social or physical activities. Measurement of the physical environment was captured objectively in environmental audits, suggesting that an interactive effect was not attributable to participants with higher levels of 'social interaction' perceiving the physical environment differently, for example, due to a stronger sense of attachment to the area.

Study 3 examined social and physical environmental factors that were perceived by residents to support physical activity in two deprived neighbourhoods in Glasgow, UK. Photo-elicitation interviews were conducted with 23 adults. Five themes coalesced around two aspects which were identified as central to an activity-supportive environment within this context: environments needed to be both diverse and physically accessible to provide the opportunity to perform activity; and safe, orderly and inviting so individuals have motivation and capability to perform activity. The five themes were named: 'diversity of destinations in the neighbourhood'; 'provision of services to support healthy environments'; 'ownership of public space and facilities'; 'collective control of public space to prevent disorder'; and 'perceived value of the neighbourhood'. Participants discussed these upstream themes as operating simultaneously to create an environment in which they have the motivation and capability to be active. Unfortunately, neighbourhood environments in the study neighbourhoods were predominantly perceived as unsupportive of physical activity. Two case studies illustrated the complex pathways of interplay and reciprocity between identified themes, which underpinned a lack of support for physical activity in these settings.

Participants drew on wider contextual factors to illustrate the salience and manifestation of themes. For example, poor economic conditions, the dismantling of historical local industry and a perceived lack of investment were considered as barriers to diversity of destinations and negatively impacted upon the perceived value of the neighbourhood. Specific features of the physical environment such as the lack of attractive places to linger were partly attributed to factors including restricted employment opportunities and individual issues arising from unmet socioeconomic need. Psychological factors, such as motivation, were also briefly discussed in relation to motivation to exploit activity-supportive features of the environment.

Qualitative research conducted in other contexts and pertaining to the use of physical activity facilities identified similar themes as those extracted in this study, encompassing safety, physical accessibility, physical aesthetics and social accessibility underpinned by social cohesion and interactions (Seaman, Jones and Ellaway, 2010; Belon *et al.*, 2014; Dadpour, Pakzad and Khankeh, 2016). ‘Perceived value of the neighbourhood’ was a novel, upstream theme identified in this setting which cut across other themes to create diversity in neighbourhood destinations which were welcoming and orderly. Burgoyne, Coleman and Perry's (2007) theme of ‘perceived neglect by local authorities’ corresponded to this theme. However, within a deprived context in the current study, a close reciprocal relationship between external and internal valuations of the neighbourhood in the treatment of environments was observed, by including perceived residents’ valuations of the neighbourhood. This theme expanded previously identified constructs.

‘Ownership of public space and facilities’ and ‘collective control of public space to prevent disorder’ both contributed to the creation of inclusive places for activity which were safe, orderly and inviting, but in slightly different ways. Ownership was important in encouraging all residents to feel empowered to use areas and facilities for social and physical activity and to be motivated to keep them well-maintained. In comparison, collective control was needed to ensure areas were socially accessible by all users, at all times of the day, and that social and physical disorder was minimal.

Extracted themes also pertain to constructs developed in the built environment literature. The 'three Ds' framework encompasses three central constructs of pedestrian-oriented planning: diversity (land-use mix), density (employment opportunities and population density) and design (pavement and street design and layout) (Cervero and Kockelman, 1997). Within the context of the current study, the importance of diversity of land-use mix for physical activity is elucidated in discussion of 'diversity in neighbourhood destinations'. The pervasive influence of local economic factors reflects the association between employment and physical activity, as reported in **Study 1** and in other populations (Macassa *et al.*, 2016). Other themes extracted in this study encapsulate concepts such as Jacob's 'eyes on the street'; a concept which underscores the sense of collective informal control which can emerge from a rich mix of land uses which vary in function and operating hours (Jacobs, 1961). It therefore closely relates to 'diversity of destinations in the neighbourhood' and 'collective control of public space'.

Complex interplay between social and physical factors provided insight into the expression of interactive effects reported in **Study 2**. For example, an interactive effect of 'cohesion and safety' and 'physical disorder' on walking and MPA might arise from increased levels of collective control. The reciprocal pathway from a cohesive community who can monitor and control disorder, and the way perceived maintenance and order can feed into better social relations is described through residents' experiences of their neighbourhood.

Findings generate hypotheses into the causal pathways through which the wider neighbourhood environment can support or discourage physical activity. As such, they provide insight into potential mechanisms operating within a system, elucidating complex multi-faceted constructs which may not be identifiable from researcher-constructed survey items and predetermined participant responses. While qualitative research is unable to estimate the effect size of causal influences and results could be interpreted as nuanced perspectives, it complements traditional quantitative approaches, which are limited in the depth or breadth of insight into complex pathways of influence through a reliance on numerical data, and statistical analysis which can remove information. Using qualitative findings to elucidate possible pathways through a system of factors is supported by previous research examining contextual neighbourhood environmental effects on health (Day, 2008; Coulson *et al.*, 2011; Mehdipanah *et al.*, 2013; Egan *et al.*, 2015). As such, the real value of these analyses, as with the quantitative analyses presented in this thesis, is not the specific effects or results observed within this context or group – rather, it is the support of a higher-level principle. This principle suggests that social and physical environmental influences on physical activity operate through complex, interdependent mechanisms. This calls for an understanding of the wider environmental context of an intervention before implementing change. If the wider context is not acknowledged in the design, implementation or evaluation of an intervention, it is likely that features of the environment which could heighten or suppress impact are missed. Policy and practice would also benefit from the application of this principle when considering the interdependent features of an activity-supportive neighbourhood. Future research should seek to test the hypothesis that this principle holds in other contexts, and is therefore generalisable, rather than seeking to replicate precise findings or effect sizes.

Longitudinal study designs can provide preliminary support for prospective effects between the physical and social environment and physical activity. **Study 4** used longitudinal data from two time points to examine the effect of change in objective and perceived quality of the neighbourhood physical and social environment, and change in self-reported walking.

Multilevel linear regression models included absolute change in multiple aspects of the social environment, audited and perceived physical disorder and perceived attractiveness of built form, parks/open space and general environment as exposure variables; absolute change in self-reported number of days of non-specific and neighbourhood-based walking were outcomes. Overall, results did not support an effect of change in the quality of the neighbourhood social or physical environment on change in self-reported walking, although a positive change in ‘social support’ was related to increased non-context-specific walking over the week. Cross-sectional relationships found no effect of perceived or audited ‘physical disorder’ on walking, but did corroborate the associations between walking and ‘social interaction’ and ‘cohesion and safety’ reported in **Study 2**.

A significant relationship between change in ‘social support‘ and non-specific walking suggests a close association between these two constructs. In their 2017 systematic review, Lindsay Smith, Banting, Eime, O’Sullivan and van Uffelen reported significant cross-sectional associations between general social support and physical activity in two of four studies in older adults in the USA and Canada (Lindsay Smith *et al.*, 2017). In a large cross-sectional study of over 19,000 adults (>18 years old) in the USA, participants reporting 1 or 2 organisational contacts (i.e. clubs, formal activities) and personal contacts (i.e. family, friends, neighbours) were more likely to report any leisure-time activity (Ford, Ahluwalia and Galuska, 2000).

Predominantly null associations may be attributable to a number of factors, as discussed in **Section 7.5**. However, these findings do contrast with previous evidence from a study using the Netherlands Housing Survey, which supports significant associations between improvements in perceived social cohesion, social and physical disorder, and green space and self-reported physical activity and sports participation over a 3-year period (Jongeneel-Grimen *et al.*, 2014). Differences are likely to be driven by the use of a different study design (i.e. longitudinal design compared with a repeat cross-sectional design) and examination of associations between change in exposure and outcomes, rather than perspective relationships. The examination of individual-level associations in neighbourhoods which have been targeted for regeneration is the basis for the current study design. Results are in line with other research in the area which demonstrates the lack of an effect of neighbourhood change on health outcomes and health behaviours including physical activity over a 6.5 year period in the Netherlands (Ruijsbroek *et al.*, 2017).

8.2.1 Summary and novel contribution to the literature

In summary, findings present novel evidence of some independent and interactive effects of the neighbourhood social and physical environment on physical activity in a deprived context in the UK. Overall, results support evidence from other countries; for example, Van Dyck, Veitch *et al.*'s (2013) study with women in 40 income-deprived neighbourhoods in Australia, in which associations between objective walkability metrics and leisure-time walking operated partly through social cohesion, safety and physical aesthetics.

Studies 1 and 2 make a unique contribution to the literature by testing a central tenant of socioecological models using a context-specific measure of activity and operationalised factors assessing multiple quality-related aspects of the social and physical environment, which arguably may be more amenable to modification than structural aspects (e.g. density, connectivity and land-use mix) (Kerr *et al.*, 2016). However, results are limited by the use of a cross-sectional study design, inhibiting inference of the direction of relationships, and the lack of consideration of other environmental influences on activity (i.e. political, ecological, economic and structural).

Study 3 elucidated upstream factors underpinning an activity-supportive neighbourhood, including economic, historical, social, physical and individual aspects. Residents' perceptions of the local neighbourhood and the ways in which it supported or failed to support activity were valuable in drawing together multiple aspects in a system, and elucidating possible pathways of influence from wider ecological factors (e.g. historical conditions) to individual perceptions (e.g. collective control) and behaviour. Discussion of upstream political, historical and economic factors in the manifestation and salience of social and physical factors emphasised the value of examining the relationship between the neighbourhood environment and physical activity in a way that is sensitive and specific to context, and the importance of simultaneously examining a whole system of environmental influences. Together with results from **Studies 1 and 2**, findings suggested that change in extracted themes capturing physical and social aspects of the environment would be associated with change in physical activity. However, it is not possible to use qualitative data to ascertain effect sizes or generalise findings to the wider population within the GoWell neighbourhoods and beyond.

In **Study 4**, null associations for longitudinal analyses assessing change in the neighbourhood and activity outcomes could be explained in several ways. First, a causal relationship may not exist for features of the environment captured in these measures: a third factor may explain cross-sectional associations. Second, change in environmental exposures may not have been sufficient to detect an effect. Finally, pathways determining cross-sectional associations might operate in a complex system which cannot be easily-identified through change in a limited number of factors. Adoption of systems approaches and assessment of the impact of more substantial changes in the neighbourhood environment may be needed to elucidate causal mechanisms underpinning observed cross-sectional associations in **Studies 2 and 4** and the relationships described by participants in **Study 3**.

Taken together, results from **Studies 1-4** support an association between the neighbourhood social and physical environment and physical activity while beginning to unpack some of the complexity which may obscure real effects of the environment in the examination of assumed linear cause-and-effects of independent associations.

8.3 Strengths and limitations

The use of self-reported measures of physical activity was a limitation of the study, as discussed in **Section 3.1.5.1.4**. However, the use of these measures afforded large sample sizes from income-deprived contexts. It is extremely rare to collect objective physical activity data in such large samples owing to financial and logistical constraints; therefore, it is a pragmatic decision to use self-report measures in larger samples. The use of the validated IPAQ-SF in **Study 4** for longitudinal and cross-sectional analyses was advantageous.

Additionally, this study only examined physical activity in terms of context, rather than domain, i.e. functional, transport or leisure-time. While it would be beneficial to examine effects across domains, there is also considerable value in examining physical activity by context. Giles-Corti *et al.* (2005) highlight this importance, describing neighbourhood-based physical activity as an independent domain of activity warranting intense research interest.

The primary focus of this thesis was the effect of quality-related aspects of the neighbourhood social and physical environment on physical activity. In brief, the rationale for this focus was the hypothesised increased importance of these micro-scale features in income-deprived contexts (Neckerman *et al.*, 2009; Sugiyama *et al.*, 2015; Zandieh *et al.*, 2016) and the potential for relatively inexpensive to modify through intervention (Kerr *et al.*, 2016). The comparative importance of quality-related aspects in deprived contexts was drawn from cross-country evidence, including evidence from the UK, but it was not possible to compare the relative importance in deprived and non-deprived contexts in Glasgow. Therefore, there remains a possibility that, particularly for the physical environment, structural, macro-scale features exert an effect on activity and may confound or modify associations between quality-related aspects and activity. Furthermore, it should be noted that measurement of quality-related aspects of the physical environment is potentially susceptible to bias as features such as maintenance and aesthetics cannot be easily quantified and require subjective judgements. The use of a standardised audit protocol, trained auditors and good inter-rater agreement between auditors goes some way to attest the reliability of the GoWell environmental audit, although validity was not formally scrutinised for the study context. Treatment of the variables means that these assessments could be viewed as relative measures of quality of the physical environment, and the potential for bias from auditor assessments should be acknowledged in the interpretation of results.

Decisions on the measurement of physical activity and environment variables were taken by the GoWell team, prior to my involvement. This a limitation of secondary analysis; however, it was offset by the opportunity to use rich data drawn from a large sample of adults living in some of the most deprived communities in the UK where self-reported and objective measurement of multiple aspects of the environment was available. Use of secondary data which were predominantly collected prior to the start of the studies described in this thesis also permitted longitudinal analyses over a sufficient time period, where change in exposures and outcome might have been expected due to large-scale regeneration activity and passage of time. It would not have been possible to conduct primary data collection of this type of data for this thesis.

Boundaries of the neighbourhood were not consistent in this thesis. Within the GoWell programme, neighbourhoods were defined by authority representatives and the GoWell research team, therefore deprivation data pertain to this geography. However, qualitative research and survey questions on perceptions of the social and physical environment and neighbourhood-based activity relied upon participant-defined neighbourhood boundaries (i.e. generically-defined as area within a 5-10-minute walk of the participants' home). Heterogeneity in neighbourhood boundaries can be important and can introduce bias: in a study conducted in England, a mismatch emerged between specified neighbourhood buffers (network or 1-mile straight-line buffers) and participant definitions, which tended to use vague spatial parameters ('local areas') or walking-based parameters ('5-10 minutes walking distance') (Smith *et al.*, 2010). There is a wider move in the literature to embrace technological advances to determine objective, individually-tailored neighbourhoods based on participants' activity spaces (Boruff, Nathan and Nijenstein, 2012). However, it seems plausible that individuals are likely to operate in and conceive of several different neighbourhoods depending on activity (social, work, leisure, cultural etc.) and their personal and historical connections to the area (Kearns and Parkinson, 2001). Overcoming the ambiguity of neighbourhood boundaries might be an insurmountable challenge – working with boundaries defined by the implementers and targets of a real-life area-based intervention may therefore be a satisfactory solution. However, it should be acknowledged that compared with non-specific activity outcomes, neighbourhood-based physical activity outcomes might be more susceptible to bias whereby individual factors, including physical activity levels, could partly determine an individual's definition of their neighbourhood boundaries.

