People and Places: using geo-linked survey data to investigate the role of neighbourhoods in adolescent health and wellbeing.

Thesis submitted in accordance with the requirements of the University College London for the degree of Doctor in Philosophy by

Charlotte Constable Fernandez

MRC Unit of Lifelong Health and Ageing

University College London

Primary supervisor: Dr Jane Maddock

Secondary supervisors: Prof Praveetha Patalay, Prof Laura Vaughan

Declaration

I, Charlotte Constable Fernandez 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.

Abstract

There is a lack of consensus around the possible influence of the neighbourhood for adolescent health. Previous studies have generated mixed results and much of the literature lacks careful consideration around spatial measures and definitions of the neighbourhood. This thesis aims to examine the relationships between features of the neighbourhood environment, specifically greenspaces, crime and high streets, and physical activity and social isolation in adolescence through secondary data analysis of the Millennium Cohort Study. This thesis uses a multidisciplinary approach to examine neighbourhood features and adolescent health outcomes from a UK perspective. This thesis benefits from the use of geo-linked survey data, including proximity measures that apply network analysis that considers real-world street connectivity. Methods utilised for statistical analysis include linear regression, zero-inflated Poisson regression and multilevel models.

This thesis consists of three empirical studies. Firstly, prospective associations between subjective neighbourhood safety and objective crime rates, linked via participant geographical identifiers, and subsequent physical activity are examined. Results indicate that feeling unsafe in the neighbourhood, IMD crime and violent crime are barriers to physical activity participation in adolescents.

Secondly, the thesis investigates the impact of proximity to greenspaces on physical activity at age 14, using participant postcode data linked to closest greenspace access points, utilising network distance. Results suggest that proximity to greenspaces alone is not associated with physical activity in this cohort.

Thirdly, longitudinal associations between proximity to high streets and social isolation outcomes are investigated. Results revealed no relationship between proximity to high streets and social isolation indicators, suggesting that high streets may either not significantly influence adolescent social engagement or that young people are willing to travel greater distances.

Overall, this thesis suggests that neighbourhoods do influence adolescent health but the effects are nuanced and often depend on neighbourhood measures.

Impact Statement

It is well acknowledged that where you live can influence a range of health outcomes. This has been a major topic of research both in the field of the built environment and epidemiology. However, evidence is limited concerning the importance of neighbourhood factors during adolescence. In particular, there is a lack of research from the UK perspective. Findings from this thesis have therefore addressed relevant knowledge gaps.

In Chapter Three of this thesis, I uniquely linked participant postcodes to *both* the Index of Multiple Deprivation (IMD) crime domain and to crime data from the Data.Police.UK database, which provides a breakdown of types of reported crime. I additionally used a measure of participant perceived safety at age 11. Similarly, physical activity was captured through a self-report measure and objectively through wrist-worn accelerometers at age 14. By using both objective and subjective measures of both exposures and outcomes we were able to gain a comprehensive and complex picture of neighbourhood crime, safety, and physical activity. Results indicate varying associations between these subjective and objective measures of crime, safety and physical activity and suggest that crime and subjective safety may impede adolescents from participating in physical activity. Results from Chapter Three have been published by Health & Place. I have also presented the findings from this chapter at the WHO Health Enhancing Physical Activity (HEPA) conference in Nice in 2022.

In Chapter Four, I used data that linked participant postcodes to greenspace access points and similarly measured physical activity objectively and subjectively. This study highlights the methodological challenges around studying greenspace and health behaviours and that proximity alone may not be a decisive factor in physical activity participation. Policymakers should consider the quality and facilities that encourage greenspace use and physical activity in adolescents. The findings of this study were presented at the International Urban Health Conference, Atlanta in November 2023.

In Chapter Five I investigated the impact of distance to high streets and social isolation. This, novel study contributes to the nuanced understanding of factors influencing social isolation and support in adolescence. The findings of this study suggest that proximity to high streets may not be significant for adolescent's social connectedness, and exploration of alternative neighbourhood features and social isolation should be encouraged. Results from this chapter are currently under peer review.

In conclusion, this thesis reports mixed findings between features of the neighbourhood and adolescent health outcomes. It is hoped that this work, both the methodology employed and results, will inform future research to better address the complex and dynamic relationship between the neighbourhood and adolescent health. This thesis benefits from expertise across health epidemiology and the built environment, promoting a multidisciplinary approach for future research.

Acknowledgements

I would firstly like to thank my wonderful supervisory team Jane Maddock, Praveetha Patalay and Laura Vaughan.

Jane – thank you for being the most understanding and helpful primary supervisor I could have wished for! Thank you for your patience, guidance and for all the meetings troubleshooting my statistical problems. You always made time for me and I appreciate that so much. I would mostly like to thank you for your kindness and for never making me feel unworthy to be doing a PhD even when I felt it myself! The PhD journey has not been an easy ride, but I always knew I could count on your support and friendship. I really did strike (Irish) gold with you!

Praveetha – it has been a joy to learn from such a talented and inspiring woman. Your knowledge never ceases to amaze me! Thank you for sharing your wisdom with me and for making me feel like I can achieve anything. Working with you has been a privilege and I hope to work with you again in the future.

Laura – thank you for all our interesting chats and for welcoming a built environment novice into your world. You have offered invaluable insight into this work and your expertise have no doubt improved the quality of this research.

My thanks also go to: Kimon Krenz, David Church, Gareth Griffiths, Alexandra Pitman, Mark Hamer and Anne-Kathrin Fett for their respective expertise and collaboration with this research.

Thank you to all the other incredible PhD students at the LHA and beyond who have inspired and kept me going. Special thanks to Louisa and Esme for the hours of free counselling.

A huge thank you goes to my family for all their love and support. Thank you to my mum for always answering my calls and being there for me no matter what and when it is. A big thank you to my fiancé Jamie for supporting me through the highs and lows of this journey and never once doubting I could achieve it. Thank you for the endless cups of tea! Thank you for believing in me when I didn't believe in myself. I'm so lucky to have you in my life.

List of Abbreviations

CI, Confidence Interval

GIS, Geographic Information System

GPS, Global Positioning System

LSOA, Lower Super Output Area

MAUP, Modifiable Areal Unit Problem

MCS, Millennium Cohort Study

MVPA, Moderate to Vigorous Physical Activity

ONS, Office for National Statistics

OR, Odds Ratio

OS, Ordnance Survey

PA, Physical Activity

SD, Standard Deviation

SEP, Socioeconomic Position

VPC, Variance Partition Coefficient

1. UCL Research Paper Declaration Form

referencing the doctoral candidate's own published work(s)

Please use this form to declare if parts of your thesis are already available in another format, e.g. if data, text, or figures:

- *have been uploaded to a preprint server*
- *are in submission to a peer-reviewed publication*
- *have been published in a peer-reviewed publication, e.g. journal, textbook.*

1. For a research manuscript that has already been published

a) **What is the title of the manuscript?**

Subjective and objective indicators of neighbourhood safety and physical activity among UK adolescents

b) **Please include a link to or doi for the work**

10.1016/j.healthplace.2023.103050

c) **Where was the work published?**

Health & Place

d) **Who published the work?** (e.g. OUP)

Elsevier

e) **When was the work published?**

20 June 2023

f) **List the manuscript's authors in the order they appear on the publication**

Charlotte Constable Fernandez, Praveetha Patalay, Laura Vaughan, David Church, Mark Hamer, Jane Maddock

g) **Was the work peer reviewed?**

Yes

h) **Have you retained the copyright?**

Yes, CC BY license

i) **Was an earlier form of the manuscript uploaded to a preprint server?** (e.g. medRxiv). If 'Yes', please give a link or doi)

Yes; https://www.medrxiv.org/content/10.1101/2023.03.10.23286997v1

If 'No', please seek permission from the relevant publisher and check the box next to the below statement:

☐

*I acknowledge permission of the publisher named under **1d** to include in this thesis portions of the publication named as included in **1c**.*

2. **For a research manuscript prepared for publication but that has not yet been published** (if already published, please skip to section 3)

   a) **What is the current title of the manuscript?**

   Click or tap here to enter text.

   b) **Has the manuscript been uploaded to a preprint server?** (e.g. medRxiv; if 'Yes', please give a link or doi)

   Click or tap here to enter text.

   c) **Where is the work intended to be published?** (e.g. journal names)

   Click or tap here to enter text.

   d) **List the manuscript's authors in the intended authorship order**

   Click or tap here to enter text.

   e) **Stage of publication** (e.g. in submission)

   Click or tap here to enter text.

3. **For multi-authored work, please give a statement of contribution covering all authors** (if single-author, please skip to section 4)

Conceptualization, C.C.F., P.P., J.M., MH., L.V.; methodology, C.C.F., P.P, J.M., L.V.; formal analysis, C.C.F.; validation, P.P., J.M.; investigation, C.C.F.; resources, C.C.F.; software: D.C.; data curation, D.C..; writing—original draft preparation, C.C.F.; writing—review and editing, C.C.F., J.M., P.P., L.V.; supervision, J.M., P.P., L.V.; project administration, C.C.F. All authors have read and agreed to the published version of the manuscript.

4. **In which chapter(s) of your thesis can this material be found?**

   Chapter Three

5. **e-Signatures confirming that the information above is accurate** (this form should be co-signed by the supervisor/ senior author unless this is not appropriate, e.g. if the paper was a single-author work)

Candidate

[redacted]

Date: 8-03-24

[redacted]

Supervisor/ Senior Author (where appropriate)

Date 8-03-24

2. UCL Research Paper Declaration Form

referencing the doctoral candidate's own published work(s)

Please use this form to declare if parts of your thesis are already available in another format, e.g. if data, text, or figures:

- *have been uploaded to a preprint server*
- *are in submission to a peer-reviewed publication*
- *have been published in a peer-reviewed publication, e.g. journal, textbook.*

This form should be completed as many times as necessary. For instance, if you have seven thesis chapters, two of which containing material that has already been published, you would complete this form twice.

1. **For a research manuscript that has already been published** (if not yet published, please skip to section 2)

j) **What is the title of the manuscript?**

Click or tap here to enter text.

k) **Please include a link to or doi for the work**

Click or tap here to enter text.

l) **Where was the work published?**

Click or tap here to enter text.

m) **Who published the work?** (e.g. OUP)

Click or tap here to enter text.

n) **When was the work published?**

Click or tap here to enter text.

o) **List the manuscript's authors in the order they appear on the publication**

Click or tap here to enter text.

p) **Was the work peer reviewed?**

Click or tap here to enter text.

q) **Have you retained the copyright?**

Click or tap here to enter text.

r) **Was an earlier form of the manuscript uploaded to a preprint server?** (e.g. medRxiv). If 'Yes', please give a link or doi)

Click or tap here to enter text.

If 'No', please seek permission from the relevant publisher and check the box next to the below statement:

☐

*I acknowledge permission of the publisher named under **1d** to include in this thesis portions of the publication named as included in **1c**.*

2. **For a research manuscript prepared for publication but that has not yet been published** (if already published, please skip to section 3)

f) **What is the current title of the manuscript?**

Proximity to high streets, social isolation and social support in British adolescents: a longitudinal analysis of sociospatial influences on social connectedness using geospatial data

g) **Has the manuscript been uploaded to a preprint server?** (e.g. medRxiv; if 'Yes', please give a link or doi)

No

h) **Where is the work intended to be published?** (e.g. journal names)

Health & Place

i) **List the manuscript's authors in the intended authorship order**

Charlotte Constable Fernandez, Jane Maddock, Praveetha Patalay, Anne-Kathrin Fett, Alexandra Pitman, Laura Vaughan, Kimon Krenz

j) **Stage of publication** (e.g. in submission)

Under review

3. **For multi-authored work, please give a statement of contribution covering all authors** (if single-author, please skip to section 4)

Conceptualization, A.F., C.C.F., P.P., A.P, L.V. and K.K.; methodology, C.C.F., P.P., A.P., J.M., L.V. and K.K.; formal analysis, C.C.F.; validation, J.M.; investigation, C.C.F., K.K.; resources, C.C.F.; software: K.K.; data curation, K.K.; writing—original draft preparation, C.C.F.; writing—review and editing, A.F., C.C.F., J.M., A.P., L.V. and K.K.; visualization, K.K.; supervision, J.M.,P.P., L.V.; project administration, A.F., C.C.F and K.K.; funding acquisition, A.F. All authors have read and agreed to the published version of the manuscript.

4. **In which chapter(s) of your thesis can this material be found?**

Chapter Five

5. **e-Signatures confirming that the information above is accurate** (this form should be co-signed by the supervisor/ senior author unless this is not appropriate, e.g. if the paper was a single-author work)

Candidate

[redacted]

Date: 8-03-24

Click or tap here to enter text.

Supervisor/ Senior Author (where appropriate)

[redacted]

Date 8-03-24

Table of Contents

Declaration.. 2

Abstract... 3

Impact Statement 4

Acknowledgements 6

List of Abbreviations 7

UCL Research Paper Declaration Form 8

List of Figures 17

List of Tables 18

Chapter One – Background.. 20

1.1 Introduction.. 20

1.2 The Concept of the Neighbourhood 21

1.3 Neighbourhood Features 23

1.3.1 Neighbourhood Safety and Crime 23

1.3.2 Neighbourhood Greenspaces.. 26

1.3.3 High Streets 28

1.4 Neighbourhoods and Adolescent Health.. 30

1.4.1 Physical Activity 30

1.4.2 Social Isolation and Social Support 31

1.5 Summary.. 34

Research Aims and Objectives 34

Chapter Two – Data and Methods... 34

2.1 The Millennium Cohort Study.. 36

2.1.1 Study Description 36

2.1.2 Study Design... 38

2.1.3 Weighting... 38

2.1.4 Survey content 39

2.1.4.1 Perceived safety... 39

2.1.4.2 Physical Activity 40

2.1.4.3 Social isolation and social support ... 40
2.1.5 Covariates ... 41
2.2 Other Datasets ... 47
2.2.1 Data.Police.UK ... 47
2.2.2 Ordnance Survey ... 47
2.3 Spatial Methodological Considerations ... 48
2.3.1 Geo-linkage methods in longitudinal studies ... 49
2.3.2 Geo-linkage in the MCS ... 49
2.4 Other Methodological Considerations ... 50
2.4.1 Multiple Imputation ... 50
2.4.2 Confounding ... 51
Chapter Three – Subjective and objective indicators of neighbourhood safety and physical activity among UK adolescents ... 52
3.1 Introduction ... 52
3.2 Methods ... 55
3.2.1 Participants ... 55
3.2.2 Safety and Crime ... 57
3.2.3 Physical Activity ... 60
2.2.4 Covariates ... 61
3.2.5 Statistical Analysis ... 62
3.3 Results ... 63
3.3.1 Descriptives ... 63
3.3.2 Self-reported physical activity ... 66
3.3.3 Objective physical activity ... 69
3.3.4 Reported Crime Incidence sub-categories ... 70
3.4 Discussion ... 71
3.5 Conclusion ... 76
Chapter Four – Proximity to greenspaces and physical activity ... 77
4.1 Introduction ... 77

4.2 Methods 80
4.2.1 Participants 80
4.2.2 Greenspaces.. 80
4.2.3 Physical Activity 82
4.2.5 Statistical analysis.. 82
4.3 Results 84
4.3.1 Descriptives 84
4.3.2 Walking time to closest greenspace (of any size) and self-reported PA............... 90
4.3.3 Walking time to closest greenspace (of any size) and device-measured MVPA .. 90
4.3.4 Walking time to closest greenspace (minimum 2 hectares) and self-reported PA 91
4.3.5 Walking time to closest greenspace (min 2 hectares) and device-measured MVPA 91
4.3.6 Secondary analysis 92
4.3.7 Sensitivity analysis 92
4.4 Discussion 100
4.5 Conclusion... 104
Chapter Five – Proximity to high streets and indicators of social isolation and social support 105
5.1 Introduction.. 105
5.2 Methods 109
5.2.1 Participants 109
5.2.2 Proximity to High Streets... 109
5.2.3 Diversity of High Streets.. 111
5.2.4 Social Isolation 112
5.2.5 Social Support.. 112
5.2.6 Covariates.. 113
5.2.7 Statistical Analysis 113
5.3 Results 115
5.3.1 Distance to closest high street.. 118

5.3.2 Diversity index of land uses of the closest high street 120
5.3.3 Sensitivity Analyses 121
5.4 Discussion 122
5.5 Conclusions 125
Chapter Six – Discussion 126
6.1 Overall Findings 126
6.2 Measurement 126
6.3 Neighbourhoods and heath from a UK perspective 128
6.4 Adolescence 129
6.5 Strengths and Limitations 130
6.6 Considerations for future research 132
6.7 Conclusion 133
References 135
Appendices 168
Appendix 1 168
1.1 Accelerometer season of wear 169
1.2 Correlations 169
1.3 Raw (unadjusted) results 169
1.4 Sensitivity analysis 171
Appendix 2 177
2.1 Descriptive characteristics 177
2.2 Sensitivity Analyses 179

List of Figures

Figure 1.1 Diagram illustrating how a neighbourhood may be defined based on different geographical and administrative boundaries…………………………………………………..22

Figure 1.2 – Euclidean distance and Network distance map illustration………………………28

Figure 1.3 – Conceptualisation of high streets, adapted from (Carmona, 2015)...…………..29

Figure 2.1 - Bar chart of achieved sample in the 7 sweeps of MCS…………………………..37

Figure 3.1 - Flowchart to show study analytical sample population…………………………...56

Figure 3.2 – Map showing a postcode centroid in a London LSOA and a one-mile radius around the postcode…………………………………………………………………………..60

Figure 3.3 - Histogram showing distribution of accelerometer measured MVPA at 80% bouts for at least 1 minute time windows…………………………………………………………...63

Figure 3.4 – Panel of graphs showing predicted self-reported days of physical activity (age 14) and objective and subjective indicators of crime (age 11) stratified by sex……………...69

Figure 3.5 – Adjusted predicted number of MVPA minutes (age 14) at IMD crime tertiles (age 11)……………………………………………………………………………………………70

Figure 3.6 – Predictive margins of violent & sexual crimes and self-reported physical activity………………………………………………………………………………………...72

Figure 4.1 – Panel of graphs showing distribution of walking time (mins) to closest greenspace……………………………………………………………………………………..89

Figure 4.2 - Distribution of device-measured moderate vigorous physical activity (MVPA)...90

Figure 4.3 - Mean size and mean walking time to closest greenspace by income quantile...90

Figure 4.4 – Associations between proximity to greenspace and self-reported physical activity and device-measured PA in adjusted random intercept model……………………….96

Figure 5.1 - Visualisation of a hypothetical participant's postcode and two shortest paths to the nearest high street entry points and of three distance decay functions…………………112

List of Tables

Table 2.1 – Overview of data collected at each MCS sweep…………………………………..46

Table 2.2 - Exposures and outcomes, and linked datasets, with year of origin utilised in Chapters 3-5……………………………………………………………………………………47

Table 3.1 - IMD Crime subcategories………………………………………………………… 59

Table 3.2 - Study sample characteristics of covariates at age 14 (n=10913)………………...62

Table 3.3 – Descriptive information for perceived safety and objective crime………………..65

Table 3.4 - Descriptive information for subjective and objective physical activity……………67

Table 3.5 - Associations between objective crime, perceived safety (age 11) and self-reported physical activity (age 14) adjusting for ethnicity, parental education and family income……………………………………………………………………………………………..68

Table 3.6 - Zero-Inflated Poisson Model and Margins for objective and subjective crime (age 11) and accelerometer-measured MVPA (age 14)……………………………………………71

Table 4.1 - Study sample characteristics at age 14 (n = 9873)……………………………..…87

Table 4.2 - Descriptive information for physical activity variables…………………………..……88

Table 4.3 - Associations between walking time to closest greenspace (of any size and min 2ha) and self-reported physical activity at age 14………………………………………….…94

Table 4.4 - Associations between walking time to closest greenspace (of any size and min 2ha) and device-measured moderate to vigorous physical activity at age 14……………..…95

Table 4.5 - Adjusted Random Intercept Model of associations between walking time to closest greenspace of any size and minimum 2 ha and self-reported physical activity and device-measured MVPA at age 14, respectively, stratified by income…………………….….97

Table 4.6 - Adjusted random intercept models for associations between size of closest greenspace and physical activity at age 14 ……………………………………………….…98

Table 4.7 - Adjusted Random Intercept Model of associations between walking time to closest greenspace of any size and minimum 2 ha and self-reported physical activity and device-measured MVPA at age 14, respectively, stratified by urban/rural……………………99

Table 4.8 - associations between categories of walking time to closest greenspace (of any size and min 2ha) and physical activity at age 14……………………………………………100

Table 5.1 - Study sample characteristics (n=5582)……………………………………………117

Table 5.2 - Distributions of indicators of social isolation at age 17 years …………………..118

Table 5.3 - Distributions of Social Provisions Scale (SPS) items used to capture social support, age 17 years……………………………………………………………………………..118

Table 5.4 - Associations between distance (km) to closest high street and indicators of social isolation and social support………………………………………………………………………120

Table 5.5 - Associations between diversity of land use of closest high street and indicators of social isolation and social support………………………………………………………………121

Chapter One – Background

1.1 Introduction

Adolescence is a formative stage of life, characterised by social, cognitive, and physical changes and is generally defined as ages 10-19 years (World Health Organisation, 2014). During this critical period many health behaviours are initiated, which can impact on health and wellbeing into adulthood (Sawyer et al., 2012). Five of the top 10 risk factors for the total burden of disease are problems that are initiated or shaped in adolescence, including physical activity (Kessler et al., 2005). In addition, social relationships during adolescence become more complex, with adolescents typically spending less time with parents and more time with peers. Adverse experiences during adolescence, such as social isolation, can be detrimental to development and lead to poorer health outcomes in adulthood (Almeida et al., 2021; Danese et al., 2009).