Despite the limitations associated with drawing a longitudinal sample from a complex area-based urban regeneration intervention, including a lack of control neighbourhood and limited observed change in the environmental conditions (presented in **Section 7.4.2**), a considerable advantage is that a real-world intervention permits examination of real-world effects with direct policy impact. Use of such data promotes a realistic, strategic approach to examining a complex system of environmental effects on health and individual health behaviours such as physical activity (Kramer *et al.*, 2017).

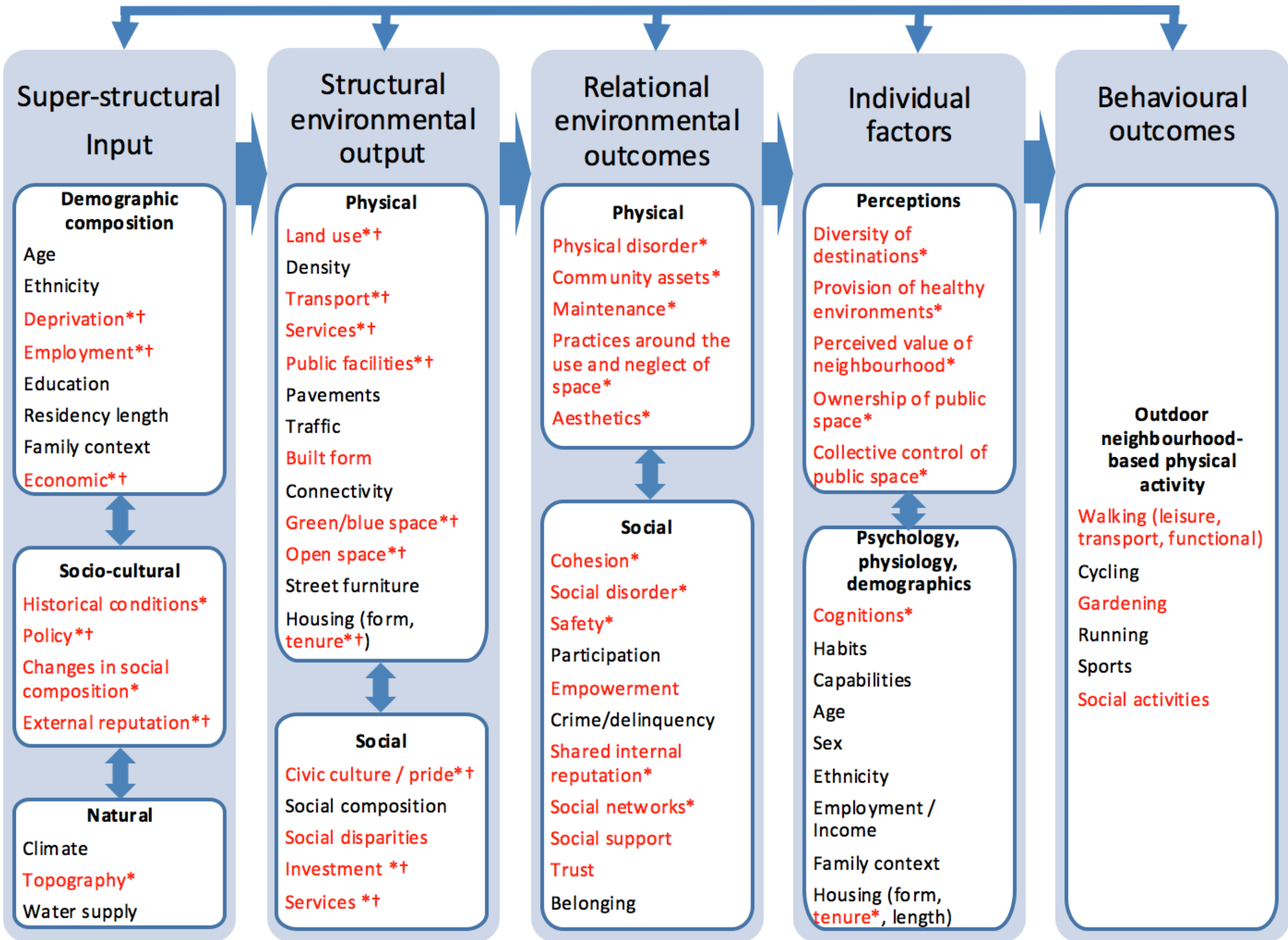
In addition, a mixed methods approach is advantageous in generating insight from quantitative and qualitative research which permits attribution of effect sizes and generalisability while also permitting in-depth assessment of relationships. A large sample from deprived areas is a further significant strength of the quantitative research.

Finally, while research in this thesis was concerned with context-specific examination of environmental effects in the UK, it is hoped that findings have broader relevance to deprived contexts and achieve impact through this relevance. Therefore, generalisability of findings is a consideration both in terms of generalising to non-participants within the study neighbourhoods but also beyond, in other deprived contexts. Although response rates to the GoWell surveys were not unusual for this type of research (47-50% for repeat cross-sectional surveys at waves 1, 2 and 4) (Parry *et al.*, 2001), there is a possibility that selection bias was introduced into the data. However, the representativeness of cross-sectional and longitudinal samples was assessed and reported to ensure results can be appropriately interpreted and generalised to other populations with similar characteristics. The proportion of participants performing no days of walking for ≥10 minutes at time point 1 in **Study 4** (31% of participants) was similar to national Scottish estimates of the proportion of adults obtaining <30minutes MVPA/week in the most deprived quartile for SIMD (29% of adults) (ScotCen Social Research, 2017), suggesting reliable estimates of physical activity in the GoWell sample. Findings can therefore contribute to the wider literature on environmental influences on physical activity in income-deprived contexts and inform future research examining the high-level principle of interplay between social and physical environmental influences on activity.

8.4 Implications and recommendations for future research

Findings from **Studies 1-4** are able to inform the development of the logic model presented in **Section 1.5** (**Figure 1.8**). **Figure 8.1** shows the developed logic model. Putative factors influencing activity in a deprived context which have been studied as exposure variables in, or developed as a result of, **Studies 1-4** are shown in red text (significant covariates of tested associations are not demarcated). An asterisk denotes a significant association with physical activity, revealed by quantitative or qualitative analyses.

Figure 8.1 Developed logic model of neighbourhood environmental influences on neighbourhood-based activity in deprived communities



Red text denotes factor examined or developed in **Studies 1-4**. * Denotes significant association with physical activity. †Denotes potential target for modification through policy.

As discussed in **Chapter 1**, the relationship between the environment and physical activity is not likely to be linear but complex, with environmental factors simultaneously acting to modify or adapt the influence of other factors on the outcome (Sallis *et al.*, 2006; Cummins *et al.*, 2007; Kremers, 2010). Therefore, putative pathways of influence are discussed here but are not intended to be extensive or comprehensive, nor detail predictable pathways of influence from super-structural input to behaviour.

Findings from this thesis support interdependency between environmental factors and some support the hypothesised interaction and feedback through the system, presented in the logic model. One potential pathway elucidated in **Study 3** which could be mapped using the logic model was that historical conditions around the decline of the local economy led to a reduction in diversity of land-use mix and a loss of formal (i.e. authorities) and informal (i.e. employed residents and visitors) investment into the area. In turn, practices around the use of space changed (i.e. unwanted loitering due to lack of employment and mono-functional land uses) and public space and buildings were not maintained to the same standard. This changed perceptions of the value, ownership and collective control of neighbourhood environments, leading to them becoming less supportive for activity. Another possible pathway highlighted in **Study 3** was that grassroots political factors led to increased social investment in community projects, which then obtained community assets such as communal gardens. When maintained by an inclusive network of residents, these assets promoted a sense of ownership over neighbourhood environments, which facilitated social and physical activities such as gardening. These posited pathways of influences indicate a need for a long-term, upstream, complex analysis of influences on physical activity, rather than an exclusive focus on proximal or more tangible factors and linear cause-and-effect. This may go some way to explain significant cross-sectional independent and interactive effects on activity and non-significant longitudinal analyses: assessing relatively short-term change in a limited number of factors may be insufficient to observe effects on behaviour within a context where upstream super-structural factors remain salient to behaviour throughout the pathway of influence.

The hypothesised parameters of the explanatory power of the logic model remain specific, aiming to examine environmental influences on neighbourhood-based physical activity in income-deprived populations. This becomes apparent as salient features of the environment are highlighted from study findings, which in other contexts or for other behaviours may not be as important a contributing factor. The degree of specificity in the model is supported by Kramer *et al.*'s (2017) program theory of leisure-time walking in deprived neighbourhoods. Such a model can therefore provide a system overview of potential factors influencing activity and then be tailored based on context- and population-specific evidence. The logic model developed in this thesis adds to Kramer *et al.*'s (2017) model, using mixed-method studies to specify putative relationships and underlining upstream and complex system influences on neighbourhood-based activity within a deprived context, highlighting avenues for future research.

8.4.1 Calls for a complex systems approach to neighbourhood-based physical activity

In The Lancet of June 2017, Rutter *et al.* (2017) made a plea for a paradigm shift to a complex systems approach in addressing public health issues. Moreover, a key recommendation for future research from the cross-country SPOTLIGHT project was to address the complex influences of the environment on physical activity (Rutter, Glonti and Lakerveld, 2016). A complex systems approach endorses a focus on the pathways of influence on health and health behaviours through a system of interdependent factors, rather than the examination of isolated linear cause-and-effect relationships between factors and outcome.

Novel research presented in this thesis reflects a need, in the broader literature, to balance empirical research to identify and estimate associations between the neighbourhood environment and physical activity which are considered reliable and valid, while also adopting context-specific approaches which acknowledge that posited associations are likely to share many of the characteristics of urban settings they examine: dynamic and fluid, with subtle interconnections, within a wider system of factors. As Jacobs (1961) remarks about the city, such a system of influence could be viewed as ‘organised complexity’. The organised processes of these complex relationships should be interrogated to observe replicable and generalisable pathways of influence.

Two responses in the wider research field will facilitate this endeavour. Firstly, the development of measurement tools which are designed specifically to be sensitive to change are needed in order to capture small but potentially meaningful change in the physical and social environment which can influence factors in a system. Currently, most audits and self-report measures of the physical and social environment have been designed to observe conditions in the neighbourhood as relatively stable constructs. Measuring and enhancing sensitivity to change in measurement tools will be an important step in enabling effective quasi-experimental and longitudinal research which can explore adaptive, dynamic relationships within a complex system. Secondly, progress in participatory research through the use of ‘citizen scientists’ will enable nuanced insight into the effects of the neighbourhood environment on behaviour by those who are local experts (Rosas *et al.*, 2016; Hinckson *et al.*, 2017). These insights could be immensely valuable in the development of hypotheses and, consequently, aiding interpretation pathways of influence which can then be appropriately modified through intervention (Hawe, Shiell and Riley, 2009).

Examination of interaction in quantitative analyses and the broad focus adopted in qualitative analyses generated novel findings in this thesis, which contribute to an understanding of how associations between the neighbourhood and physical activity can be understood in a deprived context in the UK. These findings enabled the specification of important variables operating within a system of environmental influence on physical activity in an income-deprived context, as presented in the developed logic model (**Figure 8.1**). Insight into the salience of contextual factors in an income-deprived context and preliminary interdependencies in a system of environmental influences on activity should be used to direct future research, applying a complex systems approach to examine pathways of influence across the *entire* system. The adoption of the appropriate tools and approach will be central to this endeavour.

8.5 Implications for policy and public health

In leveraging opportunities to create or modify environments which are supportive to physical activity, findings from this thesis suggests the focus on the social environment in 'active design' policies should be reframed as an upstream target, rather than a co-benefit or outcome of physical intervention, as is currently frequently the case (e.g. Centre for Active Design, 2010). In light of the putative upstream and interacting influences on activity discussed in this thesis, policy could engage in Hawe, Shiell and Riley's (2009) conceptualisation of interventions as disruptions of complex systems. In doing so, it can focus on dynamic characteristics of a system of influence where an event in the system can engender evolution of pathways of influence through the wider system.

The developed logic model presented in **Figure 8.1** illustrates opportunities for intervention through policy using the † symbol. Although most factors are amenable to modification through population-level or individual-level intervention, those suited most clearly to intervention through policy are demarcated. These factors had a significant association with physical activity in **Studies 1-4**, either directly or indirectly through influences on other parts of the system, and can be considered as amenable to modification.

Suggested strategies for modification are presented in **Table 8.1.** These strategies are developed from study findings and current regeneration activities discussed in *Will Glasgow Flourish?* (Crawford, Beck and Hanlon, 2007). Targets pertaining to socio-cultural conditions, green/blue space, open space, civic and cultural pride and investment into the social and physical environment are of particular relevance to the focus of this thesis as they relate to the quality, rather than structural elements, of the neighbourhood environment. It should also be acknowledged, following insights from **Studies 1-4**, that intervention strategies proposed here are likely to only be successful if they are implemented: i) in a context where other environmental aspects are already supportive of activity, or ii) simultaneously with strategies addressing other targets.

Table 8.1 Possible strategies for intervention in a system of factors influencing neighbourhood-based activity in deprived communities

Target	Possible intervention strategy	Related study findings
Compositional demographics: deprivation, employment, economic	Economic regeneration through increased employment opportunities and private sector investment	Study 3: pervasiveness of economic factors
Socio-cultural conditions: policy, external reputation	Localised policy decision-making with engagement from local community and responding to historical conditions; recognition of unique community assets to enhance perceived external reputation; involvement of community organisations in policy decision-making processes	Study 3: importance of local historical conditions and recognition of unique community assets to enhance external reputation; central role of community organisations
Land use	Encourage commercial investment into the area; control rents to attract commercial and non-commercial letting; develop brownfield sites; encourage community organisations with inclusive agendas; provide adequate and well-maintained street furniture	Study 3: importance of land used by community organisations
Transport	Accessible and affordable multi-modal transportation to provide access to wider city; accessible walking and cycling network	Study 3: recognition of accessible and affordable transport network
Services for physical environment	Attract private investment by developing opportunities; commit public sector investment; adopt strategies to reduce or manage physical disorder, e.g. space for community murals, effective waste management	Studies 1-4: reducing physical disorder in shared space; this may be more effective when conducted in environments which are perceived as safe and cohesive
Green/blue space	Exploit existing natural assets; management of space by third sector and/or community organisations; encourage shared spaces which have a community identity	Studies 1-4: aesthetically-pleasing and well-maintained green/blue space with a sense of shared ownership to deter anti-social behaviour and increase perceived safety
Open space	Interesting, attractive and sociable open space; social programming; adequate and well-maintained street furniture to encourage individuals to linger and interact	Studies 1-4: aesthetically-pleasing open space and built form which is well-maintained to increase opportunities for social interaction and cultural events which induce pride
Tenure	Mixed tenure communities; sustainable tenancies; resident improvements to rented accommodation to encourage a sense of shared ownership, e.g. 'own front door' initiative; improvement works to bestow sense of value	Study 3: importance of sense of ownership over shared space around residential buildings, for example, by encouraging residents to improve or maintain built form and gardens
Civic culture / pride	Develop historically- and culturally-prominent assets; inclusive social programming where possible; recognition of community assets and strategies to use them within the community; invest in communities to engage in their local area by using	Studies 1-4: importance of internal reputation of area and recognition of local landmarks with historical or cultural prominence

	tools such as the Place Standard to facilitate structured engagement (Place Standard, n.d.)	
Investment in physical and social environment	Attract private investment by developing opportunities; commit public sector investment; liaise with community organisations to respond to needs in the community and empower residents; community engagement, e.g. GHA's 'engagement vehicle' which visits communities	Study 3: importance of perceived value of the community and its social and physical resources; importance of reducing disorder and anti-social behaviour to enhance perceived safety; simultaneously targeting the social and physical environment may have increased impact
Services for social environment	Inclusive and diverse community organisations; ensure facilities are accessible across demographics (especially age) or provide opportunities for shared ownership across demographics	Study 3: role of community organisations in facilitating a positive social environment, to promote social cohesion, trust and empowerment and opportunities for social interaction

Specific to the study neighbourhoods in Glasgow, priority targets for policy intervention might be investment in social aspects (particularly developing sense of community and networks, using evidence on social interventions, to promote safety and perceived ownership and valuation) and physical features of the neighbourhood with local cultural or historical significance, which in turn could bolster a sense of cohesion within the community. It has been suggested that regeneration activities targeting aspects of the physical environment may be prioritised over the social environment (Kearns *et al.*, 2013). This might be because physical targets and outcomes are perceived as overt and therefore more amenable to change and receptive to formal and informal evaluation (e.g. conducted by stakeholders and residents, respectively). Wider acknowledgement of the role of the social environment in a complex system of environmental influence on physical activity may heighten the salience of social environmental targets for those designing and implementing regeneration activities. Further research supporting successful interventions in the social environment (e.g. Moore, Salsberg and Leroux, 2013; Coll-Planas *et al.*, 2017) and a hypothesised complex system of environmental influences would help to increase the credibility of evidence supporting hypothesised mechanisms discussed in this thesis and proposed targets for intervention displayed in **Table 8.1**.

8.6 Conclusions

Findings from studies in this thesis suggest that the quality of the neighbourhood social and physical environment had significant associations with physical activity and, alongside targeting upstream political, economic and historical factors, it could be necessary to simultaneously target social and physical factors to increase physical activity. Further research is needed to support a causal association which can be generalised to other residents of income-deprived neighbourhoods in the UK. In light of findings presented in this thesis, a complex systems approach is recommended for future research into contextual neighbourhood influences on physical activity in order to permit examination of pathways of environmental influence which are sensitive to local context.

Publications and presentations

9.1 Publications from this thesis

Sawyer, A., Jones, R., Ucci, M., Smith, L. and Fisher, A. (2017a) 'Simultaneous evaluation of physical and social environmental correlates of physical activity in adults: a systematic review.' *SSM - Population Health*, 3, pp. 506-515.

Sawyer, A., Jones, R., Ucci, M., Smith, L., Kearns, A. and Fisher, A. (2017b) 'Cross-sectional interactions between quality of the physical and social environment and self-reported physical activity in adults living in income-deprived communities'. *PLOS ONE,* 12, e0188962.

Sawyer, A., Ucci, M., Jones, R., Smith, L. and Fisher, A. (2018) 'Supportive environments for physical activity in deprived communities in the United Kingdom: A qualitative study using photo elicitation'. *Social Science & Medicine*, 197, pp. 49-58.

9.2 Conference presentations from this thesis

Sawyer, A., Ucci, M., Jones, R., Smith, L. and Fisher, A. 'Supportive environments for physical activity in deprived communities in the United Kingdom: a qualitative study using photo elicitation.' *International Conference on Urban Health*, Coimbra, Portugal, September, 2017. Oral presentation.

Sawyer, A., Jones, R., Ucci, M., Smith, L., Kearns, A. and Fisher, A. 'Independent and interactive effects of the quality of social and physical environments on physical activity in income-deprived communities.' *International Congress on Physical Activity and Public Health*, Bangkok, Thailand, November, 2016. Poster presentation.

Sawyer, A., Ucci, M., Jones, R., Smith, L. and Fisher, A. 'Active Living in Glasgow's Neighbourhoods (ALIGN): a qualitative investigation into the role of physical and social environments in physical activity*. UCL Populations & Lifelong Health Domain Symposium*, London, UK, January, 2017. Poster presentation.

9.3 Additional publications

Sawyer, A., Smith, L., Ucci, M., Jones, R., Marmot, A., Wardle, J. and Fisher, A. (2017) 'Perceived office environments and occupational physical activity in office-based workers.' *Occupational Medicine*, 67, pp. 260-267. doi: 10.1093/occmed/kqx022

Smith, L., McCourt, O., **Sawyer, A.**, Ucci, M., Marmot, A., Wardle, J. and Fisher, A. (2016) 'A review of occupational physical activity and sedentary behaviour.' *Occupational Medicine,* 66, pp.185-192.

Sawyer, A., Fisher, A., Llewellyn, C. and Gregory, A. (2015) 'Self-reported sleep quality, weight status and depression in young adult twins and siblings.' *BMC Obesity*, 2, pp.50.

Spinney, R., Smith, L., Ucci, M., Fisher, A., Konstantatou, M., **Sawyer, A.**, Wardle, J. and Marmot, A. (2015) 'Indoor tracking to understand physical activity and sedentary behaviour: exploratory study in UK office buildings.' *PLoS ONE*, 10, e0127688.

Fisher, A., Smith, L., van Jaarsveld, C.H.M., **Sawyer, A.** and Wardle, J. (2015) 'Are children's activity levels determined by their genes or environment? A systematic review of twin studies.' *Preventive Medicine Reports*, 2, pp. 548-553.

Ucci, M., Law, S., Andrews, R., Fisher, A., Smith, L., **Sawyer, A.** and Marmot, A. (2015) 'Indoor school environments, physical activity, sitting behaviour and pedagogy. *Building Research & Information*, 43, pp. 566-581.

Smith, L., Hamer, M., Ucci, M., Marmot, A., Gardner, B., **Sawyer, A.**, Wardle, J. and Fisher, A. (2015) 'Weekday and weekend patterns of objectively-measured sitting, standing and stepping in a sample of office-based workers: the active buildings study.' *BMC Public Health*, 15, pp. 9.

Sawyer, A., Smith, L., Schrempft, S., van Jaarsveld, C.H.M., Wardle, J. and Fisher, A. (2014) 'Primary caregiver knowledge of paediatric physical activity recommendations in the United Kingdom and its associations with caregiver behaviour: an observational study.' *BMC Public Health*, 14, pp. 795.

Smith, L., Ucci, M., Marmot, A., Spinney, R., Laskowski, M., **Sawyer, A.**, Konstantatou,

M., Hamer, M., Ambler, G., Wardle, J. and Fisher, A. (2013) ‘Active buildings: modelling physical activity and movement in office buildings. An observational study protocol.’ *BMJ Open*, 3, e004103.

9.4 Additional conference presentations

Sawyer, A., Smith, L., Ucci, M., Marmot, A. and Fisher, A. ‘Associations between office layout and sitting, standing and stepping: the Active Buildings study.’ *International Society of Behavioral Nutrition and Physical Activity*, Cape Town, South Africa, May, 2016, Symposium ‘Novel technologies to assess physical activity in diverse settings’. Oral presentation.

Sawyer, A., Smith, L., Ucci, M., Jones, R., Marmot, A., Wardle, J. and Fisher, A. ‘Perceptions of the office environment and occupational physical activity: Active Buildings.’ *School for Public Health Research National Institute for Health Research Annual Scientific Meeting*, Newcastle, UK, March, 2016. Poster presentation.

9.5 Awarded grants and placements

Chadwick Trust Travelling Fellowship for ‘A qualitative examination of supportive environments for physical activity in deprived neighbourhoods: Active Living in Glasgow’s Neighbourhoods’, January 2015 – January 2016.

UCL Policy Secondment Scheme to What Works team in Implementation Unit, Cabinet Office. Part-time June – August 2014.

Design Council Cabe, Built Environment Expert Scheme, Healthy Placemaking. December 2015 – Present.

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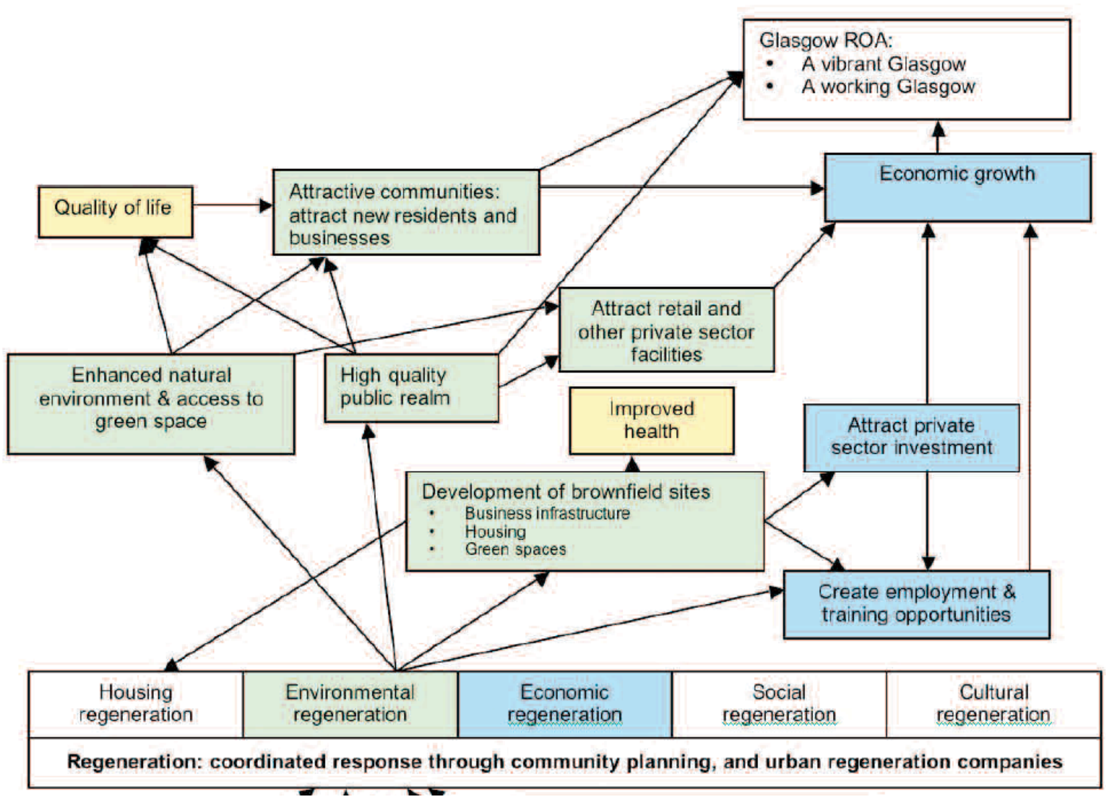
Appendices

Appendix 1

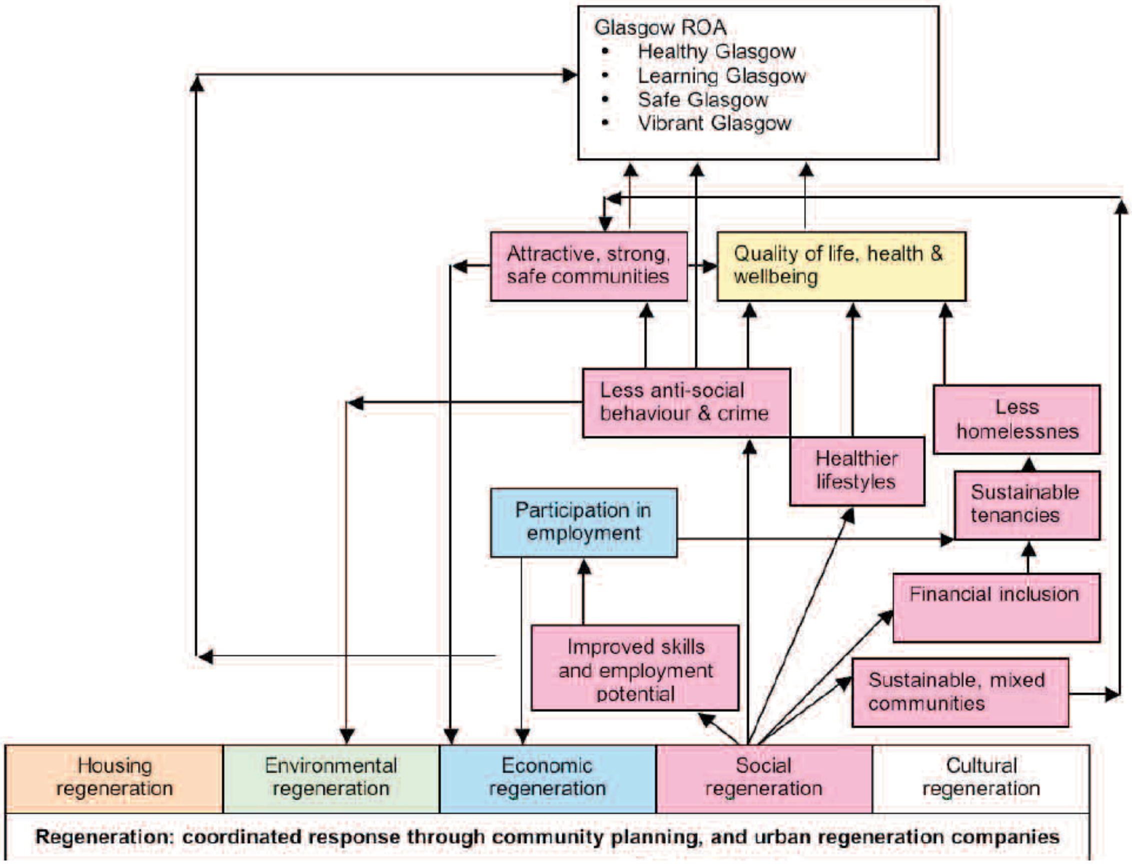
Appendix 1.1 Regeneration activities discussed in *Will Glasgow Flourish?*

Figure A1.1 Glasgow Housing Association's physical environmental regeneration activities from *Will Glasgow Flourish?*



Source: Crawford, Beck and Hanlon (2007)

Figure A1.2 Glasgow Housing Association's social regeneration activities from *Will Glasgow Flourish?*



Source: Crawford, Beck and Hanlon (2007)

Appendix 1.3 Quality appraisal for systematic review

Table A1.1 Quality appraisal tool (Croucher *et al.*, 2003)