The multitude of changes that occur during this period make adolescents particularly susceptible to their environment. It is increasingly understood that the neighbourhood physical environment exerts significant effects on health and that individual behaviours are influenced by the context in which they occur. Investigating contextual determinants of health is an important public health concern, especially given that environmental and neighbourhood features are modifiable. The rapid period of changes makes adolescence a time of opportunity for preventative interventions to improve health across the life course. Given that health and health behaviours track from adolescence into adulthood, health during adolescence is important for health of the whole population (Viner, 2013).

1.1.1 Thesis structure

The thesis is organised as follows:

1. Chapter One: this chapter provides general background information relating to the neighbourhood environment. It will discuss the key exposures explored in this thesis namely: crime and safety, greenspaces and high streets. It will also provide context for physical activity and social isolation in adolescences.
2. Chapter Two: this chapter provides a detailed description of the birth cohort used throughout this thesis, including sampling methods and descriptions of key variables. It will also lay out important spatial methodological considerations.
3. Chapter Three: this chapter describes the first empirical study and focusses on the outcome of physical activity, utilising both subjective and objective measures.
4. Chapter Four: in this chapter, I investigate associations between proximity to greenspace and physical activity outcomes.

5. Chapter Five: in the final empirical chapter, I study the role of high streets in predicting social isolation outcomes.
6. Chapter Six: this chapter provides a general discussion. It discusses the key findings of this thesis in relation to one another.

Chapters Three and Five are accompanied by extensive sensitivity analysis, which can be found in the appendix.

1.2 The Concept of the Neighbourhood

Investigating associations between the neighbourhood environment and health outcomes requires defining the neighbourhood's physical characteristics and making the concept of the 'neighbourhood' measurable (Duncan & Kawachi, 2018). In other words, defining neighbourhood boundaries to evaluate the features within them, such as greenspaces, and the impact of these features on residents and those who work there (Duncan & Kawachi, 2018). Currently, there is no universal definition of a neighbourhood, and a physical, social or subjective approach may be taken. A physical or territorial approach views neighbourhoods as independent geographical entities, for example, using administrative units such as electoral wards or neighbourhood boundaries defined by physical landmarks. There can be considerable variation in the environmental attributes captured within an administrative unit depending on the scale of aggregation. For example, smaller census units like Output Areas are potentially preferable when studying effects on physical activity as neighbourhood features, such as greenspace, are aggregated in units closer to participants home address (Moudon et al., 2016). Figure 1.1 illustrates how neighbourhoods may be defined based on different administrative boundaries. Physical, or objective, elements of the neighbourhood can be studied using observable data and measures of neighbourhood structure, such as greenspace, public infrastructure, housing density, crime rates and poverty index. Objective measures can reflect the actual characteristics of the neighbourhood but do not allow for how and when residents are exposed to and interact with their local environment (L. Zhang et al., 2019).

Alternatively, a social approach may consider neighbourhoods in terms of the social interaction patterns of residents (Campbell et al., 2009). This approach considers neighbourhoods according to social networks, social cohesion and cultural norms and behaviours (Baffoe, 2019). A social approach to neighbourhoods may be important when considering outcomes such as social isolation. Nonetheless, geographical units or boundaries and social dimensions of the local environment may not be consistent with how individuals define and view their own neighbourhood. Subjective definitions of neighbourhoods rely on individuals' perceptions of their surroundings and therefore may be divergent across residents. Indeed, residents of the same geographical area may utilise different features of the environment, socialise in different networks and rely on different forms of transport (Campbell et al., 2009). Ideally, neighbourhoods should therefore be considered subjectively and objectively. Subjective elements are based on the social context and resident perceptions which characterise their experience of the neighbourhood, such as perceived safety. However, as will be discussed in this thesis, incorporating both subjective and objective measures of the neighbourhood is a methodological challenge.

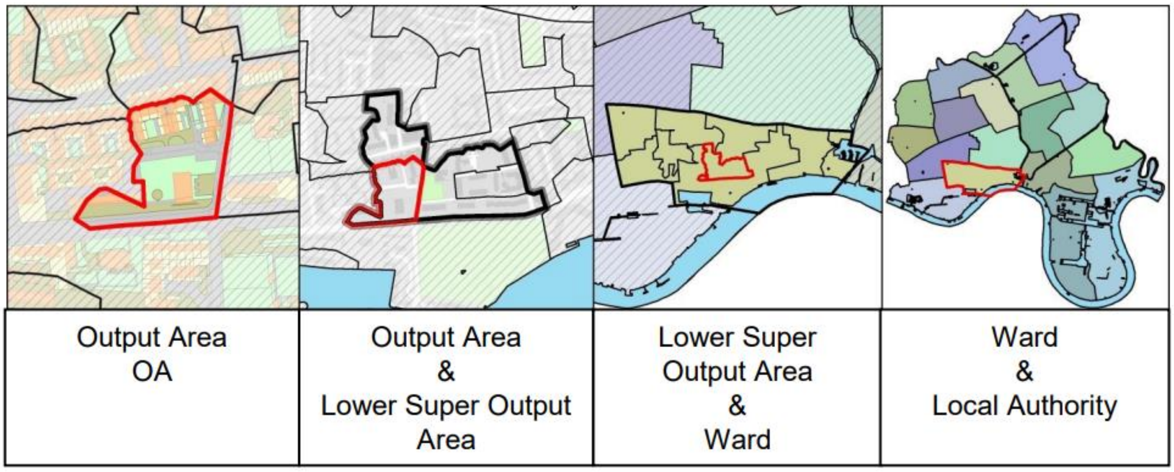

Figure 1.1 - diagram illustrating how a neighbourhood may be defined based on different geographical and administrative boundaries in Great Britain. Output Areas (OAs) are the smallest statistical unit available from census data, LSOAs are constructed out of OAs. Both OAs and LSOAs can be aggregated up into wards. Diagram from (Tower Hamlets Council, 2013).

The built environment and urban planning literature offers conceptualisation of the neighbourhood from a physical perspective. 'The Death and Life of Great American Cities', the essential text on urban planning by Jane Jacobs, pinpointed four conditions for vibrant neighbourhoods: diversity of use (e.g. a mix of commercial and residential use), high connectivity, buildings diverse in age and appearance and high building density (Jacobs, 1961). Jacobs posited that each of these conditions work together to facilitate feelings of safety, social interaction and pedestrian activity. Indeed, physical environment characteristics (such as greenspaces, access to amenities and crime) have been associated with increased social interaction and greater sense of community (Lachowycz & Jones, 2013; Mehta, 2009).

Important to note for the purpose of this thesis is that adolescent perceptions and usage of their neighbourhood are distinct from those of adults. Many studies have reported adolescents' preferences for commercial areas, areas near home and greenspace as areas for meeting others (C. Clark & Uzzell, 2002). Some research has suggested that older adolescents (17+ years) utilise the neighbourhood less frequently than younger adolescents (Hendry et al., 1993). Older adolescents have also been found to perceive their neighbourhood less positively and have fewer social or activity ties to the neighbourhood than younger adolescents (Schiavo, 1988). It is therefore not possible to generalise findings from adult studies to adolescents; further research into how adolescents interact with and perceive the neighbourhood is necessary.

1.3 Neighbourhood Features

1.3.1 Neighbourhood Safety and Crime

Crime and violence in the neighbourhood have been identified as key stressors that likely mediate the association between neighbourhood characteristics and poorer health outcomes (Lorenc et al., 2012). Several mechanisms have been proposed to describe this relationship. For example, increased neighbourhood crime may lead to disruption of the stress response or cause systemic inflammation in the body (Do et al., 2011; Nazmi et al., 2010). Furthermore, areas of higher crime may result in avoidance behaviour, with individuals minimising physical activity and social activities which can negatively impact physical and mental health outcomes (Baranyi, 2020; Lorenc et al., 2012).

Environmental criminology argues that criminal activity is closely related to the urban environment and that some environments are safe whilst others are not (Kubrin, 2009). The non-random nature of crime, namely that crime does not occur equally across neighbourhoods, is well accepted. The social disorganisation theory, developed in the US by (Shaw & McKay, 1942), considered why rates of crime differ across neighbourhoods by exploring the economic and social characteristics of communities. Shaw and McKay argued that crime was a normal response to characteristics of the community and concluded that crime and 'delinquency' was tied to neighbourhoods. In particular, distribution of 'delinquency' in Chicago neighbourhoods was linked to the location of commercial and industrial areas and community demographics. The social disorganisation theory argues that disorganisation is a property of neighbourhoods, not individuals. Whilst socially organised communities' benefit from social cohesion and integration which help to lower crime rates; socially disorganised communities lack informal social control contributing to increased crime (Kubrin, 2009). Characteristics thought to lead to disorganised neighbourhoods include residential mobility, unemployment, poverty and ethnic heterogeneity (Shaw & McKay, 1942). Communities with high residential mobility, and therefore supposed weaker social ties due to people continually moving in and out, have been linked to higher crime rates. Racial heterogeneity has also been reported as a predictor of neighbourhood crime, partly attributed to a conflict of norms leading to a lack of informal social control (Kubrin, 2000). Whilst the social disorganisation theory was developed in the US, evidence suggests that concentrated neighbourhood disadvantage is also associated with exposure to crime in a UK context (Lymperopoulou et al., 2022). Moreover, area characteristics, including percentage of renters and poverty, have been linked to property crime in Britain (Tseloni, 2006). However, ethnic heterogeneity and residential turnover may be less relevant in the UK landscape (Lymperopoulou et al., 2022). More research is required to elucidate the validity of the social disorganisation theory from a UK perspective.

The routine activity theory has heavily influenced crime and space research. In brief, the routine activity theory posits that for a crime to occur there must be a convergence at a specific location of: a motivated offender, a suitable target or victim and a lack of a guardian or protector to prevent the crime (Cohen & Felson, 1979). The focus of this theory is not on the figure of the criminal but rather that crime is an event related to space and time (Miró, 2014). The theory argues that crimes occur when the routine daily activities of an offender and victim converge. The routine activity theory therefore supports the idea that walkable and accessible neighbourhoods, where the presence of people to act as guardians is more likely, will restrict crime (Foster et al., 2010).

The spatial elements of both the social disorganisation theory and routine activity theory has led to attempts to integrate both theories. Indeed, this line of research has shown that variables representing both social disorganisation and routine activities can predict victimisation rates (Andresen, 2006; W. Smith et al., 2000).

1.3.1.1 Fear of Crime

Fear of crime can be described as an emotional response or feeling of anxiety towards crime or symbols associated with crime (Ferraro, 1996). To reduce their fears people may respond by constraining their behaviour, for example by avoiding certain places deemed as dangerous, or by employing additional security and protective measures. This often includes minimising outdoor physical activity, such as running or cycling, due to safety fears, especially in children and women (Carver et al., 2008; Kilgour & Parker, 2013). Fear of crime has been shown to impact quality of life and negatively impact mental health (Hale, 1996; Stafford et al., 2007). Other consequences of fear of crime include the fracturing of a sense of community and widening inequalities as those more socioeconomically advantaged are better able to protect themselves and their property (Hale, 1996).

Fear of crime is influenced by a multitude of factors, one of course being actual crime rates. However, there is often a discord between crime rates and perception of safety and fear. Fluctuations in regional or area level crime does not necessarily lead to mirrored fluctuations in concerns or fear of crime in that area (Curiel & Bishop, 2016).

It might be assumed that individuals that personally experience higher levels of crime and victimisation would report increased fear levels. Indeed, research suggests that previously being a victim of crime more than doubles odds of experiencing fear around crime (Tseloni, 2007). However, being a victim of crime is rarer than the phenomenon of experiencing fear of crime (Leyland & Groenewegen, 2020). In other words, high levels of fear are often reported by people that suffer little to no victimisation. Demographic factors, such as gender, age and ethnicity, may well affect perception of safety. Previous research has reported that women, the elderly and ethnic minorities tend to be more fearful of neighbourhood crime (Brunton-Smith & Sturgis, 2011; Carro et al., 2010).

Women’s fear of crime has been reported as being up to three times greater than men’s rate of fear (Snedker, 2012; Stanko, 1993b). This is even though men are more likely to be the victims of reported crimes in public spaces; sometimes referred to as the ‘gender-fear paradox’ (W. Smith & Torstensson, 1997). There are several theories and possible explanations for gender differences in the fear of crime including the (disputed) perception that women are more sensitive to risk and less able to defend themselves. Feminist criminology presents an alternative explanation arguing that women’s heightened fear of crime is reflective of an underlying fear of sexual assault (Reid & Konrad, 2004). Moreover, it is important to note that sexual assault is under-reported and that crime statistics do not accurately portray violence against women (Ministry of Justice et al., 2013). However, crime statistics do show that whilst men are more often victims of crimes such as robbery; women are almost exclusively the targets of sexual assault and rape (Snedker, 2012). Researchers have argued that the serious emotional, psychological and physical ramifications of rape escalate women’s concerns of all crimes (Gordon & Riger, 1989). It is also argued that women’s fear of crime is related to their everyday experiences of being made to feel uncomfortable in public spaces. The very common experiences of catcalling, objectification, unwanted attention and sexual harassment serve to reinforce and perpetuate women’s fear as they manoeuvre through public places (Butcher, 2020).

The sex differences seen in the fear of crime literature highlight how particular aspects of the neighbourhood environment important for health can vary according to resident characteristics, including sex. Indeed, gender norms may drive individuals into behaviours that affect their environmental exposure differently (WHO/Europe, 2009).

1.3.2.1 Measuring safety and crime

Studies assessing neighbourhood safety and crime often focus on either objective or subjective (perceived) measures. Objective crime measures include administrative records and police recorded crime incidents. UK studies have also used the Index of Multiple Deprivation, which contains a crime subdomain, to capture crime rates at the Lower Super Output Areas (LSOAs). Subjective crime can be measured with surveys where participants self-report their perceptions of crime and safety in their neighbourhood. The relative merits and drawbacks of subjective and objective measures will be explored further in Chapter Three – Subjective and objective indicators of neighbourhood safety and physical activity among UK adolescents.

1.3.2 Neighbourhood Greenspaces

Greenspace is a term used to describe either maintained or unmaintained environmental areas including woodlands, nature reserves, urban parks and outdoor sports facilities (Barton & Rogerson, 2017). There is substantial evidence that availability of and access to greenspaces is beneficial for a wide range of health outcomes, including cardiovascular mortality, obesity and self-reported overall health (Twohig-Bennett & Jones, 2018) and health behaviours such as physical activity (Van Hecke et al., 2018).

Three possible mechanisms have been suggested to explain the relationship between green spaces and health. Firstly, green spaces may facilitate participation in physical activity by, for example, providing greater opportunities for walking or cycling (Kaczynski & Henderson, 2007). Some evidence also suggests that exercising in a natural environment compared to indoors has greater benefits on self-reported mental wellbeing (Thompson Coon et al., 2011). A second proposed hypothesis posits that public green spaces promote social interaction thereby improving wellbeing (Maas et al., 2009). For example, green spaces provide meeting places for planning interactions but also allows for more opportunities for unplanned social engagement. It is known that social contact can have a positive impact of stress levels and mood (Heinrichs et al., 2003). Thirdly, contact with natural spaces may aid with stress reduction and improve mental fatigue (Wood et al., 2017). Experimental studies have shown that being in green spaces reduces physiological signs of stress including reducing blood pressure and lowering sympathetic nerve activity (Park et al., 2010). Other explanations have also been put forward, for example: the mitigation of green spaces against air and noise pollution and increased exposure to micro-organisms necessary for immune system development (Markevych et al., 2017; Rook, 2013).

Quality, design and maintenance of green spaces are important considerations for people's perceptions of them. Quality of green spaces may refer to the ecological features of the space, including the level of biodiversity. Quality also refers to the condition of the area, such as how well maintained the space is, the amenities available and the attractiveness of the area. Studies have shown that the atheistic of parks is an important factor in people's usage of the space. Poor quality footpaths, unkept areas, litter and vandalism negatively affect perceptions and may deter usage (McCormack et al., 2010). Moreover, safety also plays a key role in the usage of parks. Lack of lighting, presence of certain users such as groups of teenagers and drug users and secluded paths may contribute to perceived lack of personal safety and therefore discourage usage (McCormack et al., 2010; Ries et al., 2008).

1.3.2.1 Measuring greenspace

Studies exploring the link between green spaces and health have varied greatly in their methodology. For example, a body of research has focused on the amount of green space within an administrative boundary (Alcock et al., 2014), taking a geographical approach of the concept of the neighbourhood. A common measure of greenspace in a neighbourhood in the UK literature is the Generalised Land Use Database (GLUD) which groups land use into 9 categories with one of these categories being green space. Some studies have used this measure to calculate percentage of land area classified as green space in a specific administrative unit (Dennis & James, 2017). This approach, however, does not consider the specific type or use of green space nor any green space that may be just outside an administrative boundary.

Access to green spaces can also be measured in variety of ways including Euclidean (straight-line) distance and network distance. Network distance measures make use of Geographical Information Systems (GIS) to estimate real-world travel distances based on representation of road and path networks (Mears & Brindley, 2019). Straight-line distance may overestimate access to green spaces by not considering travel routes available – or barriers to reach them, such as busy roads or railways lines - and is therefore a less useful measure of access to green spaces. Figure 1.2 illustrates the difference between using Euclidean vs. network distance measures. Although the optimal exposure and proximity to green spaces for health is not known, it has been recommended by Natural England, and supported by the WHO, that green spaces should be available within 300 metres of homes (Natural England, 2023; WHO Regional Office for Europe, 2016).

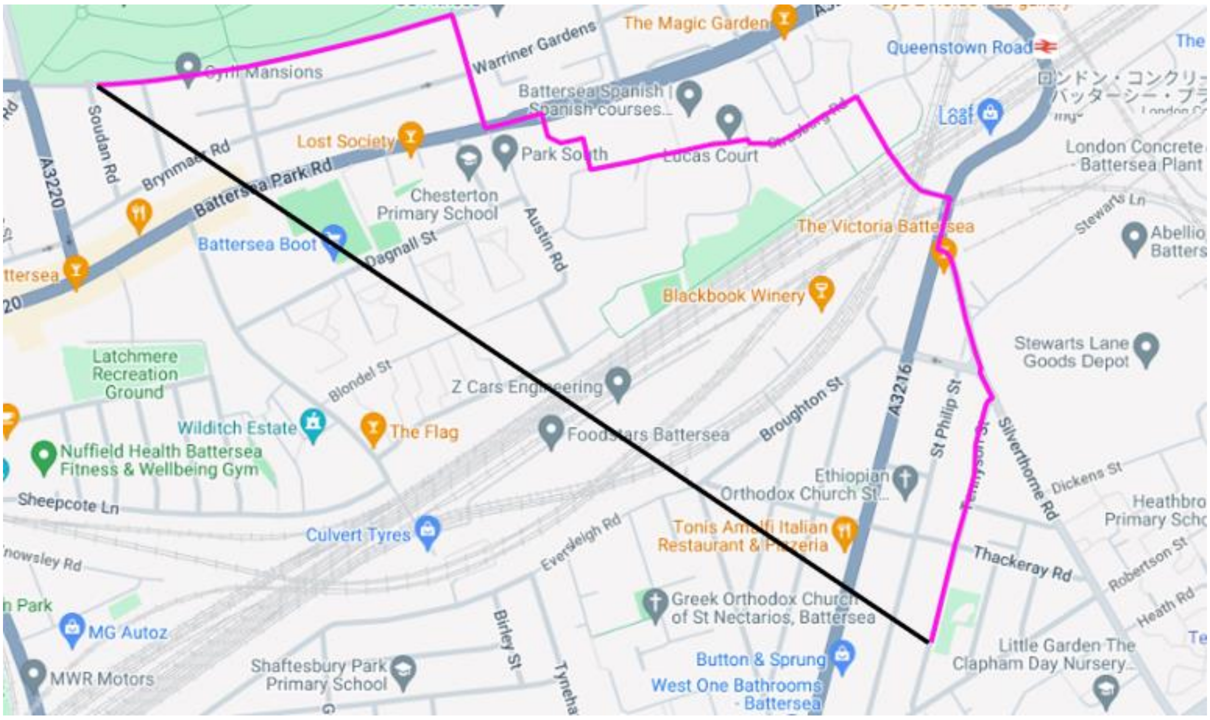

Figure 1.2 - Euclidean distance (black line) shows straight line or as-the-crow-flies distance between two points. Network distance (pink line) takes into account real-world walking routes. In this image, Euclidean distance does not consider railway lines, underestimating total distance.

1.3.3 High Streets

High streets are defined by the Office for National Statistics (ONS) as a cluster of 15 or more retail addresses within 150 metres. The ONS has calculated that there are around 7,000 high streets in Great Britain, with over 1,200 in London alone. Although often thought of as simply retail based, only a third of high street addresses belong to retail. Across Britain, over half of high street addresses are residential, around 10% belong to offices and 2-3% of addresses are community or leisure facilities (Holgate, 2020). As of 2017, 16% of the British population lived on or within 200 metres of a high street. The proportion of people able to easily walk to a high street varies greatly across the country. London, Portsmouth, Liverpool, Southend-on-Sea and Brighton are some of the areas where over a third of residents live within easy walking distance of a high street (Holgate, 2020). In contrast, rural areas have lower proportions of their residents able to walk to a high street.

A typical high street can be considered a dynamic socio-spatial entity. Griffiths et al., (2008) argue that high streets can be characterised as attractors of activity (either commercial or community-based) and as routes for through movement. High streets are often geographically well connected to the surrounding residential grid, channelling movement from the residential streets (Hillier, 1999). They are also often hubs for transport, including rail, bus and, in the case of London, the tube. The high street can be thought of as an identifiable public space and centre for local identity; for example, high streets often feature landmark features determined by their historic or distinctive appearance (P. Jones et al., 2007).

As a public space for the community, high streets play an important role in fostering social contact and encounters. Indeed, high streets can be thought of as mixed-use urban corridors and have been conceptualised by (Carmona, 2015) as is illustrated in Figure 1.3.

Physical Fabric

- Infrastructure
- Trees and landscape
- Street furniture
- Buildings

Exchange

- Social space
- Economic space
- Culture space
- Community space

Movement

- Pedestrians
- Public transport
- Private cars
- Goods/service vehicles

Real Estate

- Retail
- Civic venues
- Residential
- Workplaces
- Entertainment

Figure 1.3 – conceptualisation of high streets, adapted from (Carmona, 2015).

Furthermore, as the high street serves many functions, it has a wide range of users. For example, Jones et al., (2007) identified typical high street users including striders (those simply passing through), workers, customers buying goods or services and socialisers. Indeed, a survey of Londoners revealed that 45% of high street users' primary use was non-retail related (We Made That & LSE Cities, 2017).

It is argued that high streets should enable basic needs, including access to affordable and nutritious food, but also promote healthy choices. This would involve access to health services, cultural amenities and leisure centres. Furthermore, high streets can support wellbeing by providing opportunities for social activities and community support plus offer an inclusive place for all. However, across the UK there is a marked difference between the range of benefits high streets can offer. The Royal Society for Public Health (RSPH) ranked high streets in over 70 towns and cities in the UK based on the presence of health promoting vs health harming, or hazardous, businesses and features (Royal Society for Public Health, 2015). For example, libraries, health services, leisure centres and museums were classified as beneficial whilst payday loan shops, bookmakers and fast-food takeaways were deemed as hazards. Towns with the unhealthiest high streets, such as Grimsby and Blackpool, were also areas with worse than national average premature mortality. Comparatively, areas with the healthiest high streets, such as in Shrewsbury and Canterbury, experience lower rates of deprivation and better health outcomes (Royal Society for Public Health, 2018). However, there is limited research on the possible mechanisms between healthy high streets and health behaviours and outcomes.

1.4 Neighbourhoods and Adolescent Health

Physical activity and social isolation are integral to overall health and wellbeing. It is well-accepted that physical activity can prevent non-communicable diseases and improve mental health, quality of life and wellbeing (World Health Organization, 2022). Benefits of physical activity apply to all systems of the body, including musculoskeletal, respiratory, hormonal and immunological. Social isolation is a recognised determinant of poor mental health with evidence to support a pathway from social isolation to loneliness and subsequent depression and anxiety symptoms (Kirkbride et al., 2024). Social network structure and function are strongly intertwined with anxiety and depression symptoms in the general population (Kirkbride et al., 2024).

1.4.1 Physical Activity

There is consistent evidence of the health benefits of regular physical activity in children and youth. Regular physical activity is a protective factor against non-communicable diseases (NCDs). It is estimated that 7-8% of cases of cardiovascular disease, depression and dementia could be prevented with greater physical activity (World Health Organization, 2022). Physical activity refers to all movement including movement during leisure time, travelling to and from places or as part of a person’s work. Whilst all types of movement confer health benefits, evidence suggests that moderate and vigorous physical activity may provide the most benefit (Janssen & LeBlanc, 2010). However, the World Health Organization estimates that 80% of adolescents globally are insufficiently physically active (World Health Organization, 2022). Current UK guidelines recommend children and young people (5-18 years) achieve 60 minutes of moderate to vigorous physical activity every day (Davies et al., 2019).

Physical activity in childhood and adolescence is particularly important given that evidence suggests inactivity in youth tracks into adulthood (Telama et al., 2005). Research also indicates that participation in physical activity declines throughout adolescence; a British longitudinal study reported that over 10 minutes/day of physical activity every year is replaced by sedentary time during early adolescence (Corder et al., 2015).

The neighbourhood environment is one element that acts as a determinant of physical activity. Research suggests a relationship between aspects of the neighbourhood, such as recreational facilities, residential density and traffic volume, and physical activity in youth (Ding et al., 2011). Studies assessing associations between physical activity and the neighbourhood often consider accessibility. Accessibility can be thought of as the ability to reach destinations and desired services and is impacted by path and road network connectivity and the geographic distribution of destinations (Witten et al., 2011). For instance, greater street connectivity, and therefore greater number of routes, is posited to positively influence walking and cycling. Studies have shown that neighbourhood walkability, residential density and access to recreation facilities are positively associated with moderate to vigorous physical activity in adolescents (Loh et al., 2019).

Some aspects of the neighbourhood environment can act as barriers to physical activity. Crime and safety (including traffic safety), poor aesthetics and inadequate facility conditions have been associated with reduced physical activity (Pedersen et al., 2022; Salvo et al., 2018). However, associations between the neighbourhood environment and physical activity are inconsistent which may be due to modes of measurement in both physical activity and neighbourhood features (Brownson et al., 2009). For example, the neighbourhood environment may be measured via interviews or questionnaires which capture resident perceptions of access and barriers to the neighbourhood feature of interest. Alternatively, neighbourhood features may be objectively measured with the use of datasets and Geographical Information Systems (GIS). Similarly, physical activity may be captured with the use of devices, such as accelerometers, or self-reported. These approaches will be discussed in further detail in Chapter Three – Subjective and objective indicators of neighbourhood safety and physical activity among UK adolescents.

1.4.2 Social Isolation and Social Support

The importance of social relationships has been recognised as crucial for emotional and behavioural development. Social relationships play a key role in mental health and wellbeing by providing sources of support, companionship, and opportunities to share common interests. Indeed, those with mental ill health experience greater feelings of loneliness and a smaller social network size (Meltzer et al., 2013; Palumbo et al., 2015; Santini et al., 2021). The quality and quantity of social relationships has been associated with long-term effects on health across the life course (Umberson & Karas Montez, 2010).

1.4.2.1 Social Isolation

Social isolation is not synonymous with loneliness, but there is a lack of clarity around these concepts and how they should be defined and measured. Social isolation can be considered an objective concept, centred on the number and frequency of social interactions (Holt-Lunstad & Steptoe, 2022). Loneliness is a negative subjective feeling when an individual perceives their quality or quantity of social connection to be insufficient (Perlman & Peplau, 1984). Loneliness can be experienced by those with frequent social contact and connections whilst those with very few social connections can feel satisfied and not feel lonely. Social isolation is typically captured using indicators including frequency of social activity, marital status, cohabitation status and social network size. Researchers of childhood social isolation may consider peer rejection or withdrawn behaviour at school. Loneliness, however, can be measured via questionnaires including the UCLA Loneliness Scale which includes items such as “How often do you feel left out?” (Russell, 1996).

Social isolation in adulthood is associated with an increased risk of mortality (Holt-Lunstad et al., 2015a). Several mechanisms have been proposed to explain how social isolation negatively effects health including: poor sleep, increased inflammation, and activation of the hypothalamic pituitary adrenocortical axis (Cacioppo et al., 2015; Cacioppo & Hawkley, 2003; McLay et al., 2021). Children that experience social isolation are at increased risk of depression, both concurrently and in later life (Loades et al., 2020), in addition to physical health problems including obesity and hypertension (Caspi et al., 2006).

Although social isolation is often thought of as a phenomenon of older age, children and young people can experience social isolation, often in a different way than adults, which can be particularly detrimental to cognitive development (Orben et al., 2020). Adolescence is a critical period of development when peer relationships become increasingly important. Peer rejection and bullying are risk factors for depression in adolescence whilst friendship is a positive predictor of resilience in adolescence and early adulthood (B. Platt et al., 2013; Van Harmelen et al., 2017). Exclusion from a social group involves rejection from individuals or the peer group due to individual differences such as being shy or social deficits. Rejection may also occur due to prejudice against characteristics such as ethnicity, gender, religion or culture (Killen et al., 2013). Shy or anxious children are often socially rejected by their peers and research suggests that children who do experience rejection are more likely to become further withdrawn overtime, exacerbating shyness and isolation (Oh et al., 2008). Those with low income are also at greater risk of social isolation, which may be due to lack of financial resources to participate in entertainment and activities with their friends (Alsadoun et al., 2023; M. Stewart et al., 2009).

1.4.2.2 Social Support

Social support can be thought of as the social resources that individuals perceive to be available to them (Gottlieb & Bergen, 2010). Evidence suggests that positive social support can enhance resilience to stress and improve wellbeing whereby those that feel a strong sense of support seem better able to cope with adversity (Ozbay et al., 2007). Close relationships tend to offer different types of support, such as emotional and informational. The optimal type and source of social support may depend on age group and developmental stage. For example, it has been found that parental support is more important during early, rather than late, adolescence (Stice et al., 2004). Furthermore, emotional support from friends and informational or practical support from parents predicts wellbeing in adolescents (McGrath et al., 2009).

The social provision theory considers the function of social relationships and the role of, for example, friends, family or romantic partners (Weiss, 1974). This theory proposes six types of social provisions: attachment, integration, opportunity of nurturance, reassurance of worth, reliable alliance and guidance. Multiple types of support, or provision, may be provided by a single close relationship but the theory posits that individuals need all six provisions for optimal wellbeing. The theory forms the basis of the Social Provisions Scale (SPS), a multidimensional measure of social support that aligns with the six types of provisions (Cutrona & Russell, 1987). The SPS has been specifically validated for use in adolescence (Osmane et al., 2021) and is employed by the seventh sweep of the Millennium Cohort Study, and in Chapter Five – Proximity to high streets and indicators of social isolation and social support of this thesis.

1.4.2.3 Social isolation, social support and the neighbourhood

The neighbourhood for many young people is a key part of everyday life and may determine social interactions. Social isolation has been linked to aspects of the neighbourhood. For example, a study from the US reported that living in an unsafe neighbourhood, measured as prior exposure to community violence, was associated with a reduction in perceived social support and social interactions (Tung et al., 2019). Research from Denmark has shown that adult residents of deprived neighbourhoods are at increased risk of loneliness and social isolation, although this study did not specifically pinpoint which aspects of the neighbourhood are most damaging (Algren et al., 2020).

Social isolation has been associated with being geographically isolated. Rural communities tend to have fewer health and social services, retail outlets and limited public transport, which may put rural residents at risk of social isolation (De Koning et al., 2017). A survey conducted in Oxfordshire, UK, identified a lack of informal places to meet as a contributor to rural isolation in youth (Community First Oxfordshire, 2022). However, a UK-wide study reported that housing density, typical of urbanised areas, was associated with increased odds of social isolation in adults (Lai et al., 2021). The relationship between social isolation and the neighbourhood is complex and there remains a lack of robust evidence on the area, as outlined in a recent systematic review (T. Moore et al., 2018).

1.5 Summary

This chapter provided context for the thesis in terms of the neighbourhood features that will be explored (crime and safety, greenspace and high streets) and health outcomes of physical activity and social isolation and support. This chapter placed these neighbourhood features and health outcomes within the context of adolescence. This chapter also highlighted important gaps in the literature, including the lack of studies exploring health in adolescence from a UK spatial perspective.

Research Aims and Objectives

The overall aim of this thesis is to explore whether the features of the neighbourhood environment influence physical activity and social isolation outcomes in an adolescent population.

To achieve this aim, I use epidemiological methods alongside aspects of spatial and urban science and health geography. By employing a multidisciplinary approach, I aim to bring relevant aspects of these disciplines together to inform research questions, analytical methods, and better understand the UK spatial landscape in a health context. For example, I used geo-coded data and uses measures generated from Geographical Information Software (GIS) to better capture the neighbourhood features of interest.

This thesis recognises that the neighbourhood is multidimensional. The following chapters explore how the neighbourhood exposures of crime and safety, greenspace, and high streets may be important for adolescence. This thesis focuses on outcomes in adolescence, specifically, physical activity and social isolation and social support outcomes.

Research objectives:

1) To explore how neighbourhood crime and perceived safety impact physical activity behaviours. This study also explores the complexities around using objective and subjective measures for both exposure and outcomes.
2) To explore whether greenspace plays a role in physical activity behaviours, whilst carefully considering socio-economic confounding factors.

3) To investigate whether high streets, as a proxy for areas of social encounter, activity, and interaction, are important for social isolation and social support.

Results from this thesis will offer important insight into the UK neighbourhood environment, relevant to health in adolescence.

Chapter Two – Data and Methods

2.1 The Millennium Cohort Study

This thesis consists of secondary data analysis of the Millennium Cohort Study (MCS), a longitudinal study of children born across England, Wales, Scotland and Northern Ireland between 2000 and 2002. The MCS was set up following a 30-year gap since the last national birth cohort study (British Cohort Study 1970) and increased policy interest in the 'early years' from the UK government (Connelly & Platt, 2014). The MCS is based at the Centre for Longitudinal Study (CLS) at the Institute of Education, University College London.

2.1.1 Study Description

MCS includes a sample of all children born between 1 September 2000 and 31 August 2001 (for England and Wales), and between 24 November 2000 and 11 January 2002 (for Scotland and Northern Ireland), living in the UK at age 9 months, and eligible to receive child benefit at that age and remained living in the UK at each follow-up sweep (Plewis, 2007). The Child Benefits register was used to identify eligible children. Child Benefits is an almost universal payment, with only children with recent or temporary immigration status ineligible (Plewis, 2007). The first sweep of the MCS had a total of 18,552 families, with 18,818 cohort members (246 twins, 10 triplets and 6 families with two singletons who were eligible to participate). In the second sweep, conducted during 2003-4, 1,389 new families were contacted and asked to join the survey, of which 692 contributed. The response rate at MCS2 was 78%, with 15,590 productive respondents out of 19,941 (Ketende, 2010).

The third sweep took place between 2005-6 when cohort members were aged 5; with an issued sample of 18,528 out of which 15,246 were productive. The issued sample compromised those that had responded to either of the previous surveys, minus 718 families ineligible due to death, emigration or sensitive family circumstances (Centre for Longitudinal Studies, 2020b).

The fourth sweep of MCS took place during 2007-8 when children were aged around 7 years old. There was a total of 19,244 potential families, however, 2,213 were ineligible due to: death or emigration (n= 362), permanent refusal (n = 1,705), permanent untraced (n = 136) and sensitive family circumstance (n=10). Therefore, MCS4 had an issued sample of 17,031 with 13,857 productive families with 14,043 cohort children (Centre for Longitudinal Studies, 2020b).

The fifth sweep of MCS took place between 2012-13 when children were aged 11 years. There were 19,244 potentially eligible families, however, 2,851 of those were not issued due to death, emigration, refusal, or sensitive family situations. The issued sample was 16,393 of which there were 13,469 cohort members in 13,287 productive families (Centre for Longitudinal Studies, 2020b).

The sixth survey was carried out when cohort members were 14 years old between 2015-16. There were 19,243 families potentially eligible with 3,828 families not issued due to death or emigration, permanent refusal, untraceability, sensitive situations. The issued sample was 15,415 and of these 11,726 families took part, resulting in 11,872 cohort members (Fitzsimons, 2020).

The seventh sweep, when cohort members were 17 years old, took place in 2018-19. Out of the original 19,243 potentially eligible families, 4,747 were not issued, leaving the issued sample at 14,496. Of these, 10,625 families responded, resulting in 10,757 cohort members (Fitzsimons et al., 2020).

During the 2020 Coronavirus pandemic, the Centre for Longitudinal Studies ran a series of surveys for five national cohort studies, including the MCS (M. Brown et al., 2021). Three waves of surveys were carried out aiming to gain insights into the lives of study participants during the COVID-19 pandemic. MCS cohort members were invited via email to participate in the first survey, of which there were 2,645 responses. Postal invitations were sent out for the second and third waves; with 3,274 and 4,474 responses respectively. Figure 2.1 illustrates the achieved sample for MCS sweep. The next sweep of the MCS is currently underway, with cohort members around age 23. Data will be available from 2025 via the UK Data Service.

The analytic sample for each empirical study is outlined in the respective chapters.

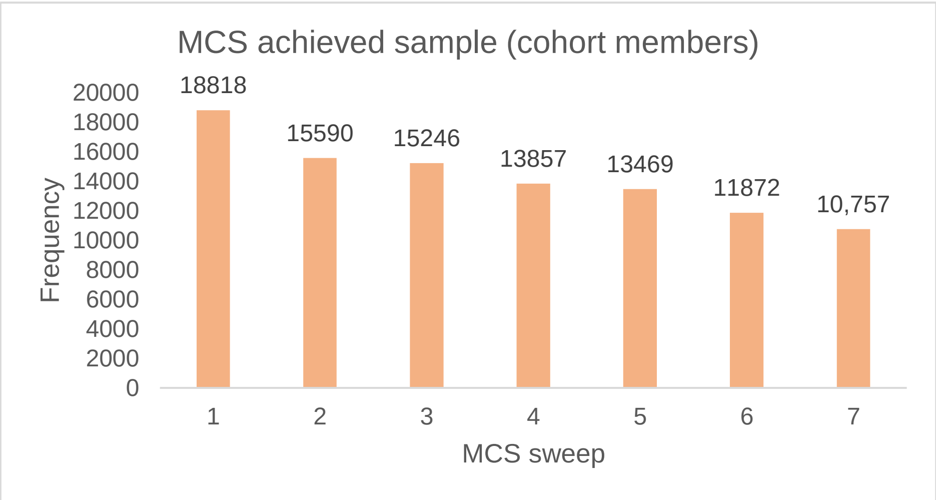

Figure 2.1 Bar chart of achieved sample in the 7 sweeps of MCS

2.1.2 Study Design

The MCS was designed to be representative of the UK population whilst certain sub-populations were intentionally over-sampled, specifically: children living in disadvantaged areas, ethnic minority backgrounds and those living in the smaller UK countries. This over sampling was intended to ensure sufficient sample sizes for analysis of ethnic minorities and those from disadvantaged backgrounds (Connelly & Platt, 2014). For England the population was stratified into three strata:

1) Ethnic minority stratum: children living in an electoral ward with at least 30% of the population were either Black (Black Caribbean, Black African or Black other) or Asian (Indian, Pakistani or Bangladeshi) as reported in the 1991 census.
2) Disadvantaged stratum: children not in the ethnic minority stratum but in the poorest 25% of electoral wards, measured by the Child Poverty Index.
3) Advantage stratum: children living in electoral wards other than those who were not in the ethnic minority or disadvantaged stratums.

For Wales, Scotland and Northern Ireland the population was stratified into two strata:

1) Disadvantaged stratum: children living in wards (known as Electoral Divisions in Wales) in 1998 (1984 in Northern Ireland) that fell into the top part of the Child Poverty Index.
2) Advantaged stratum: children not part of the poorest 25% of the Child Poverty Index.

An ethnic minority stratum was not possible in the devolved nations due to small populations of ethnic minority groups. The sample was geographically clustered by electoral wards. Clustering was a cost-efficient way to draw a sample from specific areas, and was designed to allow for exploration of neighbourhood characteristics. A total of 398 wards were selected: 200 from England, 73 from Wales, 62 from Scotland and 63 from Northern Ireland.

2.1.3 Weighting

Due to the stratified cluster design of the MCS, with overrepresentation of those from ethnic minorities and disadvantaged areas, weighted estimates of means and variances were required (Plewis, 2007). The study design meant that those born in areas with higher rates of disadvantage were more likely to be selected into the sample. Sample design weights are needed to account for the stratified clustered design and reduce sampling error. Sampling weights were applied to analysis throughout this thesis.

The MCS, as with any longitudinal study, is susceptible to attrition. Non-response weights were produced by CLS to account for biases for unit non-response. At each sweep the non-response weight is the estimated inverse of the probability of responding based on a logit regression model (Centre for Longitudinal Studies, 2020b). This logit model included predictors of non-responses between each sweep such as gender, ethnicity, housing tenure and accommodation type. Two overall weights were constructed by multiplying the sampling weights in sweep 1 by the attrition weights in each following sweep of MCS. Detailed information on the construction of weights can be found in the MCS User Guide (Centre for Longitudinal Studies, 2020b).

In all analysis in this thesis, data was set by survey design using the Stata *'svyset'* command.

2.1.4 Survey content

At each sweep of the MCS, data were collected from both co-resident parents with natural, step, foster and adoptive parents all eligible. Data collection methods included interviews, self-completion questionnaires, cognitive assessments, and interviewer observations. Computer assisted personal interviewing (CAPI) and computer assisted self-interviewing (CASI) instruments were used at each sweep. Table 2.1 gives an overview of the data collected at each MCS sweep.

This thesis focuses on variables collected at sweeps 5, 6 and 7. Chapter Three utilises the perceived safety variable asked as part of the child self-completion survey in MCS5. In MCS6, self-reported physical activity was captured with the self-completion survey whilst a subsample wore accelerometer devices for two days. Chapter Four will also use the MCS6 self-reported physical activity and accelerometer variables. Chapter Five utilises variables on activities and time spent with friends, asked as part of the Young Person Online (CAWI) Questionnaire. The social provisions scale, also asked as part of the CAWI questionnaire, measures the availability of social support. How these variables were collected is detailed below. Table 2.2 details the exposures and outcomes used in this thesis, including the years of each.

2.1.4.1 Perceived safety

At age 11 (sweep 5), as part of the self-completion questionnaire, children were asked whether they felt safe to walk or play in their area during the day, with area defined as within one mile or 20 minutes from home. Possible answers were: Very Safe, Safe, Not Very Safe or Not At All Safe.

2.1.4.2 Physical Activity

Self-reported physical activity

As part of the self-completion questionnaire completed on a tablet, young people, at age 14 (sweep 6), were asked how many days in the last week they had taken moderate to vigorous physical activity, including during school. Moderate to vigorous activity was defined as any activity that increased heart rate and breathing with examples of swimming, running and cycling given. The response categories were: Every Day, 5-6 Days, 3-4 Days, 1-2 Days or Not at All.