Item	Consideration		Requirement
1	Question	Is the research question clear?	Essential
2	Theoretical perspective	Is the theoretical or ideological perspective of the author (or funder) explicit, and has this influenced the study design, methods or research findings?	Desirable
3	Study design	Is the study design appropriate to answer the question?	Essential
4	Context	In the context or setting adequately described?	Essential
5	Sampling	(Quantitative) Is the sample size adequate for the analysis used and has it been drawn from an appropriate population?	Essential
6	Data collection	Was the data collection adequately described and rigorously conducted to ensure confidence in the findings?	Essential
7	Data analysis	Was there evidence that the data analysis was rigorously conducted to ensure confidence in the findings?	Essential
8	Reflexivity	Are the findings substantiated by the data and has consideration been given to any limitations of the methods or data that may have affected the results?	Desirable
9	Generalisability	Do any claims to generalizability following logically, theoretically and statistically from the data?	Desirable
10	Ethics	Have ethical issues been addressed and confidentially respected?	Desirable

Table A1.2 Quality assessment for included studies

Ref	Author	1	2 (D)	3	4	5	6	7	8 (D)	9 (D)	10 (D)	Score/4
1	Ali	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
2	Amorim	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
3	Adlakha	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
4	Bird	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
5	Booth	Y	Y no bias	Y	Y	Y	Y	Y	Y	Y	N	3
6	Bracy	Y	Y no bias	Y	Y	Y	Y	Y	Y	Y	Y	4
7	Caspi	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
8	Cleland	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
9	Eichinger	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
10	Fisher	Y	Y	Y	Y	Y	Y	Y	Y	Y	NA	4
11	Florindo	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
12	Foster	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
13	Gomes 2011	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	4
14	Gomes 2016	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	4
15	Granner	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
16	Handy	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
17	Heesch	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	4
18	Huston	Y	N	Y	Y	Y	Y	Y	Y	Y	N/A	4
19	Jack	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
20	Jauregui	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
21	Jia	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
22	Kamphuis	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
23	Karusisi	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
24	King 2006	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
25	King 2008	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
26	Li	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
27	Lovasi	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
28	Mason	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
29	Perez 2016	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
30	Perez 2016b	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
31	Poortinga	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
32	Prince 2011	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
33	Prince 2012	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
34	Richardson	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
35	Rohm Young	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
36	Salvador	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
37	Strath	Y	N	Y	Y	Y	Y	Y	Y	Y	NA	4
38	Troped	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
39	Trumpeter	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	4
40	Van Cauwenberg	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	4
41	Van Dyck 2013	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	4
42	Van Dyck 2015	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	4
43	Van Holle	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
44	Van Lenthe	Y	N	Y	Y	Y	Y	Y	Y	Y	NA	4
45	Voorhees	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	3
46	Wallmann	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	3
47	Weber-Corseui	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	4
48	Wen 2007	Y	Y	Y	Y	Y	Y	Y	Y	Y	NA	4
49	Wen 2009	Y	Y	Y	Y	Y	Y	Y	Y	Y	NA	4
50	Wilbur 03	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
51	Wilbur 03b	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4

52	Wilcox	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
53	Yuma-Guerrero	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	4
54	Zhou	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4
55	Zoellner	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	4

Necessary to comply with all essential requirements. Score out of 4 for desirables, 1=lowest quality, 4=highest quality. Y: yes; N: no.

Appendix 3

Appendix 3.1 GoWell community survey

Table A3.1 GoWell community survey Items; waves 1-4

Question	Response options	Source
Are you male or female? [Sex]	Male Female	GoWell
Which of the following age bands apply? [Age]	<16 years 16-17 years 18-24 years 25-39 years 40-54 years 55-64 years 65 plus years	GoWell
Do you have any longstanding illness, disability or infirmity? [Longstanding illness]	Yes No	GHA Rehousing survey
Which of these best describes your current positions? [Employment]	Full-time paid work Part-time paid work Government or other training scheme Unemployed Retired Temporary sick Long-term sick/disabled without a job Looking after the home/family Full-time education Other, specify	SHARP
Which of the following best describes your home? [Tenure]	Rented from a private landlord Rented from a family member, friend/acquaintance Rented from Glasgow Housing Association or other housing association Owned with a mortgage Owned outright Shared owner with Glasgow Housing Association or other housing association Other, please specify	GoWell
What is the relationship of each household member to you? [Household]	Spouse/partner/cohabite Son/daughter (incl. step/adopted) Grandson/granddaughter Parent/parent-in-law Other relative Other non-relative	SHARP
Which of these categories best describes your current situation? [Citizenship]	British Citizen born in the UK British Citizen born outside the UK Indefinite leave to remain in UK Exceptional leave to remain in UK	Adapted various

	Appealing a refused asylum application/Judicial review pending Received final refusal Other	
Do you own or have regular access to a car or van? [Vehicle access]	Yes No	SHARP
• People who live in this neighbourhood think highly of it [Internal reputation]	Strongly agree Agree Neither agree nor disagree Disagree Strongly disagree	GoWell
For each of the following statements, could you tell me whether you think that each of these is a serious problem? • Violence including assaults and muggings • People being insulted, pestered or intimidated in the street • Noisy neighbours and loud parties • People being attacked or harassed because of their skin colour or ethnic origin • People using or dealing drugs • People being drunk or rowdy in public places • Gang activity • Teenagers hanging around on the street • Nuisance neighbours or problem families • Dogs roaming about/dog fouling/barking • Tensions between Protestants and Catholics [Neighbourhood problems]	Not a problem Slight Problem Serious problem	GHA Social Survey, SHARP
• On your own, or with others, you can influence decisions affecting your local area [Influence decisions]	Strongly agree Agree Neither agree nor disagree Disagree Strongly disagree	Home Office Citizenship Survey 2001
• How safe would you feel walking alone in this neighbourhood after dark? [Safety at night]	Very safe Fairly safe Neither safe nor unsafe A bit unsafe Very unsafe	Home Office Citizenship Survey 2001 and British Crime Survey 2001
• To what extent do you feel that you belong to this neighbourhood? [Neighbourhood belonging]	Not at all To some extent To a large extent	British Household Panel Survey 2003, British Home Office Citizenship Survey
• To what extent do you agree that this neighbourhood is a place where people from different backgrounds get on well together? • [Harmony]	Not at all To some extent To a large extent	Adapted Home Office Citizenship Survey
Thinking about how often you personally contact your relatives, friends and neighbours but not counting the people you live with, how	Most days Once a week or more Once or twice a month Less than once a month	SHARP and ONS Measuring Social Capital in the UK

often do you do any of the following: • Meet up with relatives • Speak to relatives on the phone • Write to relatives • Meet up with friends • Speak to friends on the phone • Write to friends • Speak to neighbours [Social contact]	Never Don't know	
Thinking now about your relatives, friends and neighbours outside your home, can you tell me around how many people could you ask for the following kinds of help? • To go to the shop for messages if you are unwell • To lend you money to see you through the next few days • To give you advice and support in a crisis [Social support]	Wouldn't ask None One or two More than two Don't know	ONS, British Social Attitudes and Scottish Social Attitudes Surveys
• Over the past 12 months, have you taken part in, supported or helped any groups, clubs or organisations? [Participation in organisations]	Yes No Don't know	ONS Social Capital Module, SHARP
• It is likely that someone would intervene if a group of youths were harassing someone in the local area [Informal control]	Strongly agree Agree Neither agree nor disagree Disagree Strongly disagree	Citizen Audit for Britain 2001, MRC Your Local Area Questionnaire)
• Someone who lost a purse or wallet around here would be likely to have it returned without anything missing [Trust and honesty]	Strongly agree Agree Neither agree nor disagree Disagree Strongly disagree	Home Office Citizenship Survey

Appendix 3.2 GoWell neighbourhood environmental audit

* Items in bold were repeated in 2015 audit

GoWell sub-area neighbourhood survey:
RESIDENTIAL QUESTIONNAIRE & PHOTOGRAPH SURVEY
(one for each address- 3 for each sub-area)

	Study area		Sub-area	A, B, C
Study area/subarea/address ID:				
Surveyor Initials:				
Date: (ddmmyy)			**Time**: (24 hour format)	
Weather condition:	1=Sunny, 2=Cloudy, 3=Rain			
Other points of note:				

1. a) Which land uses *(in relation to the footprint on the land)* exist within a *100m* radius of the main external entrance to the selected address (the assessment should include outdoor communal space in the case of multi-occupancy properties)?* *(please tick as appropriate)*

	None	Some	Mostly	RANK
Occupied Housing				
Vacant or Derelict Housing				
Vacant or Derelict Land				
Building Site- currently active				
Shops				
Commercial or Industrial Buildings (non domestic use)				
Public green space or Parks				
Indoor public facilities e.g. library, sports hall *(list pubs/cafes in 'other')*				
Paved pedestrianised areas *(in addition to road and standard 3 foot wide pavement)*				
Dedicated car parking *(dedicated area for communal parking)*				
Other *(please specify)*				
Other *(please specify)*				
Other *(please specify)*				

**ignore residential access roads*

1. b) Please rank the three most common land uses listed in the far right hand column in the table above

1. c) What is the predominant housing type at and around this address (include derelict and non-derelict housing)? *(please tick one)*

Hi-rise flats (6 or more floors)	
Lo-rise flats (1-5 floors)	
Terraced houses	

Semi-detached houses (include semis split into 4 flats)	
Detached houses (incl bungalows)	
Other (please specify)……………………………………………………………..	

2. Now have a walk around the street(s) in the 100m around this property and record the following *(please tick)*:

	None	Some	A lot
There are communal or public areas with plants or greenery *(Some= 2-3 small areas of trees, grass, shrubs, flowers, 'A lot'= large area or many small areas e.g. trees along most/all streets)*			
	Yes	**No**	**Can't tell**
There are traffic calming measures, e.g. 'Twenty's Plenty' signs, speed humps, chicanes			
There are pedestrian crossings (pelican or zebra)			
There are signs of neighbourhood watch activity (posters or lamp-post signs)			

3. a) Please complete the following to describe this residential area (100m around this property). *(please tick)*

How many of the buildings or houses within 100m of this address are:	**None of the buildings**	**A few of the buildings**	**Around half of the buildings**	**Most or all buildings**
Visually interesting *(Varied in terms of design, scale, colours, textures)*				
Attractive to look at				
Damaged and have signs of disrepair *(do not include vandalism)*				
Marked with graffiti or other signs of vandalism				
Intimidating *(Have visible security measures such as barbed wire and/or security grilles, no trespassing signs- Do not include burglar alarm boxes or shutters)*				
Clean and fresh looking				

3. b) To what extent are the following statements true? *(please tick)*

Within 100m of this address:	**Not at all**	**To some extent**	**To a large extent**	**N/A**
The walls, fences or hedges between properties are well maintained				
Private gardens, yards & driveways are tidy and well maintained *(not communal flat gardens unless private main door gardens)*				
Private gardens are interesting and attractive				
There are people outside in gardens and on the streets				
The communal areas and public spaces are tidy and well maintained				

Communal and public spaces are interesting and attractive *(i.e. landscaped)*				
There is dog foul on the streets				
There are large items of furniture or cars abandoned or dumped in public areas				
The area in general is clean and fresh looking				
The area in general is visually interesting *(Varied in terms of design, scale, colours, textures)*				

Not at all= virtually no examples of this, To some extent=mixed, 'To a large extent'= virtually all the area/properties were like this

4. a) Have you noticed a public area within 100m of this address that has been seriously neglected? *(please tick)*

Yes ☐ No ☐

4. b) How does this example of neglect compare with the quality of the surrounding area (100m around address)?

Much the same	A little worse	A lot worse

	Photo taken *(please tick)*
4. c) Take a photograph (RESIDNEGLECT)	

5. Now take some photographs of this address:

Photo	Taken (tick)	Notes
Outlook or View from front of house (V)		
Front Elevation (F)		
Right (with back to property) (R)		
Left (with back to property)(L)		
Other of note (optional) (O)		

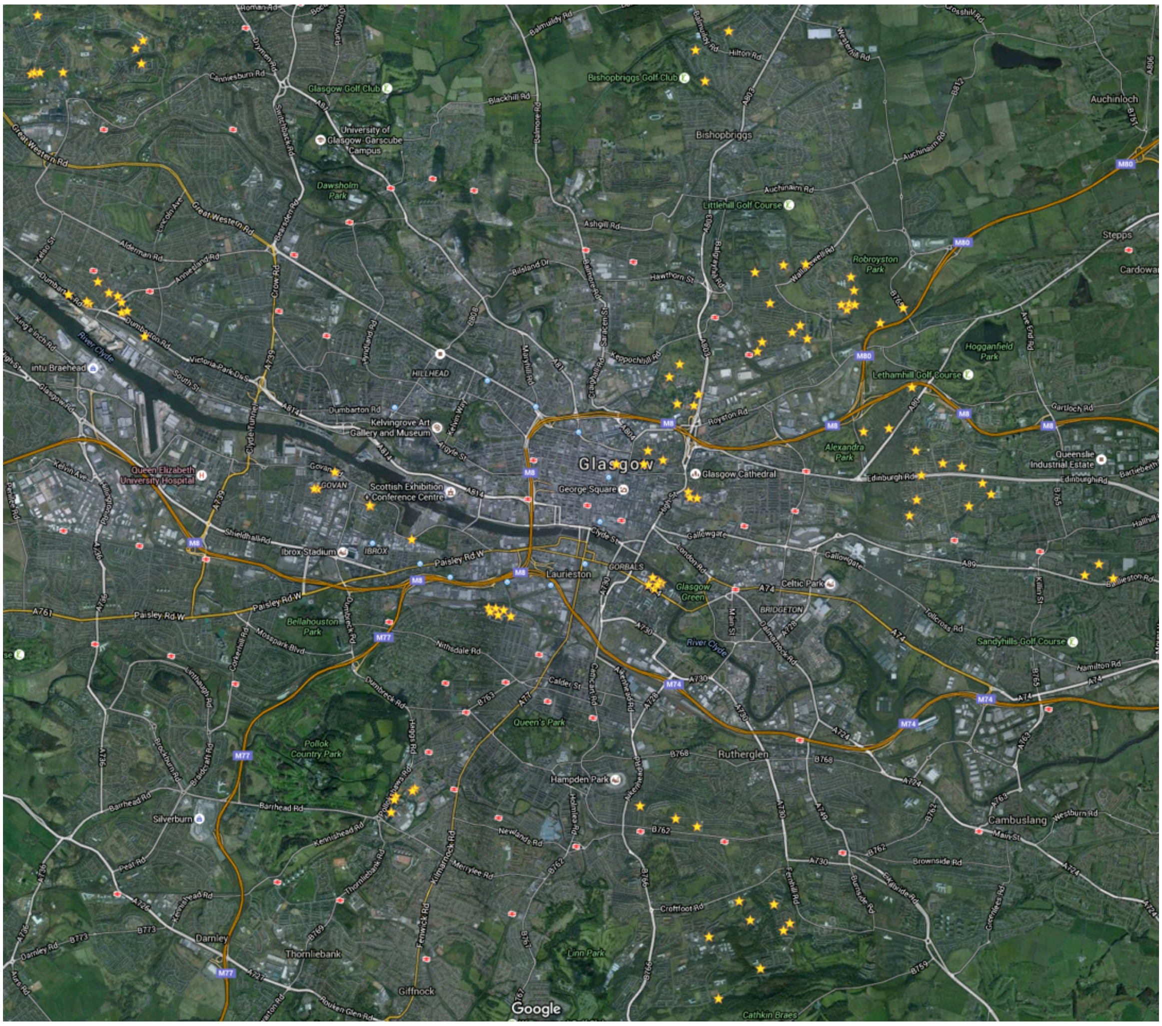
5. How would you feel about living in this area?

1 2 3 4 5 6 7

6. How many people asked you what you were doing while conducting your assessment (include taking photos) for this sub-area?	

Appendix 3.3 Environmental audit assessment sites

Figure A3.3 Environmental audit assessment sites



Sites for 2006 and 2015 audits demarcated by yellow star. Background map: https://www.google.co.uk/maps/

Appendix 3.4 ALIGN photography briefing

Active Living in Glasgow's Neighbourhoods

Investigating the interaction of the physical environment and social capital in the generation of physical activity

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Brief for photographs

This study looks at how living in Govan/Drumchapel influences your physical activity (e.g. walking, cycling, running). I am interested in what makes you get out and about in the neighbourhood. I'm asking you to take photos of your neighbourhood so that when we meet again in a couple of weeks, we can use the photos as a basis for our discussion. Nobody knows where you live better than you do, so please take the lead in what you'd like to photograph. If you're stuck, you might like to think about the following questions:

- *What do you think is good or bad about your neighbourhood?*
- *How would you describe your neighbourhood to someone who had never been here? Are there any areas that are 'typical' of your neighbourhood?*
- *When walking around your neighbourhood are there any places you like or dislike walking past?*
- *What gives your neighbourhood its social character and atmosphere?*
- *How does your neighbourhood change between night and day or over the seasons?*

Please take as many photos as you'd like, noting when and where each photo was taken on the map.

WHEN TAKING PHOTOS, PLEASE TAKE NOTE OF THE FOLLOWING:

- Please don't take photos of individuals engaging in inappropriate or illegal activities
- Please don't take photos of anything very personal or private, as a rule: if you wouldn't display the photo in a public space, please don't take the photo
- Please don't put yourself in any unusual or dangerous situations when taking photos
- Where possible, please ask permission if taking photos of private property or individuals

Thank you for your participation!

Appendix 3.5 ALIGN protocol and semi-structured interview framework

Information session (30 minutes; initial meeting)

Introduce myself and describe stages of the study (information session, 1-week opportunity for photography, interview). Provide the participant with study information sheet.

Ask participant whether they would like to take part in the study and complete the consent form. Answer any further questions about study.

Provide participant with disposable camera and printed briefing for photographs. Check that participant is comfortable using the camera and understands the briefing; answer any questions. Check that participant understands that they can self-define their neighbourhood size and shape.

Provide participant with a stamped-addressed envelope and ask them to return the camera by a specific date.

Ask participant to complete questionnaire to record demographics.

Take questionnaire but leave all other information with participant.

Interview (1 hour)

Tell participant you will be recording the interview.
Start recording.

Explain to participant that the interview will take around 45-60 minutes and will involve a set of questions and discussion of the photos they have taken.

Produce photos. Ask participant to set them out so they can all be seen in an order that makes sense to them (use floor or table). This could be in groups or in chronological order. Alternatively, participant could select a smaller number of photos to talk about.

Start asking participant questions, stating that the participant should say anything that comes to mind and there are no right or wrong answers.

End interview after 60 minutes. Thank the participant for their time and ask whether they have any questions.

Photo-elicited questions (45-60 minutes)

Thank you for taking the time to take part in this study. This research looks at the way our environment influences our activity levels, by encouraging or discouraging physical activities such as walking (for leisure, transport or errands), gardening, cycling, exercising and generally being out and out in the neighbourhood.

Previously, researchers have looked at whether the physical environment influences physical activity. For example, whether people are more active in places that are well-connected, attractive and have lots of green space or different facilities. Researchers have also asked whether people are more active in areas that have strong social networks or where people trust and respect one another.

This research study looks at the two together and asks whether it's easier to be active when both the physical and social environment encourage it. It will feed into an evidence base that asks what's the best and most efficient way to design neighbourhoods so they work for the people living there.

I'm going to ask you some questions about where you live. You can refer to the photos at any time during the discussion.

Some of my questions refer to the physical or social neighbourhood environment and physical activity so I'll start with some short definitions.

By 'physical environment', I mean the layout of your neighbourhood and any built or physical features; this can include your home, surrounding buildings, streets, play spaces, street furniture such as litter bins or benches, parks or the river.

By 'social environment' or 'social capital' I mean your sense of belonging to the neighbourhood, whether you feel you can trust and or depend on your neighbours and whether you think the community pulls together and has an identity and a set of values that it shares.

By 'getting out and about' or 'being physically active' I mean any sort of activity you may do in or around your home and neighbourhood. This can include anything from gardening, walking to a friend's house or the bus stop or going for a bike ride or run. You might also like to think about what encourages or discourages you to be physically inactive (e.g. watching TV).

If you're happy to start, I'll now ask you some questions. Please ask if you'd like me to clarify anything and remember that there are no right or wrong answers. Please refer to the photographs at any point to help you illustrate your point.

1. What activities do you do in or around your neighbourhood?

2. Would you describe yourself as physically active? What would be your main reason for being active?

Prompt: Health? Necessity? Fun?

3. Would you like to be more active? What do you think stops you from being so?

4. Are other people in your neighbourhood active?

5. Could you briefly describe the physical environment of the area you live in? Please refer to your photos where necessary.

Prompt: Are there any distinctive features in the environment? Are there any features you particularly like or don't like?

- Does the physical environment change between night and day or over different seasons?
- How has the physical environment changed over recent years?

6. Do you think the physical environment influences your decision (or other people's decision) to be active or are other factors more important?

Prompt: Where do you or don't you like to be active?

7. Do you think physical features like the outdoor gym in Elder Park/ woods/ cycle path/ fitness centre encourage people to be active? Why?

8. Could you briefly describe the social environment of the area you live in? Please refer to your photos where necessary.

Prompts: How might you or others feel when they are outside on the street? Is there anything you are particularly aware of? Are there many groups and community spaces in the area? Do you have a sense of attachment or belonging in the area? Do neighbours trust and respect each other?

- Does the environment change between night and day or over different seasons?
- Has the social environment changed over recent years?

9. Do you think the social environment influences your decisions (or other people's decisions) to be active or are other factors more important?

Prompt: Where do you or don't you like to be active?

10. Do you think community groups – whether specifically for physical activity or not - encourage people to be active? Why?

11. Do you think there is a relationship between the physical environment and the social environment in your area? In other words, do you think the people and place are related? Please refer to your photos where necessary. OPTIONAL
    - Do you think the physical environment is influenced by the people who live in the area, for good or for bad?
    - Do you think the social environment is influenced by the physical environment? Do certain features or places in the environment influence how people live together in the community?

12. Do you think a relationship between the physical and social environment influences your physical activity? / Do you think the physical or social side of things are more important? OPTIONAL

13. If you could make changes to your neighbourhood, what would they be? You might like to think about physical changes or changes to how people live together. Please refer to your photos where necessary.

14. What do you think the main benefit of these changes would be? Do you think people would be more likely to be active (either by gardening, walking, cycling, exercising) as a result of these changes?

15. Is there anything else you would like to discuss regarding physical activity and your local area or any photos we haven't yet discussed?

Talk about the experience.

1. How did you feel taking photos of your neighbourhood?

2. Has it changed the way you feel about your neighbourhood in any way?

3. If you were to do this again, do you think you would take the same photos?

Appendix 3.6 COREQ checklist for reporting qualitative studies

No	Item	Guide questions/description
Domain 1: Research team and reflexivity		
Personal Characteristics		
1.	Interviewer/facilitator	Which author/s conducted the interview or focus group?
2.	Credentials	What were the researcher's credentials? *E.g. PhD, MD*
3.	Occupation	What was their occupation at the time of the study?
4.	Gender	Was the researcher male or female?
5.	Experience and training	What experience or training did the researcher have?
Relationship with participants		
6.	Relationship established	Was a relationship established prior to study commencement?
7.	Participant knowledge of the interviewer	What did the participants know about the researcher? e.g. *personal goals, reasons for doing the research*
8.	Interviewer characteristics	What characteristics were reported about the interviewer/facilitator? e.g. *Bias, assumptions, reasons and interests in the research topic*
Domain 2: study design		
Theoretical framework		
9.	Methodological orientation and Theory	What methodological orientation was stated to underpin the study? *e.g. grounded theory, discourse analysis, ethnography, phenomenology, content analysis*
Participant selection		
10.	Sampling	How were participants selected? *e.g. purposive, convenience, consecutive, snowball*
11.	Method of approach	How were participants approached? e.g. *face-to-face, telephone, mail, email*
12.	Sample size	How many participants were in the study?
13.	Non-participation	How many people refused to participate or dropped out? Reasons?
Setting		
14.	Setting of data collection	Where was the data collected? e.g. *home, clinic, workplace*
15.	Presence of non-participants	Was anyone else present besides the participants and researchers?
16.	Description of sample	What are the important characteristics of the sample? *e.g. demographic data, date*
Data collection		
17.	Interview guide	Were questions, prompts, guides provided by the authors? Was it pilot tested?
18.	Repeat interviews	Were repeat interviews carried out? If yes, how many?
19.	Audio/visual recording	Did the research use audio or visual recording to collect the data?
20.	Field notes	Were field notes made during and/or after the interview or focus group?
21.	Duration	What was the duration of the interviews or focus group?
22.	Data saturation	Was data saturation discussed?
23.	Transcripts returned	Were transcripts returned to participants for comment and/or correction?
Domain 3: analysis and findingsz		
Data analysis		
24.	Number of data coders	How many data coders coded the data?
25.	Description of the coding tree	Did authors provide a description of the coding tree?
26.	Derivation of themes	Were themes identified in advance or derived from the data?
27.	Software	What software, if applicable, was used to manage the data?
28.	Participant checking	Did participants provide feedback on the findings?
Reporting		
29.	Quotations presented	Were participant quotations presented to illustrate the themes / findings? Was each quotation identified? e.g. *participant number*
30.	Data and findings consistent	Was there consistency between the data presented and the findings?
31.	Clarity of major themes	Were major themes clearly presented in the findings?
32.	Clarity of minor themes	Is there a description of diverse cases or discussion of minor themes?

Appendix 4

Appendix 4.1 Separate pattern matrices for factor loadings for physical environment items and social environment items

Table A4.1 Pattern matrix for factor loadings for physical environment items only (n=5,923)

Item	Rotated factor loadings		
	Physical environment factors		
	'Aesthetics of built form'	'Aesthetics & maintenance of open space'	'Cues of physical disorder'
Buildings are visually interesting (varied in terms of design, scale, colours, textures) (EA)	**.960**		
Buildings are clean and fresh looking (EA)	**.819**		-.136
Area in general is visually interesting (varied in terms of design, scale, colours, textures) (EA)	**.713**	.439	.164
Communal areas and public spaces are interesting and attractive (i.e. landscaped) (EA)		**.803**	
Private gardens are interesting and attractive (EA)		**.601**	-.394
Walls, fences or hedges between properties are well-maintained (EA)	.312	**.465**	-.196
Buildings are damaged and have signs of disrepair (EA)		.194	**.812**
Private gardens, yards and driveways are tidy and well-maintained (EA)	-.144	.390	**-.750**
Buildings are marked with graffiti or other signs of vandalism (EA)	-.504	.269	**.549**
Communal areas and public spaces are tidy and well-maintained (EA)		.120	**-.571**
Area in general is clean and fresh looking (EA)	.536		**-.486**
Eigenvalue	4.71	1.42	1.25
% of variance	42.8	12.9	11.3
Cronbach's alpha	0.8	0.6	0.8

Bold typeface indicates the highest factor loadings, specifying loading of each variable onto a factor. EA: environmental audit.

Table A4.2 Pattern matrix of factor loadings for social environment items only (n=5,923)

Item	Rotated factor loadings			
	Social environment factors			
	'Social support'	'Social interaction'	'Trust & empowerment'	'Cohesion & safety'
Thinking about your relatives, friends and neighbourhoods outside your home, how many people could you ask to go to the shop for messages if you are unwell? (CS)	**-.894**			
Thinking about your relatives, friends and neighbourhoods outside your home, how many people could you ask to give you advice and support in a crisis? (CS)	**-.892**			
Thinking about your relatives, friends and neighbourhoods outside your home, how many people could you ask to lend you money to see you through the next few days? (CS)	**-.886**			
Not counting people you live with, how often do you meet up with friends? (CS)		**.856**		
How often do you speak to neighbours? (CS)		**.777**		
Not counting people you live with, how often do you meet up with relatives? (CS)		**.760**		
People who live in this neighbourhood think highly of it (CS)	-.146	-.122	**.666**	-.131
Someone who lost a purse or wallet around here would be likely to have it returned without anything missing (CS)			**.658**	
On your own, or with others, you can influence decisions affecting your local area (CS)			**.666**	-.117
Is it likely that someone would intervene if a group of youths were harassing someone in the local area? (CS)	.112	.111	**.625**	
To what extent do you agree that this neighbourhood is a place where people from different backgrounds get on well together? (CS)			-.240	**-.801**
To what extent do you feel that you belong to this neighbourhood? (CS)		.102	.128	**-.701**
How safe would you feel walking alone in this neighbourhood after dark? (CS)			.210	**-.524**
Eigenvalue	2.80	2.04	1.71	1.20
% of variance	21.52	15.71	13.14	9.21
Cronbach's alpha	0.9	0.7	0.6	0.5

Bold typeface indicates the highest factor loadings, specifying loading of each variable onto a factor. CS: community survey.