Accelerometery

Accelerometery is the objective measurement of physical activity using accelerometers. Physical activity was objectively measured with Generative wrist-worn activity (GENEActiv) monitors at age 14. All cohort members in Wales, Scotland and Northern Ireland were included in the subsample, plus approximately 81% of cohort members in England due to constraints in resources (Fitzsimons, 2020). Cohort members were asked to wear the monitors on non-dominant wrist for two randomly selected full days including one weekday and one weekend day. Data was included if participants had ≥ 10 hours of valid wear for both days. In total, 4970 participants returned valid data.

The monitor measures activity by mean acceleration over the 24-hour period, the Euclidean norm minus one (ENMO). Mean time spent in Moderate Vigorous Physical Activity (MVPA) was calculated as time spent in acceleration (ENMO) above 100mg with variables for total number of minutes higher than 100mg for at least five seconds, one minute or five minutes (Hildebrand et al., 2014).

Additionally, a set of variables gives information on the time spent in bouts where the participant has spent over 80% of the time in moderate-to-vigorous activity for at least 1 minute, 5 minutes or 10 minutes.

2.1.4.3 Social isolation and social support

At age 17 (sweep 7) cohort members were invited to complete an online questionnaire, after the interviewer had left. Participants were encouraged to complete the questionnaire in private due to the sensitive nature of some topics. The questionnaire included a section on activities with 13 items on activities they participate in. The response options were: most days, at least once a week, at least once a month, several times a year, once a year or less, never or almost never. The activities included are listed below.

- Go to a party, dance, house party or nightclub?

- Go to the theatre (for example to see a play, pantomime or opera)?
- Go to watch live sport (for example at a stadium)?
- Sing in a choir or play in a band or orchestra?
- Go to a live music concert or gig?
- Read for enjoyment?
- Go to youth clubs, explorer scouts, senior guides or other organised activities?
- Go to a library?
- Go to museums or galleries, visit a historic place or stately home?
- Do voluntary or community work?
- Go to a political meeting, march, rally or demonstration?
- Attend a religious service?
- Spend time with friends (outside of school or work)?

The questionnaire also contained a section on life and wellbeing, including a three-item index on social support from the 10-item Social Provisions Scale. Cohort members were asked to think about their current relationship with friends and family members and indicate the extent to which they agreed with each statement from the responses: very true, partly true or not true at all. The statements were as follows:

- I have family and friends who help me feel safe, secure, and happy.
- There is someone I trust whom I would turn to for advice if I were having problems.
- There is no one I feel close to.

Chapter Five outlines in detail how these variables were operationalised.

2.1.5 Covariates

Multiple indicators of socioeconomic circumstance will be utilised in this thesis. Covariates cover key demographic and socioeconomic factors important in the relationship between neighbourhood factors and health outcomes.

2.1.5.1 Parental education

Previous research has indicated that parental education may predispose families to live in certain neighbourhoods (Lamb et al., 2020; Mouratidis, 2020). In addition, higher parental education has been associated with greater physical activity levels in adolescence (Kantomaa et al., 2007) and reduced social isolation (Kung et al., 2022).

Information about parent educational qualifications was first collected in the first sweep of MCS. At each subsequent sweep, parents were asked if they had achieved any new qualifications since the time of the last interview. Parents were asked if they had achieved any of the following academic qualifications:

1. Higher degree
2. First degree
3. Diplomas in higher education
4. A/AS/S levels
5. O level/GCSE grades A-C
6. GCSE grades D-G
7. Other academic qualifications including overseas
8. None of these

They were further asked about vocational qualifications:

1. Professional qualifications at degree level
2. Nursing / other medical qualifications
3. National Vocational Qualification (NVQ) / Scottish vocational qualifications (SVQ) / General Scottish vocational qualifications (GSVQ) level 3
4. Trade apprenticeships
5. NVQ / SVQ / GSVQ level 2
6. NVQ / SVQ / GSVQ level 1
7. Other vocational qualifications (incl. overseas)
8. None of these qualifications

These scales were then combined and collapsed into the following:

1. NVQ level 0: none of these/other qualifications

2. NVQ level 1: GCSE grades D-G, NVQ/ SVQ/ GSVQ level 1

3. NVQ level 2: GCSE grades A-C, trade apprenticeships, NVQ/ SVQ/ GSVQ level 2

4. NVQ level 3: A/ AS/ S levels, NVQ/ SVQ/ GSVQ level 3

5. NVQ level 4: first degree, diplomas in higher education, professional qualifications at degree level

6. NVQ level 5: higher degree

2.1.5.2 Family income

Household income is linked to neighbourhood characteristics, with lower income households more likely to live in disadvantaged neighbourhoods (Hernández, 2014; Propper et al., 2007). Household income has been shown to be inversely related to childhood and adolescent BMI, via the pathway of physical activity (G. W. Evans et al., 2012). Lower economic status, including household income, has also been associated with increased social isolation and a lack of social support (Kung et al., 2022).

The MCS collected data on income in a variety of ways including detailed questions on gross earnings, net earnings, earnings from a second job and income from benefits. A measure of OECD equivalised income quintiles was used in all analysis in this thesis. The OECD quintiles account for household size and composition (Office for National Statistics, 2015). In the MCS, equivalisation was applied to net weekly income and then divided into quintiles to give OECD weighted income quintiles.

2.1.5.3 Wealth

Similar to household income, overall wealth is associated with better health outcomes (Hajat et al., 2010; Moulton et al., 2021; Pollack et al., 2013). It has also been suggested that wealth reflects unique aspects of socioeconomic status, especially as wealth can vary across social groups with similar incomes (Braveman et al., 2005).

The fifth MCS sweep asked parents about their savings and assets, debts, the value of their house and outstanding mortgage. Financial wealth was calculated as total assets and investments minus total debts. Housing wealth was calculated as house value minus outstanding mortgage. Total net wealth was consequently calculated as financial wealth plus housing wealth.

2.1.5.4 Occupational status

Occupational status has been linked with neighbourhood deprivation and differences in housing (Chandola & Jenkinson, 2000; Stafford & Marmot, 2003). Moreover, occupational status has been associated with general health, depressive symptoms and wellbeing (Lopes et al., 2019; Richards & Paskov, 2016).

The MCS utilises the National Statistics Socio-economic classification (NS-SEC) as a measure of occupational status. The NS-SEC was constructed to measure employment and conditions of occupations and capture the structure of socio-economic position in modern societies. The 5 classes of the NS-SEC are as follows:

1) Higher managerial/administrative/professional occupations
2) Intermediate occupations
3) Small employers/self-employed
4) Lower supervisory and technical occupations
5) Semi-routine and routine occupations

In this thesis, an additional sixth category of ‘not in work’ was added and the highest household level of occupational status was taken.

2.1.5.5 Ethnicity

Ethnic minorities are more likely to live in deprived areas (Tinsley & Jacobs, 2006) and it is well established that health inequalities exist between ethnic groups (Darlington et al., 2015; G. D. Smith et al., 2000). Data from the UK Active Lives Survey reported that the percentage of physically active people in the Asian, Black, Chinese and other ethnic groups was lower than the national average (Sport England, 2020). Studies have also shown that ethnic minorities are at increased risk of social isolation (L. Platt, 2009).

In the MCS ethnicity was self-reported and coded into 6 categories (White, Mixed, Indian, Pakistani and Bangladeshi, Black or Black British, Other Ethnic Group (incl. Chinese, other).

Table 2.1 Overview of data collected during each MCS sweep		
Sweep	***Data collected from***	***Health and medical data***
MCS1	Main parent, second co-resident parent	Fertility treatment; antenatal care; health problems during pregnancy (e.g. hypertension); mode of delivery; pain relief during labour; complications during birth; birthweight and gestational age; breastfeeding; immunizations; incidence of and number of health problems (e.g. chest infections, ear infections, skin problems); accidents and injuries; hospital visits/admissions; developmental milestones; parental health; parental longstanding illness and disability; parental mental health; self-reported parental height and weight; mother's smoking before, during and after pregnancy; mother's alcohol consumption before, during and after pregnancy
MCS2	Main parent, second co-resident parent, older sibling (England only), child assessments	Immunisations; incidence of and number of health problems (e.g. chest infections, ear infections, skin problems); accidents and injuries; hospital visits/admissions; developmental milestones; parental health; parental longstanding illness and disability; parental mental health; self-reported parental height and weight; child sight and hearing problems; child long-standing health conditions; child cognitive assessments; child height and weight; parental smoking; parental alcohol consumption
MCS3	Main parent, second co-resident parent, older sibling (England only), child assessments, teachers	MCS2 data; child waist measurement
MCS4	Main parent, second co-resident parent, child assessments, teachers, child self-completion	MCS2 data; child body fat percentage
MCS5	Main parent, second co-resident parent, child assessments, teachers, child self-completion	MCS2 data; child body fat percentage; a parental report on pubertal development; child self-response well-being and happiness measures; self-response child's smoking and alcohol consumption
MCS6	Main parent, second co-resident parent, child assessments, teachers, child self-completion	MCS2 data; child body fat percentage; child and parent saliva samples; accelerometery; child self-response well-being and happiness measures; self-response child's smoking and alcohol consumption
MCS7	Main parent, second co-resident parent, child assessments, teachers, child self-completion	MCS2 data; body fat percentage; consent to data linkage; self-completion on attitudes, activities and risky behaviour

Table 2.2 – Exposures and outcomes, and linked datasets, with year of origin utilised in Chapters 3-5.

<table>
<tr><th></th><th colspan="2">Exposures</th><th colspan="2">Outcomes</th></tr>
<tr><th></th><th>Measure</th><th>Year</th><th>Measure</th><th>Year</th></tr>
<tr><td rowspan="4">Chapter Three</td><td>Self-reported safety (age 11)</td><td>2012-2013</td><td>Accelerometer and self-reported physical activity (age 14)</td><td>2015-2016</td></tr>
<tr><td>Sweep 5 (age 11) postcodes.</td><td>2012-2013</td><td></td><td></td></tr>
<tr><td>IMD crime</td><td>2004</td><td></td><td></td></tr>
<tr><td>Data.Police.UK</td><td>2012-2013</td><td></td><td></td></tr>
<tr><td colspan="5"></td></tr>
<tr><td rowspan="2">Chapter Four</td><td>Sweep 6 (age 14) postcodes.</td><td>2015-2016</td><td>Accelerometer and self-reported physical activity (age 14)</td><td>2015-2016</td></tr>
<tr><td>OS Greenspaces MasterMap Layer</td><td>April 2020 release</td><td></td><td></td></tr>
<tr><td colspan="5"></td></tr>
<tr><td rowspan="2">Chapter Five</td><td>Sweep 6 (age 14) postcodes.</td><td>2015-2016</td><td>Social isolation and social support (age 17)</td><td>2018-2019</td></tr>
<tr><td>OS Retail Geographies – High Streets</td><td>March 2019 release</td><td></td><td></td></tr>
</table>

2.2 Other Datasets

2.2.1 Data.Police.UK

Data are provided to Police.UK by the police forces in England and Wales, the British Transport Police, the Police Service of Northern Ireland and the Ministry of Justice. Data uploaded is anonymised before publication. Data.Police.UK records crime at the LSOA level and at street-level location including the crime type with 14 sub-categories. These 14 categories are:

- Anti-social behaviour
- Bicycle theft
- Burglary
- Criminal damage and arson
- Drugs (includes offenses related to possession, supply and production)
- Other theft (includes theft by an employee and blackmail)
- Possession of weapons
- Public order (includes offenses which causes fear, alarm or distress)
- Robbery
- Shoplifting
- Theft from the person (involves theft directly from the victim without use or threat of physical violence)
- Vehicle crime
- Violence and sexual offences (includes common assault, homicide, rape)
- Other crime (includes forgery and perjury).

2.2.2 Ordnance Survey

The Ordnance Survey (OS) is the national mapping service of Great Britain and presides over large geospatial databases. It produces digital map data and location products for business and government.

2.2.2.1 OS MasterMap Greenspace Layer

The Greenspace layer consists of topographic areas with additional information on greenspace form and function (Ordnance Survey, 2022). It includes accessible and private greenspaces, sports facilities, and natural environment spaces within an urban area. There are 18 possible greenspace functions including allotments, bowling green, camping park, golf course and playing fields. The forms included within the Greenspace Layer are woodland, open semi-natural, beach and manmade surface.

2.2.2.2 OS Highways Network and OS Retail Geographies

The OS Highways Network incorporates the Roads, Paths and Routing and Asset Management Information (RAMI) products. The Road and Path Networks are topologically structured together in a link and node network (Ordnance Survey, 2023a). The products contain features including unique street reference numbers, routing information and road names.

The OS Retail Geographies - High Streets dataset describes the spatial extent and profile of high streets across Great Britain. High streets are defined by OS as a minimum of 15 retail addresses within 150 metres of each other (Office for National Statistics & Ordnance Survey, 2019). The dataset is high street specific and excludes other retail functions including shopping centres and retail parks.

2.3 Spatial Methodological Considerations

Epidemiological studies are increasingly integrating spatial perspectives, thanks to the understanding of the importance between place and health. There are a wide variety of longitudinal health datasets, but usually they are not explicitly linked to spatial data (Desjardins et al., 2023). It is often required for researchers to link longitudinal data to spatial data themselves. However, many epidemiology studies use measures of the neighbourhood without properly considering the best indices, variables and theory between health and place (Desjardins et al., 2023).

The used of advanced spatial data and technologies forms the basis of spatial epidemiology. Four types of spatial epidemiological analysis have been described: disease mapping, geographical correlation studies, risk assessment in point or source studies and disease clustering (Elliott et al., 2001). More recently, spatial epidemiology has been described as epidemiological study designs that incorporate spatial data or spatially derived data about study participants or exposures with a primary focus on populations (Kirby et al., 2017).

The increase in interest in spatial epidemiology can be partly attributed to the increase in the availability of spatial data and geographical analysis techniques. For example, Global Positioning Systems (GPS), network data, aerial data (satellite pictures) and aggregated socio-demographic data (e.g., census data) have facilitated spatial analysis in the context of public health (Delmelle et al., 2022). In addition, Geographical Information Systems (GIS) have enabled analysis at finer scales, allowing identification of spatial patterns (such as diseases) that might otherwise have been unnoticed (Burrough et al., 2015). GIS can be used to create spatial variables, such as: availability or access to a particular geographic feature (e.g., greenspaces, high streets), land use measures, or environmental exposures (e.g., air pollution) (Kirby et al., 2017).

2.3.1 Geo-linkage methods in longitudinal studies

There are five types of spatial models that allow for the characterization of features of spatial objects (Libuy & Church, 2019):

- Points: a single point, e.g., address
- Lines: a set of ordered points connected by straight lines, e.g., streets
- Polygons: an area marked by closing lines e.g., postcodes or regions
- Grid or Raster: collection of points or rectangular cells e.g., green vegetation density
- Networks: a complex line-based structure e.g., transport network

GIS are used to manage and analyse these spatial data. Available software programmes to work with spatial data includes ArcGIS and QGIS. Measuring spatial relationships is a key function of GIS. Spatial proximity between a location, for example a postcode centroid, and a spatial object is commonly measured by distance to the nearest point, line or polygon centroid. Different metrics can be used when measuring travel or distance, including Euclidean, block distances or network based. Euclidean, or straight-line, 'as-the-crow-flies', distance is a simple approach that can lead to underestimation of distances. Block distances use the shortest angular route between two points (Libuy & Church, 2019). Network-based distances can reflect the connectivity of roads and pathways to estimate a real-world travel distance. Euclidean and block distances can be calculated with standard statistical software whilst network distances require GIS tools. ArcGIS (ESRI, https://www.esri.com) is a software programme that enables calculation of distance and travel times, accounting for road features.

Another spatial method is aggregation, whereby an area or buffer is defined to summarise geographical features of a place. An area or buffer could be defined by administrative boundaries, as illustrated in Figure 1.1, or a radius around a specific location or address as discussed in Chapter Three.

2.3.2 Geo-linkage in the MCS

Geographical identifiers provide information about a cohort members residential or other location, such as place of work or study. Common geographical identifiers include postcodes, electoral wards or geographical region. In the MCS identifiers include postcodes, Lower Super Output Area, Middle Super Output Area and census wards. Cohort member addresses are collected at interview, from which postcodes can be derived. Point data is generated using GIS and the ONS Postcode Directory, to an accuracy of 1 meter of the postcode centroid. Detailed information about this process can be found in the Millennium Cohort Study guide to geographic identifiers (D. Church, 2015). Postcode centroids can then be linked to spatial variables of interest. This thesis will utilise network-based distance and travel times to closest greenspaces and high streets, calculated using GIS techniques and ArcGIS software by the Centre for Longitudinal Studies at UCL. These will be described in the methodology of sections of Chapters Three-Five.

It is important to note that precision errors are more likely when using postcode centroids as location points. This is especially true for rural areas where postcodes tend to be larger than in urban areas, and therefore a postcode centroid may not accurately reflect a participant's actual address. It is plausible that the exact location of an address could be far from the centroid of postcode, depending on the size of the postcode. A further consideration is the Modifiable Areal Unit Problem (MAUP), whereby the way data is aggregated into spatial units, such as postcodes, can influence the results of spatial analysis. The MAUP has a scale and a zone component (Openshaw & Taylor, 1979). The scaling aspect refers to the analytical differences that arise depending on the way spatial data is aggregated, namely due to the size of units used. The zoning problem shows that differences arise depending on the way the area to be studied is divided up. Although there is no recognised comprehensive solution to the MAUP, using original point data or the smallest areal units for data aggregation may decrease the MAUP effect (Su et al., 2011).

2.4 Other Methodological Considerations

2.4.1 Missing Data and Multiple Imputation

As with any longitudinal data, the MCS is subject to attrition and missing data. Whilst sampling weights, as described in section 2.1.3 Weighting, accounts for stratified clustered design of the data and unit non-response, multiple imputation is a method of dealing with item non-response. Unit non-response refers to participants lost to follow-up whilst item non-response occurs when an observation is missing for a particular variable or point in time. Multiple imputation generates multiple copies of the dataset and replaces missing values in each with estimates. Multiple imputation assumes the data is missing at random (MAR), meaning missingness is related to other variables in the dataset so that once these variables have been accounted for, any remaining missingness is random (Graham, 2009). Multiple imputation is widely considered the most appropriate approach to deal with missingness under the MAR assumption common in longitudinal cohorts such as MCS (Sterne et al., 2009).

Multiple imputation with chained equations (MICE) was employed in Chapters Four and Five. MICE allows for continuous and categorical data to be imputed in the same imputation model, as it imputes data one variable at a time in a series of regression models (Enders, 2010). Once a completed imputed dataset is created, the planned analysis (such as linear regression) is run for each imputed dataset. The imputed datasets are analysed individually before estimates and standard errors are pooled into a single set of estimates, according to Rubin's rules (Rubin, 1987).

2.4.2 Confounding

Evidence of the impact of socio-economic position (SEP), including income and education, on health outcomes, such as physical activity, has led to the common practice of adjusting for socio-economic factors. Insufficient adjusting can result in residual confounding between neighbourhood features, such as greenspaces, and health outcomes such as physical activity. Conversely, adjustment of all available measures of SEP should also be cautioned; measures should be considered in the context of the exposure (crime, greenspaces, exposure to high streets), health outcome (physical activity, social isolation) and population of interest (adolescents) (Hajat et al., 2021). For example, adjusting for a variable on the casual pathway can introduce bias (Diemer et al., 2021) and the total causal effect of the exposure on the outcome will not be consistently estimated (Schisterman et al., 2009). Given that SEP is a multifaceted concept that captures many aspects of an individual's life over time, it can be challenging deciding which indicators to include as confounders. Indeed, any measure may not completely represent all aspects of SEP and may differ across populations and places (Hajat et al., 2021). Therefore, careful consideration of which SEP indicators to adjust for, and the hypothesized mechanisms to health outcome, is required to ensure obtained results do not reflect SEP differences. The approaches taken for this thesis are outlined in the 2.1.5 Covariates section.

Spatial confounding refers to variables that are thought to have a spatial element and influence both the exposure and outcome of interest (Gilbert et al., 2023). For example, it is important to note that greenspace is not distributed randomly. A large body of evidence shows that there are significant inequalities regarding access to greenspace and that deprived areas have less good quality greenspaces. Some research reports that individuals living in the most deprived areas in the UK are 10 times less likely to live in the greenest areas measured via the GLUD (Allen & Balfour, 2014). Similarly, a systematic review of studies in the WHO European Region concluded that deprived areas had lower greenspace availability than more affluent areas (Schüle et al., 2019).

The unequal distribution of green spaces, hypothesised in terms of both quality and access, makes it very difficult to disentangle the effect of access to green space from the effect of correlated area-characteristics, such as local housing stock, crime rates or engagement in risky behaviours.

Chapter Three – Subjective and objective indicators of neighbourhood safety and physical activity among UK adolescents

This chapter forms the basis of a published paper in Health & Place: Constable Fernandez, C., Patalay, P., Vaughan, L., Church, D., Hamer, M. & Maddock, J. (2023) Subjective and objective indicators of neighbourhood safety and physical activity among UK adolescents, *Health & Place,* 83, 103050

3.1 Introduction

The health benefits of physical activity are well documented. In children and adolescents, regular physical activity is linked to better mental health, improved cardiovascular fitness and healthy weight status (Kumar et al., 2015). Although more time spent being physically active equates to greater health benefits, even small increases in physical activity are associated with improved health (Davies et al., 2019). UK guidelines state that children and adolescents should aim for an average of 60 daily minutes of moderate intensity physical activity across the week. In 2019-2020, only 44.9% of young people (5 to 16-year-olds) in the UK reportedly met these guidelines (Sport England, 2021).

Adolescence can be described as a sensitive time-period during which many health-related behaviours are initiated, and behaviour patterns start forming including the habitualisation of physical activity (Hirvensalo & Lintunen, 2011; Viner et al., 2015). Evidence suggests that being physically active in adolescence predicts a physically active lifestyle in adulthood (Hayes et al., 2019). The habitualisation of physical activity, whereby behaviours become incorporated into everyday life and part of a routine, can also develop in childhood and track into adulthood (Hirvensalo & Lintunen, 2011).

Potential barriers to physical activity in adolescence may include time constraints, lack of resources, previous negative experience with exercise, concerns about self-appearance and environmental barriers such as safety in both boys and girls (Martins et al., 2014; Zaragoza et al., 2011). The neighbourhood environment is a key setting for physical activity during childhood and adolescence. Due to mobility restrictions imposed by parents or carers and a lack of financial independence, adolescents spend a significant amount of time in their neighbourhoods (A. L. Smith et al., 2015).

Feeling unsafe in the neighbourhood may act as a barrier to physical activity due to a perceived threat to personal safety. Fear of crime can be described as an emotional response or feelings of anxiety towards crime or symbols associated with crime (Ferraro, 1996). To reduce their fears, individuals may constrain their behaviour by, for example, avoiding certain activities or specific areas believed to be dangerous. However, not all types of crime instil the same levels of fear. Violent crimes against the person, such as assault or mugging, often form the focus of fear (Lorenc et al., 2014). Anti-social behaviour and public disorder offenses can foster a sense of insecurity in the neighbourhood and increased fear of crime(Brunton-Smith & Sturgis, 2011; Office for National Statistics, 2022). Research suggests fear of crime is particularly inhibiting amongst marginalised adolescents (Ceccato, 2012).

Researchers can use either objective or subjective measures to capture neighbourhood features and participant behaviours. Subjective (sometimes referred to as perceived) measures include questionnaires and surveys where participants self-report perceptions such as neighbourhood safety, or participation in activities. Benefits of self-reporting include cost-effectiveness and a low burden for participants. However, self-reporting may reflect individual-level characteristics and may be subject to recall bias. Children might encounter difficulties recalling events or understanding questions (Janz et al., 2008). Self-reported measures can also be influenced by cultural and societal norms. Indeed, achieving linguistic equivalence and appropriateness for different populations can be challenging (Atkin et al., 2012).

Objective measures incorporate device-measured physical activity, i.e., accelerometers, and police crime rates, which are routinely collected by UK polices forces. Objective, or device-based, measures can be more reliable in measuring time and intensity of physical activity. However, devices are expensive and time-consuming for both researchers and participants. Subjective measures are not simply proxies of objective measures or vice versa. It can be argued that objective measures of the neighbourhood do not capture experiential or relational aspects which are often important for understanding relationships and mechanisms of neighbourhood effects on health (Yakubovich et al., 2020). Subjective measures of the neighbourhood environment reflect an individual's experience of their surroundings and allow residents to report on the neighbourhood social context not possible with objective measures, although there may be limitations that have to do with how neighbourhood is defined (Corcoran et al., 2018). There is also inconsistency in how neighbourhoods are measured, meaning that results of prior research cannot be easily replicated (Ortegon-Sanchez et al., 2021).

It can be argued that objective and subjective measures of the environment are complementary to each other and can be used together to gather a rounded picture of neighbourhood environment effects. Few neighbourhood environment studies have made use of both objective and subjective measures of exposure and outcome.

Previous studies have presented inconsistent findings on neighbourhood safety, crime and physical activity; with only a small amount of the literature focussing on adolescents, and even less research from the UK. Adolescents in Poland and the Czech Republic that perceived their neighbourhood as safe were significantly more likely to meet physical activity guidelines measured through physical activity questionnaires (Mitáš et al., 2018). In addition, low neighbourhood perceived safety has been associated with reduced physical activity in 11-16 year olds in Chicago (Molnar et al., 2004). A UK study, using longitudinal data from East London, reported that adolescents' perceptions of their neighbourhood safety was not associated with self-reported physical activity (Berger et al., 2019). Similarly, research in the US found that girls, but not boys, exposed to high crime neighbourhoods (measured with census tract-level data on crime reports) had lower odds (OR = 0.74, 95% CI = 0.59-0.92) of engaging in moderate-to-vigorous physical activity (Chaparro et al., 2019). Context specific self-reported physical activity, namely free-time outside of school, was independently associated with perceived safety and local neighbourhood crime in 11-15 year olds in Canada (Janssen, 2014). Alternatively, results from an Australian study reported that adolescent perceptions of safety and crime did not influence moderate vigorous physical activity (MVPA) outcomes assessed by accelerometers (Loh et al., 2019). It should also be noted that the definition of what constitute relevant crimes is inconsistent across studies.

It is consistently found that adolescent girls are less physically active than boys, with estimates suggesting that girls perform 17% less daily activity (Ekelund et al., 2012). Possible explanations for this disparity include less participation in organised sport, less perceived enjoyment in physical education and less peer support for girls (Cairney et al., 2012) as well as the aforementioned issues to do with appearance, and sexual harassment. Early exposure to gender norms around boys and girls activities can instil lack of enjoyment of sport into girls by enforcing the idea that certain sports are 'unfeminine', shaping attitudes into adulthood (The Lancet Public Health, 2019). Gender stereotypes can also significantly increase concerns around body image; adolescent girls that are self-conscious about their bodies are less likely to participate in sport (Women's Sport and Fitness Foundation, 2008). Evidence also suggests that some girls avoid physical activity and sports rather than endure sexual attention from male coaches or peers (Women's Sport and Fitness Foundation, 2008). Moreover, women and girls' sport typically receive less funding at the grassroots level leading to reduced access to safe facilities.

The relationship between environmental perceptions, crime and physical activity may also differ by sex (J. B. Moore et al., 2014). Gender is a reliable predictor of fear of crime with women consistently reporting greater fear of crime and victimisation than men (Lane, 2015). Concerns are often raised about girls' safety in outdoor spaces such as parks, fields and streets where physical activities frequently occur. In particular, the perceived threat of sexual danger can restrict girls' ability to play and exercise outdoors (B. Evans, 2006). Indeed, sexual harassment continues to be a relevant factor in the limitations placed on adolescent girls' mobility and access to space. The idea of 'sexual terrorism' argues that threats and everyday harassment throughout their lifetime keeps women and girls on high alert, placing themselves personally responsible for their safety (Stanko, 1993a). This hyper-sensitivity leads to women limiting their own activities. There is evidence that girls' transition to secondary school is an important timepoint at which they begin to internalise fears around their safety and adjust activity choices in response to these fears (S. Clark, 2015).

This study aims to examine associations between objective neighbourhood crime rates, linked to participant geographical identifiers, and subjective safety and objective and subjective physical activity (accelerometer and self-reported physical activity). Sex disparities in these associations will also be explored.

Findings from this chapter will add to the limited literature focussing on neighbourhood environment and physical activity in young adolescents in the UK.

3.2 Methods

3.2.1 Participants

This study uses data from the Millennium Cohort Study (MCS), which I outline in detail in Research Aims and Objectives

The overall aim of this thesis is to explore whether the features of the neighbourhood environment influence physical activity and social isolation outcomes in an adolescent population.

To achieve this aim, I use epidemiological methods alongside aspects of spatial and urban science and health geography. By employing a multidisciplinary approach, I aim to bring relevant aspects of these disciplines together to inform research questions, analytical methods, and better understand the UK spatial landscape in a health context. For example, I used geo-coded data and uses measures generated from Geographical Information Software (GIS) to better capture the neighbourhood features of interest.

This thesis recognises that the neighbourhood is multidimensional. The following chapters explore how the neighbourhood exposures of crime and safety, greenspace, and high streets may be important for adolescence. This thesis focuses on outcomes in adolescence, specifically, physical activity and social isolation and social support outcomes.

Research objectives:

4) To explore how neighbourhood crime and perceived safety impact physical activity behaviours. This study also explores the complexities around using objective and subjective measures for both exposure and outcomes.
5) To explore whether greenspace plays a role in physical activity behaviours, whilst carefully considering socio-economic confounding factors.
6) To investigate whether high streets, as a proxy for areas of social encounter, activity, and interaction, are important for social isolation and social support.

Results from this thesis will offer important insight into the UK neighbourhood environment, relevant to health in adolescence.

Chapter Two – Data and Methods. For this chapter I used data from sweep 5 (age 11) and sweep 6 (age 14). There were 19,243 potentially eligible families of which there were 13,287 productive responses at sweep 5 (age 11) and 11,726 productive responses at sweep 6 (age 14) with productive defined as data from at least one of the data collection instruments including main interview or parent interview (Johnson et al., 2012). At age 14, a random sub-sample of 4,813 participants wore activity monitors for two specified full days (Centre for Longitudinal Studies, 2020a). MCS collects information directly from cohort members and their resident parent. From age 11, cohort members self-completed questionnaires.

The analytical sample was comprised of participants where information was available for any exposure (perceived safety, Index of Multiple Deprivation (IMD) crime, Reported Crime Incidence) and either outcome (self-reported physical activity or accelerometer physical activity). Figure 3.1 depicts a flow chart of the analytical sample.

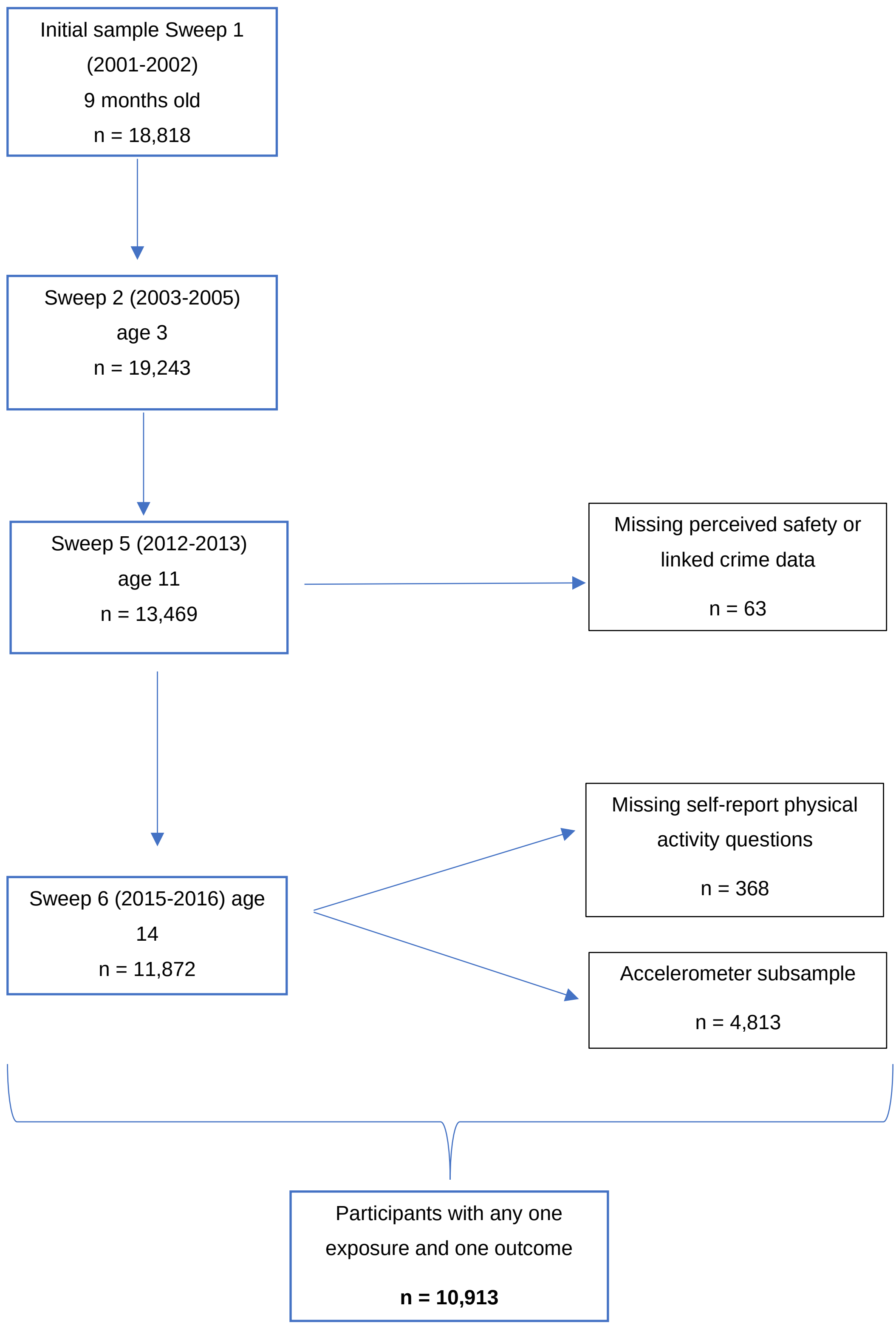

Figure 3.1 - flowchart to show study analytical sample population

3.2.2 Safety and Crime

3.2.2.1 Subjective neighbourhood safety

At age 11 (sweep 5, 2012-2013), as part of the self-completion questionnaire, children were asked whether they felt safe to walk or play in their area during the day, with area defined as within one mile or 20 minutes from home. Possible answers were: Very Safe, Safe, Not Very Safe or Not At All Safe. Not Very Safe and Not At All Safe were combined into one category due to small numbers (n = 1,020, 9.63% and n = 122, 1.15% of responses).

2.2.2 Objective Crime

Two different measures capturing objective information of neighbourhood crime were used in this study: the Index of Multiple Deprivation (IMD) crime domain and Reported Crime Incidence from Data.Police.UK.

IMD crime domain – The Index of Multiple Deprivation (IMD) is a measure of multiple deprivation made up of several domains that capture different dimensions of deprivation at the small area level (lower layer super output areas or LSOAs). LSOAs are geographical units designed for the reporting of small area statistics and contain 1,500 people or 650 households on average. The UK IMD 2004 measures are made up from the following:

- England: Office of the Deputy Prime Minister Indices of Deprivation 2004
- Wales: Welsh Assembly of Index of Multiple Deprivation 2005
- Northern Ireland: Northern Ireland Statistics & Research Agency Multiple Deprivation Measure May 2005
- Scotland: Scottish Assembly of Index of Multiple Deprivation 2004 *(not available for crime)*

The IMD provides scores and rankings at the LSOA level resulting in ten equal groups or deciles where decile 1 is the most deprived 10% of LSOAs. In MCS, participants were attributed with the IMD 2004 scores of the LSOA of their postcode at each sweep.

The IMD 2004 consists of a crime domain which represents the occurrence of material and personal victimisation at the LSOA level. Crime statistics were derived from Police Force data on burglary, theft, criminal damage and violence between April 2002 and March 2003. The crime domain consists of a total of 33 categories of recorded crime, grouped into 4 composite indicators (burglary, theft, criminal damage and violence). Whilst 14 crime offence types were recorded under violence, including homicide, harassment, and racially aggravated assault; sexual offence data were not included due to privacy sensitivity issues and low reporting. Higher decile scores represent higher crime; with decile 1 corresponding to the 10% highest crime areas. The full breakdown of IMD crime subcategories is presented in Table 3.1.

Table 3.1: IMD Crime – composite of the following:
Burglary:
Burglary in a dwelling
Aggravated burglary in a dwelling
Aggravated burglary in a building other than a dwelling
Burglary in a building other than a dwelling
Theft:
Theft from the person of another
Theft from a vehicle
Theft or unauthorised taking of motor vehicle
Vehicle interference and tampering
Aggravated vehicle taking
Criminal damage:
Arson
Criminal damage to a dwelling
Criminal damage to a building other than a dwelling
Criminal damage to a vehicle
Other criminal damage
Racially-aggravated criminal damage to a dwelling
Racially-aggravated criminal damage to a building other than a dwelling
Racially-aggravated criminal damage to a vehicle
Racially-aggravated other criminal damage
Threat etc. to commit criminal damage
Violence:
Murder
Manslaughter
Infanticide
Attempted murder
Causing death by aggravated vehicle taking
Wounding or other act endangering life
Harassment
Racially-aggravated other wounding
Racially-aggravated harassment
Common assault
Racially-aggravated common assault
Robbery of business property
Robbery of personal property

IMD 2004 was the only available IMD dataset linked to MCS age 11. Despite the mismatch in dates between the IMD crime domain and MCS age 11 data collection, comparison between the 2004, 2007 and 2010 English IMDs has shown that the majority (80.1%) of LSOAs that made up the 10% most deprived areas on the IMD 2010 were also in the most deprived decile in IMD 2004 and 2007 (McLennan et al., 2011). Evidence also suggests that area deprivation did not change significantly between 2004-2015 in the UK (Kontopantelis et al., 2018).

The IMD 2004 crime domain is available only for England, Wales and Northern Ireland. It is also important to note that the IMD crime domain methodology differs slightly between Wales, England and Northern Ireland. The indices of the UK nations are all based on a common methodology but the geographical units and weights chosen are to best suit national requirements (Noble et al., 2006; Payne & Abel, 2012). However, as domains are ranked in deciles and accurately reflect relative levels within any nation, these data were analysed together. For the purposes of this study, the IMD crime domain data were grouped into tertiles to compare areas with low, medium, and high crime rates.

Figure 3.2 demonstrates the variation between an LSOA unit, and the one-mile classification of a neighbourhood used in the MCS for the same post code centroid. As described above, for the perceived safety measure, neighbourhood was defined as within one mile or a 20-minute walk from home whilst IMD was calculated at the LSOA level. It is noted that these neighbourhood classifications are at different geographic levels which may lead to scaling issues, known as the Modifiable Areal Unit Problem (MAUP). There is no comprehensive solution to the MAUP and it was not possible to change the areal units used in IMD to match a one-mile postcode centroid radius.

Reported Crime Incidence – Reported crime incidence was measured using the Data.Police.UK database. Data.Police.UK records crime at the LSOA level and at street-level location including the crime type with 14 sub-categories. These 14 categories are: anti-social behaviour, bicycle theft, burglary, criminal damage and arson, drugs, other theft (includes blackmail), possession of weapons, public order (includes offenses which causes fear, alarm or distress), robbery, shoplifting, theft from the person, vehicle crime, violence and sexual offences and other crime (includes forgery and perjury). Data between 2012 and February 2013 was chosen to match the age 11 sweep 5 period. Following a review of the relevant literature, only those categories that were deemed relevant for fear of crime in the neighbourhood were chosen for analysis and grouped (Brunton-Smith et al., 2013; Dubourg et al., 2003; Lorenc et al., 2014; Office for National Statistics, 2022). These are anti-social behaviour, drugs, robbery, criminal damage and arson, public order, theft from the person and violence and sexual offences.

Data.Police.UK data was linked to participants at LSOA level.

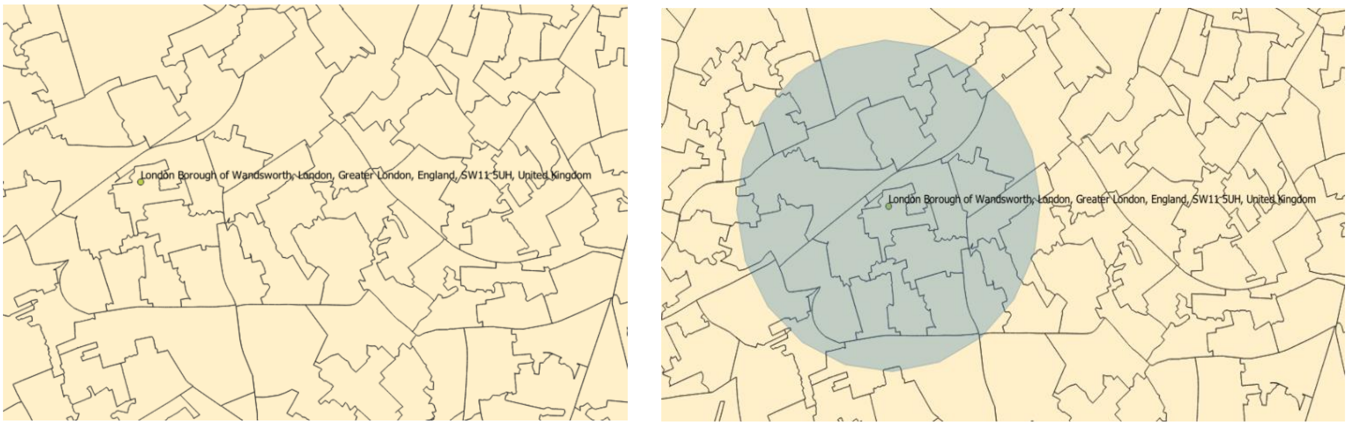

Figure 3.2 – map showing a postcode centroid in a London LSOA (left) and a one-mile radius around the postcode (right).
Scale 1:19511

3.2.3 Physical Activity

3.2.3.1 Self-reported physical activity

Self-reported leisure time physical activity has been asked in previous sweeps of MCS. As part of the self-completion questionnaire completed on a tablet, young people, at age 14, were asked how many days in the last week they had taken moderate to vigorous physical activity, including during school, Moderate to vigorous activity was defined as any activity that increased heart rate and breathing with examples of swimming, running and cycling given. The response categories were: Every Day, 5-6 Days, 3-4 Days, 1-2 Days or Not at All. We reversed and coded this as 0, 1.5, 3.5, 5.5 and 7 respectively to create a scale for the outcome that could be interpreted as number of days of exercise per week.

2.3.2 Objective measure of physical activity

Physical Activity was objectively measured with Generative wrist-worn activity (GENEActiv) monitors at age 14. Cohort members were asked to wear the monitors on non-dominant wrist for two randomly selected full days including one weekday and one weekend day. Further details on the accelerometer data collection are provided in Chapter Two.