Appendix 4.2 Participants by sub-area

Table A4.3 Number of participants by sub-area

Sub-area	Study 1 and 2 sample N (%)	Study 4 sample N (%)
1	159 (2.7)	15 (2.7)
2	186 (3.1)	20 (3.6)
3	258 (4.4)	28 (5.0)
4	256 (4.3)	17 (3.0)
5	188 (3.2)	33 (5.9)
6	222 (3.7)	25 (4.5)
7	205 (3.5)	16 (2.9)
8	263 (4.4)	30 (5.4)
9	70 (1.2)	14 (2.5)
10	97 (1.6)	20 (3.6)
11	101 (1.7)	17 (3.0)
12	86 (1.5)	21 (3.8)
13	321 (5.4)	9 (1.6)
14	210 (3.5)	21 (3.8)
15	124 (2.1)	15 (2.7)
16	176 (3.0)	18 (3.2)
17	119 (2.0)	11 (2.0)
18	126 (2.1)	24 (4.3)
19	241 (4.1)	24 (4.3)
20	218 (3.7)	15 (2.7)
21	94 (1.6)	-
22	271 (4.6)	17 (3.0)
23	172 (2.9)	24 (4.3)
24	133 (2.2)	21 (3.8)
25	149 (2.5)	-
26	284 (4.8)	-
27	211 (3.6)	-
28	440 (7.4)	-
29	64 (1.1)	22 (3.9)
30	113 (1.9)	8 (1.4)
31	224 (3.8)	30 (5.4)
32	142 (2.4)	43 (7.7)

Appendix 5

Appendix 5.1 Version of Study 2 published in *PLOS ONE*

PLOS | ONE

RESEARCH ARTICLE

Cross-sectional interactions between quality of the physical and social environment and self-reported physical activity in adults living in income-deprived communities

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Check for updates

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Abstract

Background

Understanding the environmental determinants of physical activity in populations at high risk of inactivity could contribute to the development of effective interventions. Socioecological models of activity propose that environmental factors have independent and interactive effects of physical activity but there is a lack of research into interactive effects.

Objectives

This study aimed to explore independent and interactive effects of social and physical environmental factors on self-reported physical activity in income-deprived communities.

Methods

Participants were 5,923 adults in Glasgow, United Kingdom. Features of the social environment were self-reported. Quality of the physical environment was objectively-measured. Neighbourhood walking and participation in moderate physical activity [MPA] on ≥5 days/week was self-reported. Multilevel multivariate logistic regression models tested independent and interactive effects of environmental factors on activity.

Results

'Social support' (walking: OR:1.22,95%CI = 1.06–1.41,p<0.01; MPA: OR:0.79,95%CI = 0.67–0.94,p<0.01), 'social interaction' (walking: OR:1.25,95%CI = 1.10–1.42,p<0.01; MPA: OR:6.16,95%CI = 5.14–7.37,p<0.001) and 'cohesion and safety' (walking: OR:1.78,95% CI = 1.56–2.03,p<0.001; MPA: OR:1.93,95%CI = 1.65–2.27,p<0.001), but not 'trust and empowerment', had independent effects on physical activity. 'Aesthetics of built form'

(OR:1.47,95%CI = 1.22–1.77,p <0.001) and 'aesthetics and maintenance of open space' (OR:1.32, 95%CI = 1.13–1.54,p <0.01) were related to walking. 'Physical disorder' (OR:1.63,95%CI = 1.31–2.03,p <0.001) had an independent effect on MPA. Interactive effects of social and physical factors on walking and MPA were revealed.

Conclusions

Findings suggest that intervening to create activity-supportive environments in deprived communities may be most effective when simultaneously targeting the social and physical neighbourhood environment.

included the following requirements: (1) Only the research team will have access to the data generated by the study. (2) Access to the data will be controlled by a data guardian, who is the study's statistician. (3) The participants in the study consented to the fact that the information they provided would not be seen by anyone outside the study. Qualified researchers can request to access the data by emailing Dr. Andrew Fraser, Director of Public Health Science, NHS Health Scotland, who is the Chair of the study Steering Group: andrew.fraser2@nhs.net.

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Introduction

It is well-established that sufficient levels of physical activity aid in the reduction of chronic disease, and mortality [1–4]. The United Kingdom (UK) government currently recommends that adults (19–64 years old) are active daily and should accumulate either ≥150 minutes of moderate activity (MPA; e.g. cycling), 75 minutes of vigorous activity (VPA; e.g. running), or a combination, over the week [5]. Additionally, walking 10,000 steps per day is recommended to obtain health benefits [6,7].

However, adults in the UK have low levels of physical activity, even when compared with similar European countries [8,9]. For example, accelerometer data from the Health Survey for England 2008 showed that only 6% of males and 4% of females met national guidelines [10]. Levels of inactivity (i.e. <30 minutes/week of MPA) are particularly high in deprived groups: self-reported data from 163,099 adults in England revealed that levels of inactivity were almost 10% higher in local authorities with the highest levels of socio-economic deprivation compared with the lowest [9]. Even small increases in MPA may be beneficial for inactive groups. A European cohort study including 334,161 adults estimated that moving individuals from inactivity to moderate activity (equivalent to a daily 20-minute walk) produced a 7.35% reduction in all-cause mortality [3].

Understanding the determinants of physical activity, particularly in populations at higher risk of inactivity, could contribute to the development of interventions to increase physical activity. Socioecological approaches to physical activity posit that individual characteristics, the social environment, the physical environment and policies are all key determinants of activity, which are interrelated and embedded in a complex system [11–13]. In addition to having simultaneous independent effects, it is postulated that these influences can also have interactive effects. Growing evidence suggests independent effects of the objectively-measured and perceived aspects of the neighbourhood physical and social environment on physical activity (e.g. [14–17]). However, as Gubbels et al. highlight, while there is a move towards the integration of influences through the use of multivariate models, there is still very limited research examining the *interaction* of factors [18].

Addressing this gap in the literature is an important next step for physical activity research. Firstly, accounting for potential variance arising from hitherto unmeasured interactive effects could help to explain inconsistent results in the literature examining neighbourhood effects. For example, inconsistent effects of crime and aesthetics on physical activity could arise from interactive effects of other aspects of the social and physical environment suppressing or heightening measured effects within certain environmental conditions [19–24]. Secondly, understanding pathways of influence between environmental variables and physical activity could inform development of interventions to create activity-supportive environments in specific contexts, embracing the complexity of environmental influences and ensuring that unmeasured features of the environment do not suppress effects [25]. Examining interactive effects is required to address these points and to test a central tenant of socioecological models of physical activity.

Recent research examining the health effect of micro-scale features of the environment (e.g. disorder, aesthetics, street lighting) in deprived neighbourhoods suggests that disparities in these features between deprived and non-deprived neighbourhoods could contribute to inequalities in health and behaviours [26,27]. Geographic Information Systems (GIS) measures and neighbourhood audits of streetscapes in New York City revealed that more deprived neighbourhoods had poorer aesthetics and safety conditions (e.g. fewer clean streets, fewer landmarked buildings, more felony complaints) than non-deprived neighbourhoods, potentially offsetting macro-scale elements of deprived urban neighbourhoods that ostensibly create walkable environments (e.g. increased land use mix or density) [27]. Results were corroborated by further research in USA demonstrating poorer aesthetics and worse maintenance of the environment (e.g. litter, vandalism) in deprived neighbourhoods with larger populations of racial and ethnic minorities than in higher-income neighbourhoods [26]. Variation in neighbourhood quality between 3 cities (Seattle, San Diego and Baltimore) underscored the necessity of context-specific investigation [26]. Both studies recommended further research examining how features of social and physical environments impact physical activity behaviours, and whether they interact to produce effects, particularly in deprived communities [26,27].

Emerging research in the USA explores interactive associations. Bracy et al. presented few significant interactive effects of perceived safety and perceived physical environment features on objectively-measured moderate-to-vigorous physical activity (MVPA) in a sample from Washington metropolitan areas [28]. However, there was an interaction between perceived safety and walkability: adults who felt unsafe (i.e. reported low levels of perceived safety) and lived in a neighbourhood with low walkability achieved 91.2 fewer minutes of MVPA per week than adults who felt unsafe but lived in a highly-walkable neighbourhood with low walkability. The difference in MVPA between adults living in neighbourhoods with high and low walkability was markedly less (38.8 minutes) among adults reporting high levels of perceived safety, suggesting feelings of safety might have mitigated the effects of walkability. To the best of our knowledge, there is no research examining interactive environmental effects on physical activity in a deprived context in the UK. It is possible that within this context, the social environment and micro-scale features of the physical environment interact in creating an environment which supports physical activity by altering the way in which the space is used or perceived. As such, environmental features could operate synergistically or a feature could modify the effect of the other through mediation or moderation. For example, an individual with higher levels of social interaction in the neighbourhood may be feel more inclined to be active with friends or walk to a neighbour's house when the local physical environment is attractive and aesthetically-pleasing than when it is not, while the quality of local physical environment has less influence on individuals with fewer social contacts with which to be active. Alternatively, an environment that is clean and orderly might suggest residents abide by social norms, generating feelings of safety and creating an environment in which individuals feel comfortable walking (e.g. [29]).

This study aimed to explore independent and interactive effects of social and physical environmental factors on neighbourhood walking and MPA in adults in income-deprived communities. Focus was on the quality of micro-scale features of the physical environment (disorder, maintenance and aesthetics) and social environment (cohesion, trust, social interaction, social support, participation and safety), furthering previously discussed research exploring the independent effects of these components in deprived settings elsewhere [26,27]. It was hypothesised that higher quality social and physical environments would be independently and interactively associated with increased physical activity.

Methods

Population

Participants were adults (aged ≥16 years) taking part in the first wave of data collection of the GoWell programme, a study of the health impact of housing and neighbourhood regeneration in Glasgow, a major city in the UK (http://www.gowellonline.com/). In the UK, the National Health Service classifies individuals over 16 years as (young) adults. Data were collected from 14 inner-city neighbourhoods across the city (S1 Fig), comprising 32 sub-areas. All neighbourhoods were classified as income-deprived, with between 25–54% of the neighbourhood population being in receipt of income-related benefits in comparison to the contemporaneous Scottish average of 14% and Glasgow average of 25%. Health and wellbeing profiles (e.g. life expectancy, hospitalization) were broadly similar between study neighbourhoods and other Scottish neighbourhoods with similar levels of deprivation [30]. Neighbourhoods included inner city mass housing estates (mostly comprising high-rise flats), inner suburban garden estates (comprising semi-detached houses and cottage flats) and large peripheral estates (comprising low and medium-rise flats).

Participants were selected by random selection of addresses from the Postal Address File which includes all registered addresses. One adult per household was invited by letter to take part in the GoWell community survey; fieldworkers visited households up to 5 times to seek consent to participation. The survey was conducted at the participant's home by a trained fieldworker during a 40-minute face-to-face meeting. The response rate to invitations to participate was 50.3%. Compared with national statistics at the time of data collection, in the sample from this wave of data collection in the GoWell study, there were slightly more females (60% of this sample compared with 55% nationally) but comparable levels of individuals identifying as Scottish/British and single-person households. The sample was drawn from neighbourhoods with similar health profiles (e.g. life expectancy and alcohol- and drug-related hospitalisations) to other deprived neighbourhoods in Scotland. Therefore, the sample was deemed to be broadly representative of the target population [30,31]. The GoWell study obtained ethical approval from NHS Scotland B MREC committee (no. 05/MRE10/89). All participants provided informed written consent. Further information on the recruitment process and community survey can be found elsewhere [32,33].

Measures

Neighbourhood walking was assessed in the GoWell community survey using the item: *'In a typical week, on how many days do you go for a walk around your neighbourhood?'* This item did not distinguish between walking for recreational or utilitarian purposes and captured frequency rather than duration of walking periods. Participation in MPA was measured using the item: *'In a typical week, on how many days do you do 30 minutes of moderate physical exercise such as brisk walking, cleaning the house–it doesn't have to be 30 minutes all at once?'*. Responses were collapsed into two binary variables using 5 days as a cut-off (walking/participating in MPA on at least 5 days/week; equivalent to >150 minutes MPA/week), in order to assess whether participants were meeting national recommended guidelines for physical activity [5]. Although participation in vigorous physical activity (VPA) was also measured in the survey, levels of VPA were very low (5% participating in ≥5 days/week). Therefore, only MPA was examined in this study.

The quality of the neighbourhood social environment was self-reported using the GoWell community survey. Items were drawn or adapted from previous surveys including the Home Office Citizenship Survey [34], Scottish Social Attitudes Survey [35], British Social Attitudes Survey [36], Office for National Statistics Measuring Social Capital in the UK [37] and the SHARP Questionnaire [38]. Responses to items assessing diverse aspects of the quality of the social environment (e.g. social support: *'how many people could you ask to give you advice and support in a crisis?'*; community cohesion: *'to what extent do you agree that this neighbourhood is a place where people from different backgrounds get on well together?'*; social interaction: *'On how many days a week do you speak to your neighbours?'*) were scored on 4-6-point Likert scales. The neighbourhood was described to participants as the area within 5–10 minutes' walk from their home.

A neighbourhood audit collected data on the quality of the physical environment. The audit was conducted by two trained surveyors across 95 randomly-selected postcodes within the GoWell study neighbourhoods. Evaluations pertained to the 100-metre area surrounding the central point of the postcode (comprising the 'audit site'), encompassing streets, buildings, gardens, paths, fences, outdoor communal areas and public spaces. Items selected from the audit assessed the quality of the physical environment in terms of aesthetics, maintenance and disorder (e.g. '*Are buildings marked with graffiti or other signs of vandalism?*' and '*Buildings are clean and fresh looking*'). Items were scored on 4-point Likert scales. Distance to the central point of the nearest audit site was calculated for each participant to permit data linkage (median distance: 151 metres). Audit data were aggregated at the level of the audit site, creating 95 data points.

A principal components analysis was previously conducted on items measuring the social environment and physical environment using this sample. Items measuring the social environment were drawn from the GoWell community survey and items measuring the physical environment were drawn from the neighbourhood audit. Items were retained on a factor if the loading in the pattern matrix was >0.4. Reliability of the scale was deemed satisfactory if ≥ 0.5, consistent with recommended levels for scales with few items [39]. The analysis obtained 4 factors assessing the quality of the neighbourhood social environment: 'social support' (Cronbach's alpha = 0.9); 'social interaction' (Cronbach's alpha = 0.7); 'trust and empowerment' (Cronbach's alpha = 0.6); 'cohesion and safety' (Cronbach's alpha = 0.5) and 3 factors assessing the quality of the neighbourhood physical environment: 'aesthetics of built form' (Cronbach's alpha = 0.8); 'cues of physical disorder' (Cronbach's alpha = 0.8) and 'aesthetics and maintenance of open space' (Cronbach's alpha = 0.6). Items for each factor are presented in Table 1. Each factor was scored from 0.0 to 1.0. These factors were included in analyses and are collectively referred to as environmental factors.

Socio-demographics previously found to be associated with environmental factors were included as covariates: sex, tenure, age, citizenship, employment status and neighbourhood income-deprivation (% residents in receipt of income-related benefits). Mobility-limiting illness and vehicle ownership were also included as covariates owing to their possible relationship with physical activity [40,41]. All socio-demographics were self-reported in the GoWell community survey. Neighbourhood income-deprivation was previously calculated at neighbourhood level using the Scottish Index of Multiple Deprivation (SIMD) income deprivation domain [42].

Statistical analyses

Descriptive statistics characterised the sample by socio-demographics. Chi-square analyses tested for differences in the likelihood of neighbourhood walking or MPA by socio-

Table 1. Items comprising environmental factors.