A set of MCS variables gives information on the time spent in bouts where the participant has spent over 80% of the time in moderate-to-vigorous activity for at least 1 minute, 5 minutes or 10 minutes. Data for weekday and weekend were combined and averaged. Separate weekend and weekday sensitivity analysis can be found in Appendix 1.

When choosing which measure of activity to use in analysis, differences in physical activity between children and adolescents and adults were considered. Although longer bout periods, of for example 10 minutes, may represent more structured exercise, this is likely to be more relevant in adults. Evidence from previous research suggests that children's and adolescent's movement include more short periods of high intensity compared to adults (da Silva et al., 2014). This may be partly attributed to adolescents being more likely to be involved in organised sports activities and/or less reliance on a car for transport. Indeed, children's and adolescent's movements tend to be underestimated using long bout durations. The UK chief medical officers' guidelines state that there is no minimum amount of physical activity required to achieve some health benefits and that total time of activity is more important than time spent in specific bouts (Davies et al., 2019). Therefore, MVPA by accelerometer was measured as 1-minute time windows for which 80% of 5-second epoch values were equal to or higher than the 100-mg threshold.

2.2.4 Covariates

Covariates at sweep 6 were selected *a priori* and based on existing evidence around factors that might confound the association between safety and physical activity. These comprised parental education, ethnicity, family income and sex based on existing literature (G. W. Evans et al., 2012; Gidlow et al., 2006; Kantomaa et al., 2007; Sport England, 2020). For accelerometer, seasonality based on month of wear was also accounted for (Bélanger et al., 2009).

As described in Research Aims and Objectives

The overall aim of this thesis is to explore whether the features of the neighbourhood environment influence physical activity and social isolation outcomes in an adolescent population.

To achieve this aim, I use epidemiological methods alongside aspects of spatial and urban science and health geography. By employing a multidisciplinary approach, I aim to bring relevant aspects of these disciplines together to inform research questions, analytical methods, and better understand the UK spatial landscape in a health context. For example, I used geo-coded data and uses measures generated from Geographical Information Software (GIS) to better capture the neighbourhood features of interest.

This thesis recognises that the neighbourhood is multidimensional. The following chapters explore how the neighbourhood exposures of crime and safety, greenspace, and high streets may be important for adolescence. This thesis focuses on outcomes in adolescence, specifically, physical activity and social isolation and social support outcomes.

Research objectives:

7) To explore how neighbourhood crime and perceived safety impact physical activity behaviours. This study also explores the complexities around using objective and subjective measures for both exposure and outcomes.
8) To explore whether greenspace plays a role in physical activity behaviours, whilst carefully considering socio-economic confounding factors.
9) To investigate whether high streets, as a proxy for areas of social encounter, activity, and interaction, are important for social isolation and social support.

Results from this thesis will offer important insight into the UK neighbourhood environment, relevant to health in adolescence.

Chapter Two – Data and Methods, parental education was measured as the overall highest level of educational attainment recorded up to sweep 6. Ethnicity was self-reported and coded into 6 categories (White, Mixed, Indian, Pakistani and Bangladeshi, Black or Black British, Other Ethnic Group (incl. Chinese, other).

Income has been collected at each sweep of MCS where main caregivers and partners answered a banded income question; respondents were shown a card with weekly, monthly and annual bands of total income after tax and other deductions.1,689 MCS families in sweep 6 did not provide banded income data; income for missing data for two-parent families have previously been imputed (Centre for Longitudinal Studies, 2020a). Following imputation, income values were equivalised by country and UK wide. Further detail on the methods used by the Centre for Longitudinal Studies is provided in the MCS user guide (Centre for Longitudinal Studies, 2020a).

3.2.5 Statistical Analysis

Descriptive statistics are presented as frequencies and percentages and means with standard deviations. To assess correlation between subjective and objective physical activity and crime I computed pair-wise correlation coefficients.

I fitted separate linear regression models to examine relationships between the objective and subjective indicators of crime and self-reported physical activity. Unadjusted models were run first before fully adjusted models (adjusting for parental education, ethnicity and family income as described above).

Accelerometer MVPA variables were non-normally distributed with left skew, a histogram depicting this is shown in Figure 3.3. I fitted Zero Inflated Poisson (ZIP) regression models for analysis between subjective safety and objective crime variables and objective (accelerometer) physical activity. ZIP models have two sets of parameters, one for the standard probability distribution (Poisson) and the other for the probability of being zero (Long et al., 2014). To interpret the model, I used predicted margins analysis and marginal effects at the mean (MEM). Marginal effects are useful in describing how the dependent variable (physical activity) changes when the independent variable (crime and safety) changes. MEM calculates the marginal effect for each variable whilst keeping all covariates constant at the mean. As previously stated, I run unadjusted models before adjusting for covariates.

To assess whether associations between safety, crime and physical activity differed by sex, a multiplicative interaction term between sex and the crime variables was tested (sex*safety measure) and then I also stratified all models by sex.

To account for non-response and adjust for attrition at age 14, combined survey and non-response weights were used (Fitzsimons, 2020).

All models were initially performed with the full sample using non-response weights. Sensitivity analysis was conducted between the full sample, accelerometer sub-sample and the sample without Scottish participants (due to the lack of IMD crime domain in the Scottish IMD variable) results of which are shown in Appendix 1. Subcategories of the Reported Crime Incidence were individually analysed for associations with physical activity, also shown in Appendix 1.

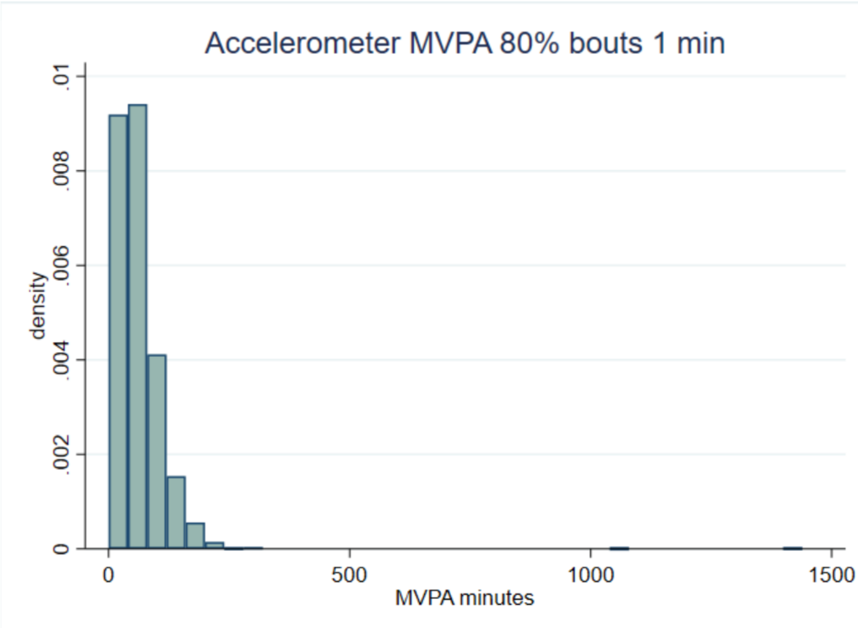

Figure 3.3 - Histogram showing distribution of accelerometer measured MVPA at 80% bouts for at least 1 minute time windows.

3.3 Results

3.3.1 Descriptives

Table 3.2 shows sample descriptives of the covariates at age 14. At age 11 cohort members were asked whether they felt safe to walk or play in their area. Out of 10,595 responses (97% of total analytical sample), approximately 11% of the participants reported feeling not safe, whilst 59% and 31% felt safe and very safe respectively with similar responses for boys and girls (Table 3.3). 10,896 participants in the analytical sample answered the physical activity question at age 14, with nearly 25% of boys reported engaging in physical activity every day compared to only 12% of girls. Accelerometer measured MVPA showed that, at 80% bouts for 1 minute, boys achieved an average of 68 minutes per day whilst girls achieved approximately 54 minutes (Table 3.4).

Out of the total analytic sample (n=10,913) over 85% (n= 9,316) remained at the same address between sweeps 5 and 6.

Correlation between IMD crime and Reported Crime incidence was weak (r = 0.10) as was correlation between MVPA and self-reported physical activity (r = 0.22). A correlation matrix can be found in Appendix 1.

Table 3.2: study sample characteristics of covariates at age 14 (n=10913)

Sex	**Frequency**	**Percent**
Female	5421	49.67
Male	5492	50.33
Total	10913	100.00
Highest Parental Education		
NVQ level 1 (CSE below grade 1/GCSE or O Level below grade C, SCE Standard, Ordinary grades below grade 3 or Junior Certificate below grade C)	282	2.98
NVQ level 2 (O Level or GCSE grade A-C, SCE Standard, Ordinary grades 1-3 or Junior Certificate grade A-C)	1563	16.52
NVQ level 3 (A/AS/S levels, SCE Higher, Scottish Certificate Sixth Year Studies, Leaving Certificate)	1387	14.66
NVQ level 4 (first degree, diplomas in higher education, teaching qualifications for schools or further education)	3785	40.00
NVQ level 5 (higher degree, postgraduate qualification, certificate or diploma)	1961	20.73
Other academic qualifications (incl. overseas)	484	5.12
Total	9462	100.00
Ethnicity		
White	8643	80.01
Mixed	512	4.74
Indian	292	2.70
Pakistani and Bangladeshi	768	7.11
Black or Black British	331	3.06
Other ethnic group (inc Chinese, other)	257	2.38
Total	10803	100.00
Income Quintile		
First quintile	1752	16.07
Second quintile	1774	16.27
Third quintile	2215	20.32
Fourth quintile	2576	23.63
Highest quintile	2585	23.71
Total	10902	100.00

Table 3.3 – Descriptive information for perceived safety and objective crime						
Perceived Safety age 11						
	All (n = 10,595)		Male (n = 5,230)		Female (n = 5,365)	
Very Safe	3,243	30.61%	1,623	31.03%	1,620	30.20%
Safe	6,210	58.61%	3,072	58.78%	3,138	58.49%
Not Safe	1,142	10.78%	535	10.23%	607	11.31%
IMD 2004 Crime (England, Wales, Northern Ireland)						
	All (n = 9,762)		Male (n = 4,863)		Female (n = 4,899)	
1 (least crime)	2,853	29.23%	1,455	29.92%	1,398	28.54%
2	3,052	31.26%	1,525	31.36%	1,527	31.17%
3 (most crime)	3,857	39.51%	1,883	38.72%	1,974	40.29%
Reported Crime Incidence (Data.Police.UK 2012-13)						
	All (n = 8,697)		Male (n = 4,344)		Female (n= 4,353)	
1 (least crime)	4,303	49.48%	2,127	48.96%	2,176	49.99%
2	1,626	18.70%	838	19.29%	788	18.10%
3 (most crime)	2,768	31.83%	1,379	31.74%	1,389	31.91%

Table 3.4: Descriptive information for subjective and objective physical activity			
Accelerometer measured physical activity at age 14. Mean (95% confidence intervals)			
Variable	**All (n = 4,813)**	**Male (n = 2,344)**	**Female (n = 2,468)**
Mean acceleration (ENMO – Euclidean Norm Minus One) for the day (24 hours)	34.06 (32.59, 35.53)	35.68 (35.02, 36.33)	32.52 (29.73, 35.32)
Moderate to Vigorous Physical activity (MVPA)			
Total minutes in MVPA: 5sec epochs where ENMO > 100mg	124.78 (123.00, 126.55)	129.28 (126.72, 131.85)	120.50 (118.05, 122.96)
Total minutes in MVPA: 1min epochs where ENMO > 100mg	122.69 (120.67,124.70)	131.35 (128.38, 134.32)	114.46 (111.77, 117.16)
Total minutes in MVPA: 5min epochs where ENMO > 100mg	113.38 (111.14, 115.62)	126.19 (122.87, 129.50)	101.219 (98.28, 104.16)
Moderate to Vigorous Physical activity (MVPA) at bouts of 80%			
Mins in mod/vig: 5sec epoch, 80% bout criteria 100 ENMO 1min	60.62 (59.15, 62.10)	67.85 (65.78, 69.92)	53.76 (51.69, 55.83)
Mins in mod/vig: 5sec epoch, 80% bout criteria 100 ENMO 5min	37.18 (35.83, 38.53)	45.00 (43.15, 46.85)	29.76 (27.85, 31.67)
Mins in mod/vig: 5sec epoch, 80% bout criteria 100 ENMO 10min	28.17 (26.89, 29.46)	35.51 (33.77, 37.25)	21.21 (19.36, 23.06)

Self-reported physical activity at age 14. N (%)						
	All (10,896)		**Male (5,413)**		**Female (5,483**	
0 days	460	(4.22%)	200	(3.96%)	260	(4.74%)
1.5 days	2,620	(24.05%)	966	(17.85%)	1,654	(30.17%)
3 days	3,683	(33.80%)	1,694	(31.30%)	1,989	(36.28%)
5.5 days	2,119	(19.45%)	1.204	(22.28%)	913	(16.65%)
7 days	2,014	(18.48%)	1,347	(24.88%)	667	(12.16%)

3.3.2 Self-reported physical activity

3.3.2.1 Subjective Safety

Those that described feeling not safe compared to very safe at age 11 reported 0.29 (95% CI -0.50, -0.09) fewer days of physical activity at age 14 (Table 3.5). There was no evidence for an interaction between perceived safety and sex, suggesting no difference in the association between feelings of neighbourhood safety and reporting physical activity between boys and girls. For boys, feeling not safe, compared to very safe, was associated with 0.30 (95 % CI -0.57, -0.03) fewer days of physical activity.

In girls, feeling not safe compared to very safe was associated with 0.21 (95% CI -0.49, 0.08) fewer days of physical activity (Table 3.5). Unadjusted results can be found in the Appendix 1 (Tables A1.3 and A1.4).

Table 3.5: Associations between objective crime, perceived safety (age 11) and self-reported physical activity (age 14) adjusting for ethnicity, parental education and family income

	Self-reported physical activity age 14		
Perceived safety age 11			
	All (n = 9127)	Male (n = 4551)	Female (n = 4576)
Very Safe (ref)			
Safe	-0.09 (-0.21, 0.02) p = 0.108	-0.01 (-0.17, 0.16) p = 0.955	-0.12 (-0.28, 0.04) p = 0.138
Not safe	-0.29 (-0.49, -0.09) p = 0.005	-0.30 (-0.57, -0.03) p = 0.031	-0.21 (-0.49, 0.08) p = 0.153
IMD 2004 crime			
	All (n = 8318)	Male (n= 4178)	Female (n = 4140)
1 (least crime)			
2	-0.23 (-0.37, -0.10) p = 0.001	-0.29 (-0.47, -0.10) p = 0.002	-0.17 (-0.36, 0.03) p = 0.100
3 (highest crime)	-0.32 (-0.47, -0.16) p = 0.000	-0.32 (-0.52, -0.11) p = 0.003	-0.27 (-0.48, -0.05) p = 0.015
Reported crime incidence (Data.Police.UK 2012-13)			
	All (n = 7431)	Male (n= 3743)	Female (n = 3688)
1 (least crime)			
2	0.23 (-0.13, 0.18) p = 0.765	-0.03 (-0.24, 0.19) p = 0.799	0.32 (-0.18, 0.24) p = 0.763
3 (highest crime)	-0.09 (-0.22, 0.05) p = 0.206	-0.06 (-0.25, -0.14) p = 0.573	-0.11 (-0.29, 0.06) p = 0.197

Note: separate linear regression models were fitted to examine relationships between objective and subjective indicators of crime and self-reported physical activity

IMD 2004 crime domain and Data.Police.UK 2012-2013 linked to MCS age 11 at the LSOA level.

3.3.2.2 Objective crime

An association was seen between IMD 2004 crime and self-reported physical activity at age 14, with those living in the top third highest crime areas reporting 0.32 (95% CI -0.47, -0.16) fewer days of moderate to vigorous physical activity compared to those living in the lowest crime tertile after adjusting for family income, ethnicity and parental education (Table 3.5). An interaction test showed no evidence of sex modifying this association.

No association was seen between reported crime incidence, measured via Data.Police.UK, and self-reported physical activity (Table 3.5).

Figure 3.4 presents predicted margins analysis of self-reported days of physical activity (age 14) and objective and subjective indicators of crime (age 11) stratified by sex. We did not observe sex differences in the associations between objective or subjective crime measures and self-reported psychical activity. However, girls reported lower physical activity across all levels of objective or subjective crime measures.

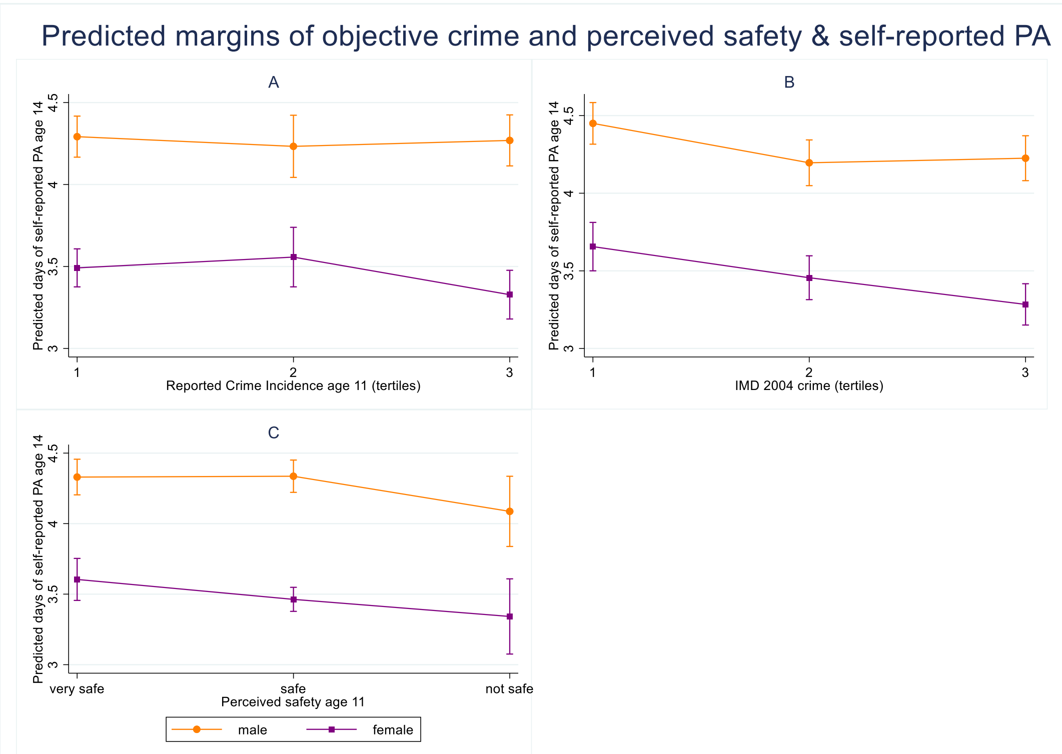

Figure 3.4 – Panel of graphs showing predicted self-reported days of physical activity (age 14) and objective and subjective indicators of crime (age 11) stratified by sex; A) perceived neighbourhood safety B) IMD 2004 crime tertiles C) Reported Crime Incidence measured via Data.Police.UK 2012-13. Although an interaction test showed no evidence of sex modifying these relationships, a clear difference in levels of physical activity between sexes is observed.

3.3.3 Objective physical activity

3.3.3.1 Subjective safety

There was no association between subjective (perceived) safety and doing zero minutes of exercise. For those achieving some MVPA (i.e., not in the zero minutes category), feeling not safe compared to very safe was not associated with decreased MVPA (Table 3.6).

3.3.3.2 Objective crime

For those achieving some MVPA (i.e., not in the zero minutes category), living in the highest IMD crime tertile compared to the lowest was associated with decreased MVPA at 80% bouts for 1 minute (Table 3.6). Individuals that lived in the highest crime areas achieved 7.38 (95% CI -13.21, -1.55) fewer minutes of exercise than those living in the least crime areas as shown in Figure 3.5.

Reported Crime Incidence, measured via Data.Police.UK, did not predict achieving zero minutes of MVPA (0.81 (95% CI -.39, 0.55). Living in a high versus low crime area was also not associated with MVPA for individuals in the non-zero category (Table 3.6).

No difference was seen between separate weekend and weekday accelerometer sensitivity analysis (Appendix Tables A1.10 and A1.11).

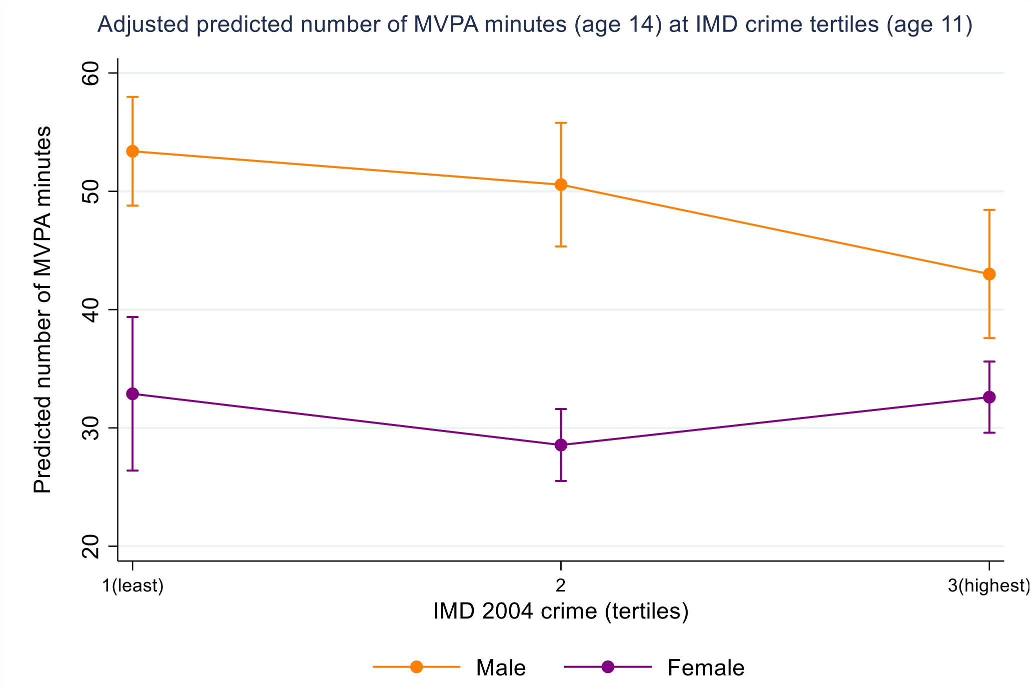

Figure 3.5 - Predicted margins analysis showed that, with covariates held at the mean, boys that lived in the highest crime areas at age 11 achieved 10.38 (95% CI -18.31, -2.62) fewer minutes of accelerometer-measured MVPA at age 14 than those living in the least crime areas. Girls in the highest crime areas achieved 0.28 (95% CI -7.11, 6.55) fewer minutes of MVPA.