Environmental factor	Item	Factor loading
'Social support'	*How many people could you ask to go to the shop for messages (everyday goods) if you are unwell?*	-0.89
	How many people could you ask to lend you money to see you through the next few days?	-0.89
	How many people could you ask to give you advice and support in a crisis?	-0.89
'Social interaction'	*How many days a week do you speak to your neighbours?*	0.78
	How many days a week do you meet up with relatives?	0.76
	How many days a week do you meet up with friends?	0.86
'Trust and empowerment'	*People who live in this neighbourhood think highly of it*	0.66
	Someone who lost a purse or wallet around here would be likely to have it returned without anything missing	0.66
	On your own, or with others, you can influence decisions affecting your local area	0.66
	Is it likely that someone would intervene if a group of youths were harassing someone in the local area?	0.62
'Cohesion and safety'	*To what extent do you agree that this neighbourhood is a place where people from different backgrounds get on well together?*	-0.80
	To what extent do you feel that you belong to this neighbourhood?	-0.71
	How safe would you feel walking alone in this neighbourhood after dark?	-0.55
'Aesthetics of built form'	*Buildings are visually interesting (varied in terms of design, scale, colours, textures)*	0.92
	Buildings are clean and fresh looking	0.79
	Area in general is visually interesting (varied in design, scale, colours, textures)	0.68
'Physical disorder'	*Buildings show signs of damage or disrepair (not vandalism)*	0.83
	Private gardens, yards and driveways are tidy and well maintained	-0.66
	Buildings are marked with graffiti or other signs of vandalism	0.60
	Communal areas and public spaces are tidy and well-maintained	-0.58
	Area in general is clean and fresh looking	-0.51
'Aesthetics and maintenance of open space'	*Communal areas and public spaces are interesting and attractive (i.e. landscaped)*	0.79
	Private are gardens are interesting and attractive	0.66
	The walls, fences or hedges between properties are well maintained	0.51

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demographics. A series of multilevel binary logistic regression models were conducted. Model 1 included a single environmental factor, adjusting for covariates and participant sub-area (i.e. postcode). Model 2 included all environmental factors, adjusting for covariates and participant sub-area. Model 3 included main effects and all pairwise interactions between social and physical environment factors, adjusting for covariates and participant sub-area. Using a data-driven approach in line with Aiken and West's [43] recommendation for exploratory analyses, all pairwise interaction terms were initially entered and insignificant interaction terms were dropped progressively, starting with the least significant term, until only significant terms remained in the model. Post-hoc tests explored significant interactions. Two-level random intercept models accounted for the possibility of clustered responses within sub-areas. Analyses were conducted in Stata 12. Alpha was set at $p<0.01$, acknowledging the large number of statistical tests.

Results

Complete data were available for 5,923 participants. Numbers of missing values were low because data were collected face-to-face (<2% of the original sample of 6,008 participants were excluded because of incomplete data). Imputation of missing data was deemed inappropriate owing to the very small number of excluded participants which would have an inconsequential effect on statistical inferences [44]. Participant characteristics are presented in Table 2. There were slightly more females than males, British citizens than non-British citizens, unemployed individuals than employed or retired individuals, and more individuals living in social- or private-rented accommodation than those in owner-occupied accommodation.

Only 29.4% of participants reported walking in the neighbourhood on at least 5 days/week and 23.5% reported participating in MPA on at least 5 days/week. Frequent walking was associated with participation in MPA ($X^2(1) = 955.49$, $p<0.001$). Younger participants were more likely to report frequent walking and MPA, with a linear trend across the age groups. Participants in and out of employment were significantly more likely to walk or perform MPA on at least 5 days/week compared with retired participants and those with vehicles, were more likely to engage in frequent walking and MPA than others were. Those in family households were more likely to report frequent walking and MPA compared with those living in adult or older adult households, as were participants residing in owned accommodation compared with rented accommodation. Female participants were also significantly more likely to perform MPA on ≥5 days/week, as were British participants.

Table 2. Participant characteristics and differences in walking and MPA by socio-demographics (n = 5,923).

	Whole sample N(%)	Walk ≥5 days/week N(%)	MPA ≥5 days/week N(%)
Sex			
Male	2369 (40.0)	729 (30.8)	**495 (20.9)**
Female	3554 (60.0)	1013 (28.5)	**897 (25.2)**
Age group			
16–24	464 (7.8)	**191 (41.2)**	**141 (30.4)**
25–39	1650 (27.9)	**528 (32.0)**	**415 (25.2)**
40–54	1531 (25.8)	**482 (31.5)**	**399 (26.1)**
55–64	808 (13.6)	**239 (29.6)**	**178 (22.0)**
65+	1470 (24.8)	**302 (20.5)**	**259 (17.6)**
Citizenship			
British	5091 (86.0)	1512 (29.7)	**1276 (25.1)**
Non-British	832 (14.0)	230 (27.6)	**116 (13.9)**
Employment			
Working	1389 (23.5)	**535 (30.7)**	**485 (34.9)**
Not working	2773 (46.8)	**811 (29.2)**	**579 (20.9)**
Retired	1761 (29.7)	**396 (22.5)**	**328 (18.6)**
Household			
Adult	2364 (39.9)	**730 (30.9)**	**569 (24.1)**
Family	1885 (31.8)	**647 (34.3)**	**501 (26.6)**
Older	1674 (28.3)	**365 (21.8)**	**322 (19.2)**
Tenure			
Own	1379 (23.3)	**491 (35.6)**	**401 (29.1)**
Rent	4544 (76.7)	**1251 (27.5)**	**991 (21.8)**
Vehicle ownership			
Yes	1451 (24.5)	**492 (33.9)**	**459 (31.6)**
No	4472 (75.5)	**1250 (28.0)**	**933 (20.9)**

Bold typeface indicates significant difference at p<0.01 level controlling for area, distance to audit site and other demographic characteristics.

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Associations between social environmental factors and physical activity

Table 3 presents findings for model 1 (containing main effects of environmental factors separately and adjusting for confounders) and model 2 (multivariate model containing main effects for all environmental factors, but no interaction terms, and adjusting for confounders) with walking as the outcome. Models were also conducted using continuous physical activity outcomes; associations were in the same direction and therefore are not reported here. In model 1, independent effects of all social factors were obtained, in the direction expected, i.e. stronger social factors associated with more walking. In model 2 (the multivariate model), three social factors retained significant positive associations with walking, they were: 'social support' (OR:1.22, 95%CI = 1.06–1.41, $p<0.01$), 'social interaction' (OR:1.25, 95%CI = 1.10–1.42, $p<0.01$) and 'cohesion and safety' (OR:1.78, 95%CI = 1.56–2.03, $p<0.001$). There was no effect of 'trust and empowerment' on walking in the multivariate model.

Table 4 presents findings for participation in MPA on ≥5 days/week. In model 1, there was a significant effect of 'social interaction' and 'cohesion and safety', only, both in the direction expected, i.e. stronger social factors associated with more physical activity. In model 2, there was an independent effect of three social factors: two were in the direction expected, namely 'social interaction' (OR:6.16, 95%CI = 5.14–7.37, $p<0.001$) and 'cohesion and safety' (OR:1.93, 95%CI = 1.65–2.27, $p<0.001$); one association was negative, namely 'social support' (OR:0.79, 95%CI = 0.67–0.94, $p<0.01$). There was no effect of 'trust and empowerment' in the multivariate model.

Table 3. Independent effects of social and physical environment factors on neighbourhood walking on at least 5 days/week (n = 5,923).

Environmental factor	% walking ≥5 days	Model 1			Model 2		
		OR	95% CI	p	OR	95% CI	p
'Social support'							
Lower	25.4	1.00			1.00		
Higher	30.9	1.27	1.11–1.47	**.001**	1.22	1.06–1.41	**.006**
'Trust and empowerment'							
Lower	27.8	1.00			1.00		
Higher	30.9	1.21	1.07–1.37	**.003**	1.10	0.97–1.25	.141
'Social interaction'							
Weaker	25.0	1.00			1.00		
Stronger	32.8	1.34	1.18–1.52	**.000**	1.25	1.10–1.42	**.001**
'Cohesion and safety'							
Lower	21.3	1.00			1.00		
Higher	35.6	1.89	1.66–2.15	**.000**	1.78	1.56–2.03	**.000**
'Aesthetics of built form'							
Poorer	25.7	1.00			1.00		
Better	33.2	1.60	1.35–1.90	**.000**	1.47	1.22–1.77	**.000**
'Physical disorder'							
More cues	26.4	1.00			1.00		
Fewer cues	32.1	1.43	1.20–1.70	**.000**	1.13	0.94–1.36	.190
'Aesthetics & maintenance of open space'							
Poorer	28.4	1.00			1.00		
Better	29.9	1.42	1.22–1.66	**.000**	1.32	1.13–1.54	**.001**

Model 1: single social or physical environmental factor and covariates (sex, age, citizenship, employment status, tenure, mobility-limiting illness, vehicle ownership, distance to audit site and neighbourhood deprivation), adjusted for participant sub-area. Model 2: random intercept included in model to account for possible clustering within participant sub-area; model included all social and physical environmental factors and covariates.

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Table 4. Independent effects of social and physical environment factors on moderate physical activity on at least 5 days/week (n = 5,923).

Environmental factor	% MPA ≥5 days	Model 1			Model 2		
		OR	95% CI	p	OR	95% CI	p
'Social support'							
Lower	22.8	1.00			1.00		
Higher	23.8	0.85	0.72–0.99	.034	0.79	0.67–0.94	**.007**
'Trust and empowerment'							
Lower	20.5	1.00			1.00		
Higher	26.3	1.14	0.99–1.31	.063	1.14	0.98–1.33	.087
'Social interaction'							
Weaker	7.4	1.00			1.00		
Stronger	35.6	6.68	5.59–7.97	**.000**	6.16	5.14–7.37	**.000**
'Cohesion and safety'							
Lower	13.0	1.00			1.00		
Higher	31.5	2.38	2.04–2.77	**.000**	1.93	1.65–2.27	**.000**
'Aesthetics of built form'							
Poorer	21.4	1.00			1.00		
Better	25.6	1.21	1.00–1.46	.050	1.02	0.82–1.27	.838
'Physical disorder'							
More cues	19.2	1.00			1.00		
Fewer cues	27.3	1.94	1.60–2.36	**.000**	1.63	1.31–2.03	**.000**
'Aesthetics & maintenance of open space'							
Poorer	25.4	1.00			1.00		
Better	22.5	1.32	1.11–1.56	**.001**	1.16	0.97–1.40	.107

Model 1: single social or physical environmental factor and covariates (sex, age, citizenship, employment status, tenure, mobility-limiting illness, vehicle ownership, distance to audit site and neighbourhood deprivation), adjusted for participant sub-area. Model 2: random intercept included in model to account for possible clustering within participant sub-area; model included all social and physical environmental factors and covariates.

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Associations between physical environmental factors and physical activity

Table 3 presents results for associations between physical factors and walking for both model 1 and model 2. In model 1, all physical environment factors were related to walking in the direction expected, i.e. better conditions associated with more walking. In model 2 (multivariate model), only two physical environmental factors retained significance. 'Aesthetics of the built form' (OR:1.47, 95%CI = 1.22–1.77, $p<0.001$) and 'aesthetics and maintenance of open space' (OR:1.32, 95%CI = 1.13–1.54, $p<0.01$) had significant positive effects on regular walking. There was no independent effect of 'physical disorder'.

Table 4 presents results for MPA for model 1 and model 2. In model 1, 'physical disorder' and 'aesthetics and maintenance of open space' had positive effects on MPA. In model 2 (multivariate model), only 'physical disorder' was related to increased likelihood of participating in MPA on ≥5 days/week (OR:1.63, 95%CI = 1.31–2.03, $p<0.001$). There was no effect of 'aesthetics of built form' or 'aesthetics and maintenance of open space' on MPA in the multivariate model.

Interactions between social and physical environment and impact on physical activity

Progressive removal of non-significant interaction terms in model 3 revealed significant interactive effects. There were two significant interactions between the social and built environments in relation to walking; between 'trust and empowerment' and 'aesthetics and maintenance of open space' ($p<0.001$); and between 'cohesion and safety' and 'physical disorder' ($p<0.01$).

For MPA, there were three significant interactions: between 'trust and empowerment' and 'aesthetics and maintenance of open space' ($p<0.01$) between 'cohesion and safety' and 'physical disorder' ($p<0.01$); and between 'social interaction' and 'aesthetics of the built form' ($p<0.001$). No other interaction terms between social and physical factors reached significance at $p<0.01$ for either walking or MPA.

In post hoc analyses (full results are presented in S1 Table), 'cohesion and safety' appeared to moderate the effect of 'physical disorder' on walking and MPA: 'physical disorder' only had a significant influence on activity outcomes when there was a higher level of 'cohesion and safety' (walking: OR = 1.50, 95%CI = 1.20–1.86, $p<0.001$; MPA: OR = 1.94, 95%CI = 1.53–2.47, $p<0.001$). In contrast, 'cohesion and safety' had a significant influence on activity outcomes regardless of 'physical disorder'.

'Social interaction' moderated the influence of 'aesthetics of built form' on MPA: 'aesthetics of built form' only had an effect when 'social interaction' was high (OR = 1.40, 95%CI = 1.10–1.77, $p<0.01$) but 'social interaction' had a significant effect on MPA regardless of 'aesthetics of built form'.

'Trust and empowerment' and 'aesthetics and maintenance of open space' appeared to operate synergistically upon walking and MPA: 'aesthetics and maintenance of open space' only had a significant influence on activity outcomes when 'trust and empowerment' was high (walking: OR = 2.12, 95%CI = 1.70–2.64, $p<0.001$; MPA: OR = 1.47, 95%CI = 1.15–1.87, $p<0.01$) and 'trust and empowerment' only had a significant effect when 'aesthetics and maintenance of open space' was high (walking: OR = 1.52, 95%CI = 1.30–1.77, $p<0.001$; MPA: OR = 1.29, 95%CI = 1.08–1.54, $p<0.01$).

Discussion

In an adult population living in deprived communities in Glasgow, UK, independent and interactive effects of the social and physical environment on neighbourhood walking and participation in MPA were revealed. In models including a single environmental factor and adjusting for covariates and nesting in sub-area, all environment factors ('social support', 'trust and empowerment', 'social interaction', 'cohesion and safety', 'aesthetics of built form', 'physical disorder' and 'aesthetics and maintenance of open space') were significantly associated with increased likelihood of walking in the neighbourhood on $\geq$5 days/week. 'Cohesion and safety' had the largest effect, with participants reporting higher levels of cohesion being nearly twice as likely to regularly walk around their neighbourhood. In models with MPA as the outcome, 'social interaction', 'cohesion and safety', 'physical disorder' and 'aesthetics and maintenance of open space' were significant. 'Social interaction' had the largest independent effect on MPA, with participants reporting higher levels of 'social interaction' being more than 6 times more likely to meet national guidelines by participating in $>$30 minutes of MPA on $\geq$5 days/week. Interactive effects on walking and MPA were reported between i) 'trust and empowerment' and 'aesthetics and maintenance of open space' and ii) 'cohesion and safety' and 'physical disorder'. There was also an interactive effect on MPA between 'social interaction' and 'aesthetics or built form'.