Table 3.6: Zero-Inflated Poisson Model and Margins for objective and subjective crime (age 11) and accelerometer-measured MVPA (age 14) Adjusted for family income, ethnicity, parental education, sex and season of wear. Coefficients (95% CI).				
IMD 2004 crime (n = 3008)				
	Incidence Rate Ratio (IRR)	Inflate coefficient	Adjusted predictions (mins)	Marginal Effects at the Mean (MEMs)
1 (ref)			67.22 (62.34, 72.10)	
2	0.93 (0.86, 1.00) p = 0.070	0.13 (-0.89, 3.60) p = 0.236	62.43 (59.00, 65.85)	-4.79 (-10.06, 0.47)
3 (highest crime)	0.89 (0.81, 0.97) p = 0.011	0.74 (-0.14, 0.73) p = 0.527	59.84 (56.79, 62.89)	-7.38 (-13.21, -1.55)
Reported Crime Incidence (n = 2617)				
1 (ref)			63.26 (60.55, 65.97)	
2	1.05 (0.94, 1.17) p = 0.409	0.81 (-.39, 0.55) p = 0.736	66.33 (59.04, 73.66)	3.07 (-4.36, 10.49)
3 (highest crime)	0.96 (0.90, 1.04) p = 0.327	0.21 (-0.16, 0.60) p = 0.281	61.04 (57.36, 64.71)	-2.23 (-6.66, 2.21)
Perceived safety age 11 (n = 3085)				
Very Safe (ref)			61.38 (57.42, 65.34)	
Safe	1.05 (0.98, 1.21) p = 0.148	-0.82 (-2.54, 0.91) p = 0.353	64.46 (62.43, 66.49)	3.08 (-1.02, 7.17)
Not safe	0.96 (0.81, 1.14) p = 0.670	-0.59 (-3.15, 1.97) p = 0.651	59.16 (49.51, 68.81)	-2.22 (-12.35, 7.90)
Note: inflate coefficient predicts whether individuals are likely to achieve zero minutes of MVPA. Adjusted predictions analysis shows predicted minutes of MVPA with all other covariates held at the mean.				

3.3.4 Reported Crime Incidence sub-categories

It was decided *a priori* that the relevant subcategories that were grouped together to form the Reported Crime Incidence variable would be individually analysed for associations with physical activity outcomes. These subcategories were: anti-social behaviour, drugs, robbery, criminal damage and arson, public order, theft from the person and violent and sexual offenses.

No associations were found between anti-social behaviour, drugs, robbery, criminal damage and arson, public order or theft from the person (results of these analyses can be found in Appendix 1). However, the subcategory of violence and sexual offenses was associated with

0.20 (95% CI -0.39, -0.20) fewer days of self-reported physical activity but not accelerometer physical activity. Figure 3.6 shows predicted days of self-reported physical activity at 3 tertiles of violence and sexual offences, stratified by sex, showing a stronger association in girls.

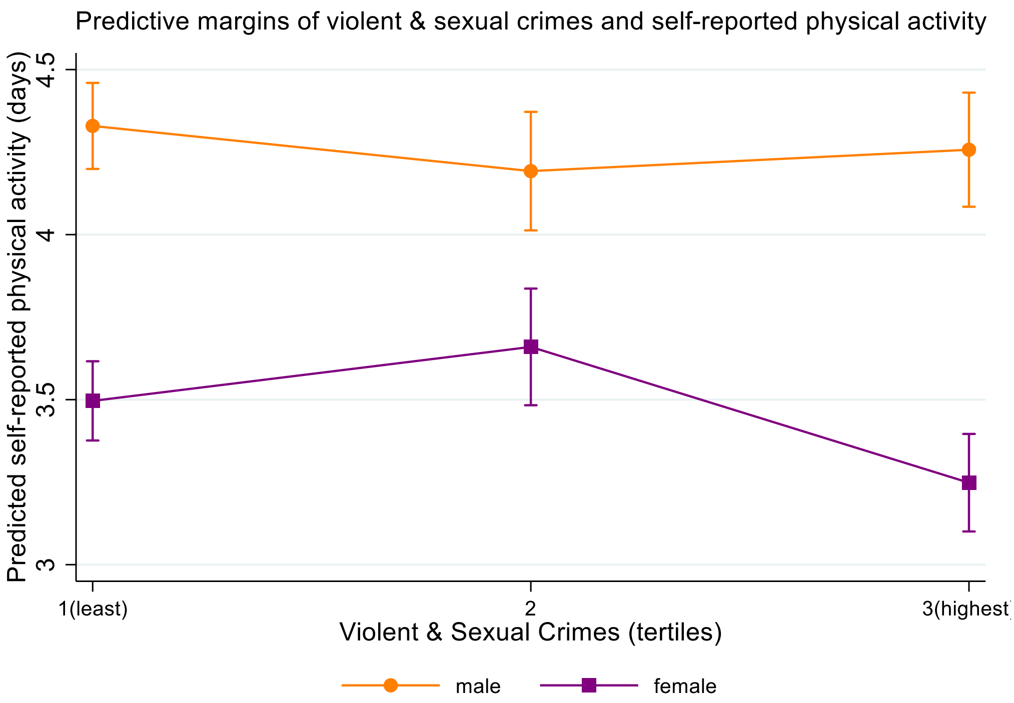

Figure 3.6 – predicted self-reported days of physical activity (age 14) at tertiles of reported Violent and Sexual crimes, measured via Data.Police.UK 2012-13 (age 11) linked to participant LSOAs. Girls living in areas with the highest reported violent and sexual crimes achieved -0.25 (95% CI -0.43, -0.7) fewer days of physical activity. Boys in the highest tertile of violent and sexual crimes achieved -0.07 (95% CI -0.28, 0.14) fewer days of physical activity.

3.4 Discussion

Neighbourhood safety is important for physical activity outcomes in adolescents. Results from this study show that reporting feeling very safe at age 11 and living in a lower crime area, measured with the IMD crime domain, are associated with more frequent self-reported physical activity at age 14. IMD crime at age 11 was associated with physical activity measured with accelerometer. However, age 11 subjective safety was not associated with device-measured physical activity at age 14. Reported Crime Incidence measured via Data.Police.UK did not have any relationship with physical activity - except for the subcategory of violence and sexual offenses, where an association was found particularly for girls.

The findings are consistent with existing evidence for similar studies of adults in the UK that show lower neighbourhood perceived safety is related to lower levels of self-reported physical activity (Brown et al., 2014; Harrison et al., 2007). Evidence focussed on the adolescent population is more limited but research from North America has found associations between perceived neighbourhood safety and self-reported physical activity (Lenhart et al., 2017); however, this North American study used cross-sectional data.

Neighbourhood outdoor spaces offer social opportunities for physical activity as well as inexpensive offerings such as walking or cycling. Adolescents can easily access their nearby outdoor spaces as they do not have to rely on adults for transport. Physical activity that occurs in the neighbourhood, as is likely during adolescence, is likely to be impacted by perceptions of safety within that space (British Heart Foundation National Centre, 2014). Feeling unsafe may decrease confidence in an individual's capacity to participate in physical activity through an inability to identify safe, convenient, and comfortable contexts in which to exercise (Bennett et al., 2007). Authors of a literature review, examining studies from Europe, Australia and USA, reported that perceived threat to personal safety and stranger danger leads to restriction of outdoor physical activity in children (Carver et al., 2008). Another review reported that crime and area deprivation are negatively associated with children and adolescent's physical activity participation (Davison & Lawson, 2006).

Research from a UK perspective highlights that fear of crime can restrict children's outdoor physical activity (Lorenc et al., 2013) and that children perceive public places to be less safe than home (Harden, 2000). Traffic safety perceptions may play a role in limiting physical activity with research suggesting young people associate increased traffic with reduced safety for walking or playing in their neighbourhood (Mullan, 2003). Low trust in the neighbourhood community has also been associated with reduced outdoor physical activity in adolescence (Berger et al., 2020).Moreover, parents' perception of the local environment on street lighting, graffiti and anti-social behaviour has been linked to reduced physical activity in children (Eyre et al., 2014).

Evidence from US studies show that fear of crime and gang-related activity prevents adolescents visiting parks and restricts outdoor activity (Stodolska et al., 2013). The presence of gangs in parks can lead to avoidance behaviour and limiting outdoor recreation and participation in physical activity (Shinew et al., 2013). However, it is important to note that the spatial landscape differs significantly between North America and the UK. For example, compared to the US, the UK has a less distinctive residential segregation of ethnic minorities (N. Zhang et al., 2017), whilst US cities also tend to be less dense and less compact that UK cities (Cox, 2022).

Although girls achieve lower levels of physical activity than boys in both measures, we did not find any evidence of sex differences in the relationship between safety, crime, and physical activity. Girls and boys also had similar responses to perceived safety at age 11 in their neighbourhood. This contrasts with research from the UK that suggest girls are more fearful of crime than boys (Lorenc et al., 2013), and it is possible that these differences become more apparent as children age. Previous studies have also reported greater associations between safety and physical activity in girls than boys, which was not the case in the present study. However, our measure of perceived safety did not explore the nature of concern of participants or ask what features of the neighbourhood made them feel unsafe in their area. It is therefore not possible to infer which aspects of the neighbourhood contributed to perceived lack of safety. For example, it is not clear if a lack of perceived safety stemmed from, for example, fear of crime-related activity, traffic density or lack of street lighting. It may be that specific aspects of neighbourhood safety are more salient to girls or boys and our measure was not able to capture this. We analysed subcategories of our Reported Crime Incidence measure, finding only an association between reported incidence of sexual and violent crimes and self-reported physical activity. This finding is consistent with research conducted with UK adults that reported violent crime, measured with police records, had a deterrent effect on self-reported physical activity, specifically walking (Janke et al., 2016).

I observed a larger effect size between lack of perceived safety and lower self-reported physical activity levels than IMD crime rate. This is consistent with the literature that suggests perceived feelings of safety are not just a reflection of recorded crime and may hold stronger implications for behaviour than subjective measures of crime (Lovasi et al., 2014). Perceived safety is shaped by fear plus broader perceptions of the social and physical environment and may have a stronger influence on behaviour than actual crime rate (Lorenc et al., 2012; Mason et al., 2013). Indeed, perceptions of crime can be influenced by reporting of crime in the media and social media, level of trust in the community or visible disorder in the neighbourhood (Brunton-Smith, 2011). Measurement error in crime statistics may also contribute towards a lack of agreement between objective and subjective measures of crime. Actual crime may be underrepresented due to lack of reporting of certain crimes. For example, anti-social or nuisance behaviour may be underreported in some neighbourhoods, but can increase an individual's perception of fear, especially if the police are less present. Similarly, sexual violence is hugely underreported, with some studies showing that only 15% of victims report an incident to police in England and Wales (Ministry of Justice et al., 2013). It is also necessary to note that differential reporting can occur between neighbourhoods with socioeconomically disadvantaged neighbourhoods reporting offenses less often (McGinn et al., 2008).

I also found discordance between IMD crime and Reported Crime Incidence measured via Data.Police.UK with these variables being weakly correlated (r = 0.10). This discrepancy between the two measures could be due to several factors. Firstly, although the IMD crime domain is based on police recorded crime, it does not include sexual offense or drug-related crimes. While it is possible that the different time periods covered by the IMD 2004 and our Reported Crime Incidence variable (January 2012 – February 2013) partly explains the weak correlation between the two; evidence suggests that area-level deprivation did not change significantly between the 2004, 2007 and 2010 IMD (Kontopantelis et al., 2018; McLennan et al., 2011). Linking both measures of crime to participant geographical identifiers is a novel aspect of this study which indicates that these measures may represent crime distinctly.

It is important to consider the idea of the 'neighbourhood' itself. The neighbourhood can be defined in many ways, for example, by physical boundaries such as rivers, by administrative boundaries or by social relationships (Holland et al., 2011). It has been argued that geographical administrative units, such as electoral wards or local authority districts, are not well-suited to examine environmental effects on health as they do not represent an individual's potentially accessible environment and may not be representative of individual spatial experience (Perchoux et al., 2013). Moreover, geographical units are likely to be less representative of environmental exposures for individuals living at the boundary compared to those living at centre of a unit. However, as LSOAs are units of an average of 1,500 people; they benefit from a more local scale than electoral wards. Some research has indeed indicated that smaller geographic areas may be more meaningful (Stein, 2014) and that residents of the same LSOAs are likely to share similar socioeconomic characteristics therefore providing more homogeneity. Nevertheless, this may not be the case in rural areas where LSOAs tend to be much larger. In the present study, the MCS cohort represents participants living in both rural and urban areas.

Physical activity as measured by accelerometer did not show any association with either perceived safety, IMD crime or Reported Crime Incidence. Previous research has indicated a divergence between self-report and objectively measured physical activity. The output of the accelerometer and physical activity question we used are not directly comparable. Participants were asked about the number of days per week they engage in physical activity whilst the accelerometer measured continuous movement and MVPA. It is possible that the accelerometer recorded more movement than the participant recalled. Furthermore, participants wore accelerometers for two days (one weekday and one weekend) meaning that only a small snapshot of the participants regular habits were captured.

3.4.1 Strengths and limitations

Strengths of this study include a large sample size with good response rate. This study also benefits from the use of nationally representative, demographically diverse longitudinal data and analyses disaggregated by sex.

This study is further strengthened from the use of both subjective and objective measures of both exposure and outcome allowing us to gain a well-rounded and nuanced picture of associations. I was able to analyse self-reported physical activity data together with its objectively measured counterpart. Similarly, participants perception of neighbourhood safety was available alongside objectively collected crime incidence. To our knowledge, this is the first study to utilise the IMD crime domain plus reported crime incidence from Data.Police.UK linked to participant LSOAs.

Limitations of this study include the use of IMD 2004 comprised of crime data from April 2002 to March 2003; the sixth survey of MCS was carried out between 2015-2016. The IMD crime domain is an aggregate score of different crime subtypes. This aggregated measure lacks specificity and could obscure effects that may have been present if analysis had been conducted with component variables. Furthermore, IMD crime data for Scotland were not available and therefore participants from Scotland were omitted from analysis that utilised IMD as the exposure. However, we conducted sensitivity analyses with a sample excluding participants from Scotland (supplementary material 6.2) which showed no differences in the trends between the full sample and sample without Scottish participants. Lastly, the summary data from the IMD crime domain may suffer from the MAUP, whereby the IMD's geographical boundaries are purely administrative, so are not especially meaningful for representing everyday activity in the area. The data summarised may be masking underlying patterns in the spatial distribution of the data.

Physical activity conducted at school or during after-school clubs would contribute to an individual's self-reported physical activity score and accelerometer results, but these activities are unlikely to be impacted by neighbourhood crime or safety. In this study I focused on moderate vigorous physical activity, described in the questionnaire as any activity that raises heart rate and breathing. However, walking is a common form of physical activity and is typically performed in neighbourhood streets and green spaces and is therefore an important consideration for future research in this area.

Accelerometer data was recorded on one weekday and one weekend day to balance time coverage and participant burden. However, this approach covers a limited time window in participants' lives and previous studies have indicated that 3 days of measurement is optimal for reliability in children (Mattocks et al., 2008). The accelerometer data came from a sub-set of the full sample which may have been subject to selection bias. However, sensitivity analyses (Appendix 1) showed no differences between subsample and study sample results.

3.5 Conclusion

I examined associations between subjective safety, IMD crime and Reported Crime Incidence at age 11 with self-reported and accelerometer-measured physical activity at age 14. I found associations between subjective safety, IMD crime and self-reported physical activity levels in adolescence.

Results from this study highlight that safety and fear of crime in the neighbourhood are important considerations for physical activity in adolescence, especially when considering environments that are welcoming to adolescent girls. Improving feelings of safety could be a key approach to reducing barriers to physical activity participation. Future research work should focus on investigating the aspects of the neighbourhood which lead to reduced perceived safety and interventions to address this. Similarly, features of the neighbourhood which may encourage physical activity are necessitated as is explored in Chapter Four. From a methodological view, researchers should also consider that IMD and Reported Crime Incidence measured via Data.Police.UK are not proxies for each other and reflects the importance of triangulation.

Chapter Four – Proximity to greenspaces and subjective and objective indicators of physical activity

4.1 Introduction

In the previous chapter I examined associations between neighbourhood crime and safety and physical activity. In this chapter, I explore other aspects of the neighbourhood, namely whether proximity to greenspace may also affect adolescent physical activity behaviours.

The health benefits of physical activity are well known, with evidence that regular physical activity reduces the risk of cardiovascular disease and type 2 diabetes and contributes to healthy weight status (Davies et al., 2019; Kumar et al., 2015). As previously discussed in Chapter Three, adolescence is a critical period of development where habits and lifestyle behaviours, including physical activity, are shaped. Previous research suggests that participation in physical activity in adolescence (12-18 years) predicts activity in adulthood (Huotari et al., 2011), highlighting the public health importance of reducing barriers to physical activity in adolescence.

Socio-ecological models of health consider the social, cultural, environmental, and individual circumstances which influence health behaviours. It is increasingly recognised that the built environment plays a pivotal role in shaping health and wellbeing. Greenspaces are considered an environmental factor that can influence physical activity participation (Gardsjord et al., 2014; R. Zhang et al., 2019). Greenspace is a term used to describe either maintained or unmaintained environmental areas including woodlands, nature reserves, urban parks and outdoor sports facilities (Barton & Rogerson, 2017). Natural England state that everyone should have access to good quality greenspace within 15 walking minutes of their home, plus a 'doorstep' or local greenspace within 5 walking minutes, due to the positive influence of greenspaces on health and wellbeing (Natural England, 2023).

There are a wide range of measures used to capture access to greenspace. For example, there is a significant body of research that focusses on the amount of greenspace within an administrative boundary. A common measure in the UK literature is the Generalised Land Use Database (GLUD) which groups land use into 9 categories with one of these categories being greenspace. Some studies have used this measure to calculate percentage of land area classified as green space within a specific administrative unit (Dennis & James, 2017). This approach, however, does not consider the specific type or use of greenspace nor any greenspace that may be just outside an administrative boundary. For example, an individual may live at the edges of an administrative boundary, very close to a greenspace in a neighbouring administrative area, but coded as lacking access to green space. This is sometimes referred to as 'platial' geography whereby places are conceptualised as areas that are meaningful to a person and based on patterns of behaviour rather than spatial boundaries (Mocnik, 2022; Wolf et al., 2021). Proximity to greenspaces can also be measured in variety of ways including Euclidean (straight line) distance and network distance. Proximity measures, unlike amount of greenspace in a spatial unit, do not rely on administrative boundaries. Euclidean distance does not consider spatial configuration and usually results in an underestimation of the distance to the access point (Sander et al., 2010), however, it remains a popular measure due to ease of calculation. Network distance represents the metric distance between points along a specific network accounting for roads and pathways, as illustrated in Chapter One – Background, Figure 1.1. This is achieved via network analysis, using Geographical Information Systems (GIS), which has the limitation of being computationally intensive when analysing large areas. However, proximity measures calculated via network analysis have the advantage of being more likely to capture actual exposure to greenspace compared with measures such as the GLUD.

The relative importance of types of greenspaces may differ by age-group. For example, research from the US suggests that adults aged 30-50 years use greenspaces with paved paths for exercising whilst young males, but not females, aged 18-29 years are more likely to use forested areas (Sander et al., 2017). Adolescents, generally defined as ages 10-19 years (World Health Organisation, 2014), compared to young children, have greater independence and ability to explore their neighbourhood and make use of greenspaces, but are still limited in their ability to visit locations at greater distances (Van Hecke et al., 2018). Evidence from Madrid, Spain, suggests that adolescents' sense of place and perception of their local area extends to around 1km (or 10–12-minute walk) (Hewitt et al., 2020), suggesting that proximity to local greenspaces may be significant for usage in this age group.

As children have less independence and mobility than adults, their local environment may be a particularly important determinant of their participation in physical activity. It is widely hypothesised that environmental attributes play an important role in physical activity in youth (Ding et al., 2011). By offering an accessible and attractive place for exercising it is posited that greenspaces encourage physical activity. An observational study using data from the Health Survey for England found a positive association between adults living in the greenest quintile, compared to the least, and self-reported physical activity (Mytton et al., 2012). Moreover, a recent systematic review found a positive association between greenspace and physical activity in children and adolescents (Zare Sakhvidi et al., 2023). However, this review highlights the heterogeneity in measurement of greenspaces and physical activity and is not specific to the UK, nor adolescence. A Canadian study reported living near more parks increased achievement of moderate-vigorous physical activity, particularly in younger people (18-34 years) (Kaczynski et al., 2009). Research from the US has shown that greater availability of parks in urban areas is positively associated with self-reported physical activity in adolescents aged 12-17 years, but not for those from lower-income families (Babey et al., 2008). However, equivocal relationships between neighbourhood greenspaces and physical activity have been reported in the literature with some studies reporting counter-intuitive associations (Burbidge & Goulias, 2009). A study of 13–15-year-olds in Bristol, UK, concluded that adolescents living in less supportive neighbourhoods, measured as availability of greenspaces, walkability and destinations to visit, achieved the same volume of physical activity as those living in more supportive neighbourhoods (Coombes et al., 2017).