Most independent effects were in the expected direction, with better quality social and physical environments related to an increased likelihood of frequent walking or MPA. The only negative relationship was between 'social support' and MPA which was non-significant in a univariate model (while also controlling for covariates) but attained significance in the multivariate model. This could be a spurious result (despite an alpha level $p<0.01$) or could be indicative of reverse causality whereby individuals with a greater need for social support (and therefore higher self-reported levels) are less able or likely to participate in higher-intensity physical activity. Results replicate previous findings from the GoWell sample where individual measures of safety after dark, informal social control (intervening in harassment), belonging to the neighbourhood and cohesion between residents of different backgrounds had significant positive independent effects on neighbourhood walking [45]. Findings also support those from other populations. For example, Shelton et al. found in a sample of 1,112 adults in low-income communities in the USA that participants who reported stronger social networks (and thereby higher levels of social interaction) also performed higher levels of pedometer-assessed physical activity [46]. Positive associations between objectively-measured aesthetics of the built form and open space and self-reported walking reflect previous findings from the IPEN study across 17 cities in 12 countries which found an effect of self-reported perceived aesthetics and self-reported walking for transport for $\geq$150 minutes per week [47]. As noted in Kerr et al., an effect of micro-scale features of the physical environment such as aesthetics presents a potentially low-cost intervention strategy [47].

There were some notable differences between independent environmental effects on neighbourhood-based walking and MPA. In models including all environmental factors and covariates, there was an effect of all social environmental factors except 'trust and empowerment' on both activity outcomes. However, effects on MPA, compared with neighbourhood-based walking, were much stronger for 'social interaction', slighter stronger for 'cohesion and safety' and in the opposite direction for 'social support'. This is somewhat surprising as it might be expected that if there are neighbourhood effects on activity, the local neighbourhood environment would be more closely associated with activity performed in the neighbourhood. However, it is likely that although the measure of MPA was not context-specific, the majority of activity reported by participants was in fact performed in the neighbourhood and encompassed walking and additional activities such as household chores, gardening or using local physical activity facilities [48]. There were also differences in the effect of the built environment on activity outcomes:–'physical disorder' only had an independent effect on MPA while 'aesthetics of built form' and 'aesthetics and maintenance of open space' only had an effect on walking. It is possible these differences can be attributed to the activities included in MPA other than walking, such as use of physical activity facilities, and the comparative importance of a pleasant and attractive public realm for walking-based activities. Differences might be explained by the extent to which the physical environment interacted with the social environment, as discussed below.

Interactions between i) 'trust and empowerment' and 'aesthetics and maintenance of open space' and ii) 'cohesion and safety' and 'physical disorder' were found for both walking and MPA. An interactive effect of 'social interaction' and 'aesthetics of built form' was also reported for MPA. Post hoc analyses suggested that the effect of 'physical disorder' appeared to operate through 'cohesion and safety', with fewer cues of disorder supporting higher levels of activity only when participants viewed their neighbourhoods as socially-cohesive and safe. Post-hoc tests showed that the largest effect was observed for participants reporting high levels of 'cohesion and safety' and living in areas with fewer cues of 'physical disorder'. These participants were 2.2 times more likely to walk or perform MPA on at least 5 days/week than participants living in areas with fewer cues of 'physical disorder' but reporting lower levels of 'cohesion and safety'. There was no independent effect of 'physical disorder'.

The effect of 'aesthetics of built form' on MPA was similarly constrained by 'social interaction': only when participants had higher levels of social interaction did the positive influence of aesthetics of the built form occur–there was no effect of 'aesthetics of built form' when 'social interaction' levels were lower. The largest effect was apparent when both 'social interaction' and 'aesthetics of built form' were high, in this case, participants were 10 times more likely to perform MPA on 5 days/week, than participants reporting low levels of 'social interaction' in areas with better 'aesthetics of built form'.

Previous research has documented an association between physical disorder and anti-social behaviour [49,50], speculating that cues of neglect and 'physical incivilities' suggest residents do not abide by social norms and are therefore more likely to engage in anti-social or criminal behaviour [29]. It is therefore feasible that physical disorder acts as a cue to harmonious relationships between neighbours, or that harmonious relationships encourage individuals to take care of their physical environment. Findings from this study suggests that when individuals perceived low levels of safety and cohesion there was no effect of physical disorder, possibly because cues for safety and cohesion that were usually elicited from physical disorder were overridden. However, physical disorder had an effect on physical activity in individuals reporting high levels of safety and cohesion; possibly disorder was neutralised as a cue for safety but still created an uninviting, smelly or dirty environment.

Additionally, it could be speculated from results that aesthetically-pleasing built form only supported MPA when individuals had many friends and neighbours because visually interesting and attractive environments and buildings were only important when they could be used for recreational team sports or joint activities (e.g. an attractive green space or leisure centre). Because assessments of the built form were objectively reported by auditors, it suggests that an interactive effect is not due to individuals with higher levels of social interaction feeling more attached to the neighbourhood and therefore perceiving the local physical environment in a more positive light. However, it is possible that an attractive built form might be more readily felt by individuals with higher levels of social interaction, who then are more motivated to use, and be active in, their local environment.

These interactive effects support a key tenet of socioecological models of physical activity and are substantiated by emerging evidence from the USA. For example, perceived safety appeared to interact with walkability, mitigating the effect of neighbourhood walkability whereby walkability exerted a smaller effect on MVPA when levels of perceived safety were held constant (e.g. constantly high) than did the effect of safety when levels of walkability were held constant [28]. Such findings suggest that aspects of the social environment may be more important than physical aspects in encouraging individuals to be active within a deprived context. Intervening to increase physical activity through reduction of physical disorder or creation of more attractive and interesting built form might therefore be successful only when the social environment is also supportive of physical activity.

In the current study, 'trust and empowerment' and 'aesthetics and maintenance of open space' appeared to act synergistically upon walking and MPA: 'aesthetics and maintenance of open space' was only important when there was a high level of 'trust and empowerment' and vice versa. It is feasible that these aspects of the social and physical environment reinforce one another. For example, residents who trust each other and feel empowered may have the capability and motivation to maintain and/or advocate for attractive open space, resulting in attractive open spaces which prompt further mutual trust and empowerment. Similarly, in Kaczynski and Glover's study of 380 adults in Canada, the highest levels of walking for transport or recreation were reported in neighbourhoods with high walkability (a composite measure including macro- and micro-scale physical features) *and* high levels of cohesion and trust [51]. To our knowledge, this is the first time an interactive effect of community trust and empowerment and quality of open space on physical activity has been reported in a deprived setting in the UK.

Findings should be replicated and further explored within deprived contexts and using longitudinal or quasi-experimental study designs in order to establish the reliability of associations and unpick the direction of causality. If supported by future research, interactive environmental effects on physical activity may have important implications for future research and policy within the field of active design. Firstly, if unmeasured factors moderate or act synergistically upon measured factors, variance arising from the influence of unmeasured factors might underpin some of the reported inconsistency within the physical activity literature examining neighbourhood effects. This is highlighted by the independent effects reported in the multivariate models that did not include interactive effects. Insight into these relationships can contribute to the development of theoretical frameworks of neighbourhood influence on physical activity.

Secondly, as discussed, it is possible that simultaneously targeting aspects of social and physical environment that work together to influence activity will harness the largest effects on walking and MPA. For example, interventions may be most successful when they simultaneously target aspects of the environment or deploy specific strategies in neighbourhoods with existing social/physical environmental characteristics conducive to activity. Findings are therefore supportive of a holistic approach to regeneration which includes strategies for both social and physical regeneration or leverages the effect of existing supportive social contexts.

Strengths and limitations

It is important that interventions or policy employing active design principles are informed by timely research that is, as far as possible, specific to resident populations and contexts. However, context-specific research also limits generalizability and it is necessary to bear in mind that assessments of the environment in this study were relative: a high level of trust and empowerment or better aesthetics of built form may not be regarded as 'high quality' in another context. Moreover, because analyses were cross-sectional, it is not possible to assess the causal direction of relationships: better quality social and physical environments might be an outcome of increased physical activity or a third factor might act upon both the environment and physical activity.

Neighbourhood deprivation, participant employment status and vehicle ownership were controlled for in statistical models as proxy measures of socio-economic status but we were unable to control for individual income or deprivation due to a lack of complete data (<25% of sample). Individual income could act on the perceived social environment and physical activity behaviour but is unlikely to act on the physical environment beyond any effect of neighbourhood deprivation, unless there is spatial clustering of income or individual deprivation within neighbourhoods. Longitudinal analyses and natural experiments will provide insight into the causal pathways between the environment and physical activity although it is conceivable that the relationship between the environment and physical activity is not linear, but dynamic and complex, with environmental aspects being both determinants and outcomes of physical activity in the neighbourhood.

A large sample increases the reliability and generalisability of the results and is necessary to test for an interaction effect [18,43]. Obtaining a large sample from deprived neighbourhoods is therefore a major strength of this study. However, it is expensive and often unfeasible to collect objective measurements of physical activity in large samples. Therefore, self-reported physical activity was used in this study, potentially reducing the validity and reliability of this measure. Nonetheless, previous studies using single-item self-report physical activity measures have shown that they can have adequate criterion validity against accelerometry and moderate validity and strong repeatability against more extensive self-report tools [52,53]. In addition, there is a valuable congruence in using self-reported data to assess adherence to physical activity guidelines (e.g. participation in physical activity on approximately 5 days/week) which were themselves developed using self-reported physical activity data as a basis to estimate associated health benefits [54,55]. Examining environmental influences on two physical activity outcomes adds strength to our findings, which corroborated one another in terms of strength and direction of effects. Neighbourhood was generically defined in the survey as the area within a 5–10 minutes' walk of the respondent's home. However, it should be acknowledged that in comparison to the non-specific MPA outcome, the context-specific physical activity outcome (neighbourhood-based walking) might be vulnerable to response bias in that individual factors or physical activity levels could influence the exact size and shape of participants' own self-defined interpretation of their neighbourhood. Future research should aim to replicate these results using objective measures of physical activity and explore whether the effect differs for various domains of activity (e.g. transport, recreational).

Structural elements of the physical environment that are typically used to assess walkability (e.g. density, connectivity and land use) were not within the scope of the current study. Instead, this study responded to recent evidence that quality-related features of the physical environment (e.g. aesthetics, maintenance, disorder) may present more affordable and practical targets for neighbourhood interventions to increase physical activity and alleviate health inequalities by lessening reported disparities in these features between lower- and higher-income communities [26,27]. Nonetheless, results should be interpreted in light of possible additional influence of structural macro-scale elements of the environment on neighbourhood walking and MPA.

Conclusions

Findings reveal independent and interactive associations between the quality of the social and physical environment and neighbourhood walking and MPA. Results demonstrate the importance of simultaneous consideration of multiple aspects of the social and physical environment in both research and active design policy. To our knowledge, this is the first examination of interactive effects of the social and physical environment in a sample of adults living in income-deprived neighbourhoods in the UK.

Supporting information

S1 Fig. GoWell neighbourhood locations in 2006. Background map sourced from Google Maps; www.google.co.uk/maps. Accessed February 2017.
(DOCX)

S1 Table. Results for post-hoc tests examining effect of selected environment factor on walking and moderate physical activity. Models were conducted by stratified group and included selected environment factors and covariates (sex, age, citizenship, employment status, tenure, mobility-limiting illness, vehicle ownership, distance to audit site and neighbourhood deprivation), adjusted for participant sub-area.
(DOCX)

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Appendix 5.2 Results for linear regressions analyses for cross-sectional associations between environmental factors and activity

Table A5.1 Independent effects of social and physical environment factors on neighbourhood days of walking in neighbourhood per week (n=5,923)

Environmental factor	Model 1			Model 2		
	b	95% CI	p	b	95% CI	p
'Social support' Higher	.091	-0.03 – 0.21	.144	.054	-0.07 – 0.18	.385
'Trust and empowerment' Higher	.213	0.10 – 0.32	**.000**	.134	0.02 – 0.24	.016
'Social interaction' Higher	.223	0.11 – 0.33	**.000**	.160	0.05 – 0.27	**.004**
'Cohesion and safety' Higher	.584	0.47 – 0.69	**.000**	.530	0.42 – 0.64	**.000**
'Aesthetics of built form' Better	.329	0.18 – 0.48	**.000**	.260	0.10 – 0.42	**.001**
'Physical disorder' Fewer cues of disorder	.249	0.10 – 0.40	**.001**	.051	-0.11 – 0.21	.531
'Aesthetics & maintenance of open space' Better	.331	0.19 – 0.47	**.000**	.268	0.13 – 0.41	**.000**

Bold typeface indicates significance at p<0.01. Model 1: single social or physical environmental factor and covariates (sex, age, citizenship, employment status, tenure, mobility-limiting illness, vehicle access, distance to audit assessment site and neighbourhood deprivation), adjusted for sub-area. Model 2: all social and physical environmental factors and covariates, adjusted for sub-area.

Table A5.2 Independent effects of social and physical environment factors on days of moderate physical activity per week (n=5,923)

Environmental factor	Model 1			Model 2		
	b	95% CI	p	b	95% CI	p
'Social support' Higher	-.130	-0.25 - -0.01	.035	-.128	-0.24 - -0.01	.032
'Trust and empowerment' Higher	-.030	-0.14 – 0.08	.573	-0.02	-0.13 – 0.08	.660
'Social interaction' Higher	1.12	1.01 – 1.22	**.000**	1.07	0.96 – 1.17	**.000**
'Cohesion and safety' Higher	.435	0.33 – 0.54	**.000**	.284	0.18 – 0.39	**.000**
'Aesthetics of built form' Better	.025	-0.13 – 0.18	.749	-.117	-0.27 – 0.04	.136
'Physical disorder' Fewer cues of disorder	.508	0.36 – 0.66	**.000**	.453	0.30 – 0.61	**.000**
'Aesthetics & maintenance of open space' Better	.175	0.04 – 0.31	.011	.079	-0.05 – 0.21	.245

Bold typeface indicates significance at p<0.01. Model 1: single social or physical environmental factor and covariates (sex, age, citizenship, employment status, tenure, mobility-limiting illness, vehicle access, distance to audit assessment site and neighbourhood deprivation), adjusted for participant sub-area. Model 2: all social and physical environmental factors and covariates, adjusted for sub-area.

Appendix 6.2 Second-level and thematic coding hierarchy

Figure A6.1 Second-level and thematic coding hierarchy