There are varying approaches when measuring physical activity participation as also discussed in Chapter Three. Briefly, device-measured, sometimes referred to as objective measures, utilise accelerometers to accurately capture physical activity in participants. Objective measures can be more reliable in measuring time and intensity of physical activity. However, devices are expensive and time-consuming for both researchers and participants. Subjective measures include questionnaires allowing participants to self-report their physical activity. This is a low-cost, low-burden approach to capturing physical activity. Questionnaires can also be distributed on a larger scale than devices. However, subjective measures may be subject to recall bias. Study results are likely to vary depending on whether subjective or objective measures are used. Chapter Three has demonstrated how results can differ when using different measures of neighbourhood safety and crime and physical activity (Constable Fernandez et al., 2023).

This study aims to investigate the relationship between proximity to greenspaces and physical activity in adolescents by employing GIS network analysis and both device-measured and subjective measures of physical activity. I also aim to carefully consider socioeconomic confounding, the importance of which is outlined in Chapter Two 2.4.2 Confounding.

Findings from this chapter will address gaps in the literature by focusing on proximity to greenspaces from participants home location and will only include greenspaces specifically relevant to physical activity.

4.2 Methods

4.2.1 Participants

This study uses data from sweep 6 of the Millennium Cohort Study (MCS) which is described in detail in Chapter Two. There were 11,726 productive responses at sweep 6 (age 14) with productive defined as data from at least one of the data collection instruments including main interview or parent interview.

The analytical sample was compromised of participants with postcode data available, and successfully linked to closest greenspace access point, and with either outcome measure n=9873 (self-reported or device-measured PA) at age 14.

4.2.2 Greenspaces

Postcodes were gathered from participant addresses collected at age 14 (sweep 6). Due to confidentiality and the need to protect cohort member's identity, address level data is not available.

Neighbourhood greenspace data was calculated using the Ordnance Survey MasterMap Greenspace Layer which gives a comprehensive view of greenspaces within an urban area. It includes public and private green spaces including the access points, sports facilities and natural environmental areas. Types of greenspaces are categorised into: playing field, public park or garden, play space, allotment, cemetery, sports facility, religious grounds, golf course, tennis court, bowling green. Based on existing literature, which I outline below, only greenspaces that are relevant to adolescents and their physical activity will be included in the analysis. These are: playing fields, public park or public garden, play space, sports facility and tennis courts (though a limitation remains that the latter two may include facilities not freely available to the public).

Previous research has shown that parks (including formal maintained parks, heathland and woodland) are important spaces for children to be active (Lachowycz et al., 2012). Private greenspaces can be considered passive greenspaces due to their minimal benefits to the wider public (Daras et al., 2019). The Access to Health Assets and Hazards (AHAH), an index developed by Great Britain's Consumer Data Research Centre, excludes bowling greens, golf courses, religious grounds and cemeteries from its greenspace indicator for being non-conducive to physical activity (Consumer Data Research Centre, n.d.). Participation rates suggest that outdoor bowls, played on bowling greens, is predominantly played by adults with Sport Scotland reporting only 1% of 16-24 year olds playing (Sport Scotland, 2006) and no statistics are available for participation in younger children. The OS MasterMap Greenspace Layer does not distinguish between public and private golf courses.

Moreover, the Active Lives 2021-22 survey reported a golf participation rate of 0.3% in 5-16 year olds (Sport England, 2022). Allotment use is also largely dominated by older adults; allotments are not publicly accessible with UK plot-holders required to be 18 years or older.

Network distance between the access points of greenspaces and the postcode centroid of cohort members was calculated using GIS software tools. It is important to note that calculating distances from centroids in rural areas (where postcodes are larger in size) can lead to reduced precision (Burden et al., 2014) as discussed in Research Aims and Objectives

The overall aim of this thesis is to explore whether the features of the neighbourhood environment influence physical activity and social isolation outcomes in an adolescent population.

To achieve this aim, I use epidemiological methods alongside aspects of spatial and urban science and health geography. By employing a multidisciplinary approach, I aim to bring relevant aspects of these disciplines together to inform research questions, analytical methods, and better understand the UK spatial landscape in a health context. For example, I used geo-coded data and uses measures generated from Geographical Information Software (GIS) to better capture the neighbourhood features of interest.

This thesis recognises that the neighbourhood is multidimensional. The following chapters explore how the neighbourhood exposures of crime and safety, greenspace, and high streets may be important for adolescence. This thesis focuses on outcomes in adolescence, specifically, physical activity and social isolation and social support outcomes.

Research objectives:

10) To explore how neighbourhood crime and perceived safety impact physical activity behaviours. This study also explores the complexities around using objective and subjective measures for both exposure and outcomes.
11) To explore whether greenspace plays a role in physical activity behaviours, whilst carefully considering socio-economic confounding factors.
12) To investigate whether high streets, as a proxy for areas of social encounter, activity, and interaction, are important for social isolation and social support.

Results from this thesis will offer important insight into the UK neighbourhood environment, relevant to health in adolescence.

Over 75% of the access points used in the Open Greenspace data are pedestrian only access points with the remaining being combined pedestrian and motor access points. Using network distance accounts for real-life walking or travel distance to the access point. GIS network analysis calculates distance to the access point based on road networks and pathways. Using ArcGIS software, a network service area can be created; this is a region which encapsulates all the accessible streets along with all entry points to green spaces within a given distance from the defined point.

Walking time in minutes and network route distance in metres to the postcode centroids were calculated (correlated r = 0.99). Network distance is measured along publicly accessible roads and footpaths to capture how a person might walk. We utilised the walking time of the network distance given that policy guidance often makes recommendations based on walking minutes. Walking speed is calculated at 5 kilometres per hour. Walking time is rescaled so that one unit represents 10 minutes.

I also examine an exposure that is based on guidance around green space access. According to guidance from the UK government's National Planning Policy Framework, there is no minimum size for a local greenspace. However, Natural England recommend that everyone should live within 5 mins walk of a 2-hectare accessible greenspace (Natural England, 2023). This also in line the World Health Organisation's recommendations (World Health Organization., 2016). Other studies investigating physical activity and greenspace have also considered a minimum of 2 hectares (A. Jones et al., 2009). Hence, I also created a variable of walking time to participant's closest greenspace that is at least 2 hectares.

As 99% of observations of walking time to closest greenspace of any size were below 40 minutes, observations above 40 minutes were recoded to 40 minutes. Similarly, 99% of observations of walking time to closest greenspace of 2 hectares were below 100 minutes, therefore, observations above 100 were recoded as 100.

4.2.3 Physical Activity

Physical activity was similarly measured as in Chapter Three (3.2.3 Physical Activity) using self-report questionnaires and accelerometers.

4.2.3.1 Self-report

At the age 14 survey, participants were asked how many days in the last week they had taken moderate to vigorous physical activity. The response categories were: Every Day, 5-6 Days, 3-4 Days, 1-2 Days or Not at All. We reversed and coded this as 0, 1.5, 3.5, 5.5 and 7 respectively to create a scale for the outcome that could be interpreted as number of days of exercise per week.

4.2.3.1 Device-measured

Physical activity was objectively measured with Generative wrist-worn activity (GENEActiv) monitors at age 14. The variable chosen in this study as the MVPA outcome was 1-minute time windows for which 80% of 5-second epoch values were equal to or higher than the 100-mg threshold. Data for weekday and weekend were combined and averaged.

4.2.4 Covariates

I included ethnicity and sex as covariates. The MCS has a rich set of SEP indicator variables which were all used to achieve the most thorough socio-economic confounding adjustment possible with these data. I included: parental education, occupational status, income and household wealth. Chapter Two (2.1.5 Covariates) specifies how each covariate was measured in the MCS.

4.2.5 Statistical analysis

I conducted descriptive statistics presented as frequencies and percentages and means with ranges or confidence intervals.

In preliminary analyses I used linear regression to examine associations between walking time to nearest greenspace access point from the participant postcode centroid and self-reported physical activity at age 14 and device-measured MVPA. I log-transformed device-measured MVPA since the variable had a right-skewed distribution.

To account for the geographical structure of the dataset, I then used multilevel linear regression for each outcome. Multilevel, or hierarchical, models can be useful when confounding occurs at multiple levels and when observations are correlated due to clustering. Multilevel techniques are increasingly used in social epidemiology and health geography to allow the investigation of spatial effects. In the multilevel approach, relationships estimated using individual level variables can be appropriately nested within a relevant spatial framework to account for non-random area clustering (Griffith & Jones, 2020). Neighbourhood effects on a given outcome can therefore be captured, net of the characteristics of the individuals living within them (Owen et al., 2016). The MCS sample was clustered by characteristics of electoral ward (n=398), hereafter referred to as neighbourhood clusters. Therefore, I created two-level models where individual participants were considered level 1 and neighbourhood clusters as level 2. I first created a baseline random intercept multilevel model which included physical activity only. This serves as a baseline reference, indicating the maximum proportion of variance in physical activity that could potentially be attributed to differences among neighbourhood clusters.

For each outcome, I then included our exposure of walking time in minutes to closest greenspace in the random intercept model. I then included a random intercept and random slope. This allows the effects of the predictor variables on the outcomes to vary across areas. However, where the data best fit a random intercept model, as assessed with AIC and BIC, random slope was not included. This was the case for models where device-measured MVPA was the outcome. I then created a fully adjusted model including parental education, parental income, occupational status and wealth plus ethnicity and sex.

I finally used a further statistical approach to consider neighbourhood spatial effects. The Mundlak model measures the "contextual effect" by adding group-means of independent variables which vary within groups (Bell et al., 2019; Mundlak, 1978). This approach can measure the effect of the neighbourhood, once the individual-level factors have been accounted for, or in other words, to explain mean differences between neighbourhoods. Using this approach, the area mean of the individual variable is included in the model. In this case, mean of the walking time to nearest greenspace, by the neighbourhood cluster, for MCS participants is included as an additional variable in the model.

Variance Partitioning Coefficients (VPC) were calculated for each model. The VPC measures how much variance in the independent variable (physical activity) is accounted for by clustering.

I also investigated whether physical activity participation is associated with walking time to nearest greenspace that is at least 2 hectares, as per the Natural England recommendations (Natural England, 2023). Association between walking time to nearest greenspaces, that are a minimum of 2 hectares, and self-reported and device-measured MVPA was quantified using the multilevel random effects models as above.

4.2.5.1 Missing Data

For missing information within the analytic sample, multiple imputation with chained equations was used with 35 imputations. To account for non-response and adjust for attrition at age 14, combined survey and non-response weights were used. Further information on the missing data strategy can be found in Chapter Two.

4.2.5.2 Secondary analysis

The fully adjusted models were also stratified by sex and income tertiles, as a proxy for socio-economic status, to allow for assessment of any difference in associations within each income stratum.

It has been hypothesised that greenspace size may be important, with larger greenspaces more likely to be used for physical activity (Rey Gozalo et al., 2019). As a further secondary analysis, associations between the size of closest greenspace and physical activity were analysed.

4.2.5.3 Sensitivity analysis

As the risk of measurement errors in creating distance measurements is greater in rural areas, partly due to larger postcode sizes, a sensitivity analysis between participants living in rural and urban areas was conducted. MCS postcodes were grouped into the 2005 ONS rural/urban classification which uses 6 categories defined as follows: major urban; large urban; other urban; significant rural; rural-50 and rural-80.

Additionally, the possibility of a non-linear relationship was explored by categorising walking time into groups of 5 minutes up to 40 minutes.

4.3 Results

4.3.1 Descriptives

Table 4.1 shows descriptives of the analytic sample at age 14. 49.82% of the sample were female and 78.37% were white. The mean walking time to closest greenspace (of any size) access point was 5.90 minutes (min: 0.004, max: 128.81), whilst the mean walking time to closest greenspace (minimum 2 hectares) was 12.58 minutes (min: 0.04, max: 428.90). Figure 4.1 shows the distribution of the raw and recoded variables of walking time to closest greenspace of any size and of least 2 hectares.

At age 14, 9,858 participants (99.85% of the analytical sample) in the analytical sample answered the self-reported physical activity question, with approximately 24% of boys reporting taking part in physical activity everyday compared to 12% of girls. The subsample of participants that wore accelerometers (n = 4078) achieved a daily average of 61.20 minutes (95% CI 59.53, 62.87) device-measured physical activity, at 80% bouts for 1 minute (Table 4.2), with males achieving more at 68.60 minutes (95% CI 66.30, 70.91) compared to females at 54.24 minutes (95% CI 51.87, 56.60). The device-measured MVPA variable was skewed to the right with a peak at zero.

We also examined greenspace proximity based on income quantiles. Figure 4.3 illustrates the distribution of walking time (and mean size) of closest greenspace by income. The histogram shows that those in higher income quantiles tended to have greater walking times to closest greenspace.

Table 4.1: Study sample characteristics at age 14 (n = 9873)

Sex		**Frequency**	**Percent**
Female		4919	49.82
Male		4954	50.18
	Total	9873	100.00
Highest Parental Education			
NVQ level 1 (CSE below grade 1/GCSE or O Level below grade C, SCE Standard, Ordinary grades below grade 3 or Junior Certificate below grade C)		255	2.61
NVQ level 2 (O Level or GCSE grade A-C, SCE Standard, Ordinary grades 1-3 or Junior Certificate grade A-C)		1392	14.09
NVQ level 3 (A/AS/S levels, SCE Higher, Scottish Certificate Sixth Year Studies, Leaving Certificate)		1246	12.62
NVQ level 4 (first degree, diplomas in higher education, teaching qualifications for schools or further education)		3451	34.95
NVQ level 5 (higher degree, postgraduate qualification, certificate or diploma)		1778	18.01
Other academic qualifications (incl. overseas)		459	4.64
	Missing	1292	13.08
	Total	9873	100.00
Ethnicity			
White		7665	78.37
Mixed		490	5.00
Indian		292	2.98
Pakistani and Bangladeshi		768	7.86
Black or Black British		323	3.30
Other ethnic group (inc Chinese, other)		241	2.48
	Missing	1	0.01
	Total	9873	100.00
Income Quintile			
First quintile		1576	15.96
Second quintile		1577	15.97
Third quintile		1891	19.15
Fourth quintile		2318	23.49
Highest quintile		2500	25.32
	Missing	11	0.11
	Total	9873	100.00
Occupational Status			
Not in work		2480	25.12
Semi-routine and routine		1673	16.95
Lower supervisory, technical		233	2.36
Small employers/self-employed		601	6.09
Intermediate		1558	15.78
Managerial and professional		2832	28.68
	Missing	496	5.02
	Total	9873	100.00

Table 4.2: Descriptive information for physical activity variables

Accelerometer measured physical activity at age 14. Mean (95% confidence intervals)			
Variable	**All (n = 4078)**	**Male (n = 1976)**	**Female (n = 2102)**
Mean acceleration (ENMO – Euclidean Norm Minus One) for the day (24 hours)	34.31 (32.59, 36.03)	35.76 (35.04, 36.48)	32.94 (29.67, 36.22)
Moderate to Vigorous Physical activity (MVPA)			
Total minutes in MVPA: 5sec epochs where ENMO > 100mg	125.33 (123.35, 127.31)	129.92 (127.08, 132.76)	121.01 (118.26, 123.76)
Total minutes in MVPA: 1min epochs where ENMO > 100mg	123.21 (120.96, 125.45)	132.02 (128.73, 135.30)	114.92 (111.90, 117.95)
Total minutes in MVPA: 5min epochs where ENMO > 100mg	114.02 (111.53, 116.50)	126.99 (123.32, 130.66)	101.82 (98.53, 105.11)
Moderate to Vigorous Physical activity (MVPA) at bouts of 80%			
Mins in mod/vig: 5sec epoch, 80% bout criteria 100 ENMO 1min	61.20 (59.53, 62.87)	68.60 (66.30, 70.91)	54.24 (51.87, 56.60)
Mins in mod/vig: 5sec epoch, 80% bout criteria 100 ENMO 5min	37.87 (36.34, 39.40)	45.81 (43.74, 47.88)	30.41 (28.20, 32.62)
Mins in mod/vig: 5sec epoch, 80% bout criteria 100 ENMO 10min	28.82 (27.35, 30.29)	36.20 (34.25, 38.15)	21.88 (19.74, 24.02)

Self-reported physical activity at age 14. N (%)

	All (9858)		**Male (4912)**		**Female (4946)**	
0 days	421	(4.27%)	186	(3.79%)	235	(4.75%)
1.5 days	2398	(23.33%)	888	(18.08%)	1510	(30.53%)
3 days	3345	(33.93%)	1552	(31.60%)	1793	(36.25%)
5.5 days	1908	(19.35%)	1090	(22.19%)	818	(16.54%)
7 days	1786	(18.12%)	1196	(24.35%)	590	(11.93%)

Distribution of walking time (mins) to closest greenspace

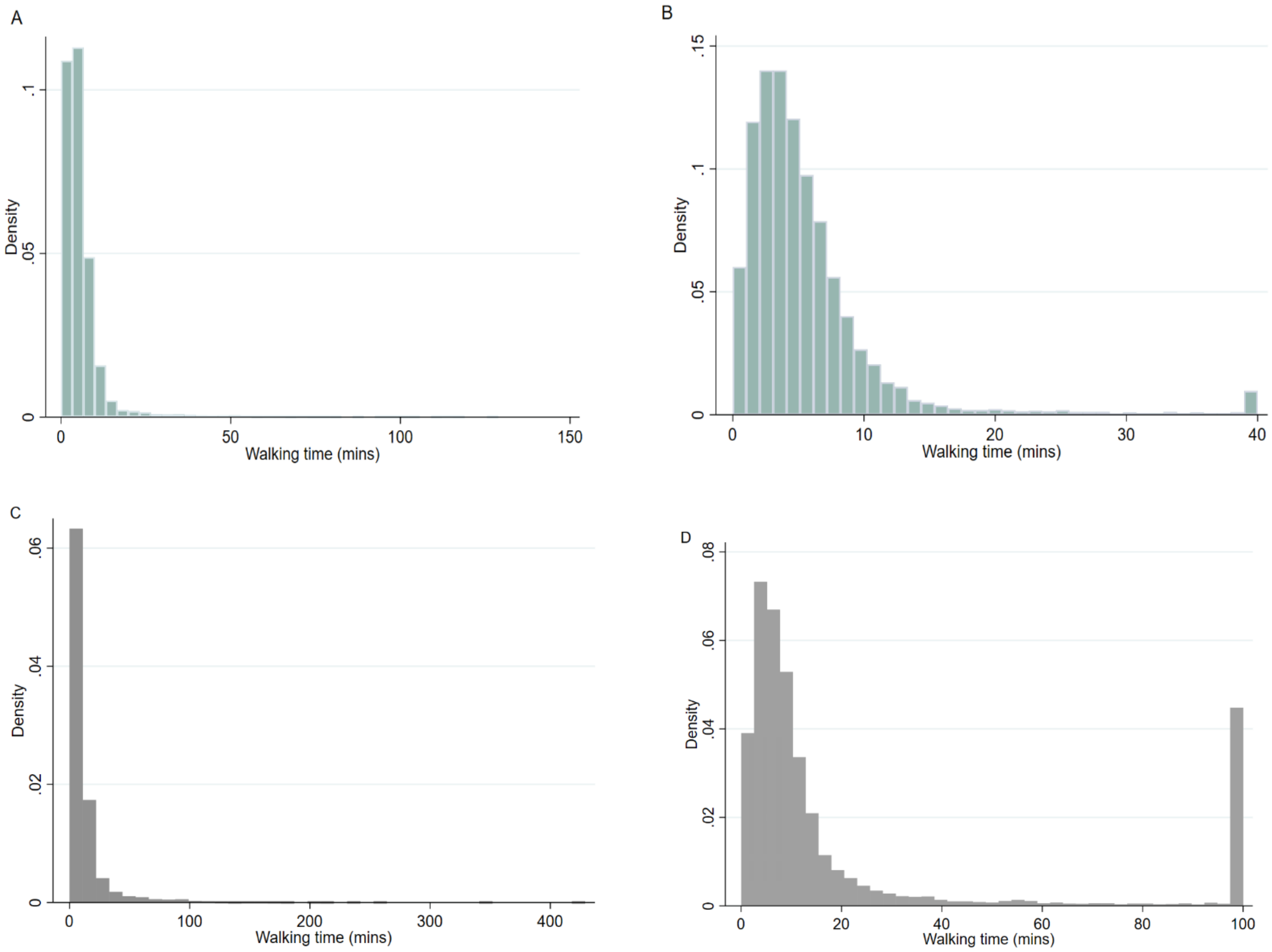

*Figure 4.1 - **A:** raw variable for walking time to greenspace of any size. Mean = 5.90 (min 0.004, max 128.81) **B:** recoded variable with walking time to greenspace of any size to maximum 40 mins. Mean = 5.70 (min 0.004, max 40). **C**: raw variable walking time to greenspace of minimum 2 hectares. Mean = 12.58 (min 0.04, max = 428.90) **D:** recoded variable, mean = 21.49 mins (min 0.04, max 100)*

Distribution of device-measured moderate vigorous physical activity (MVPA)

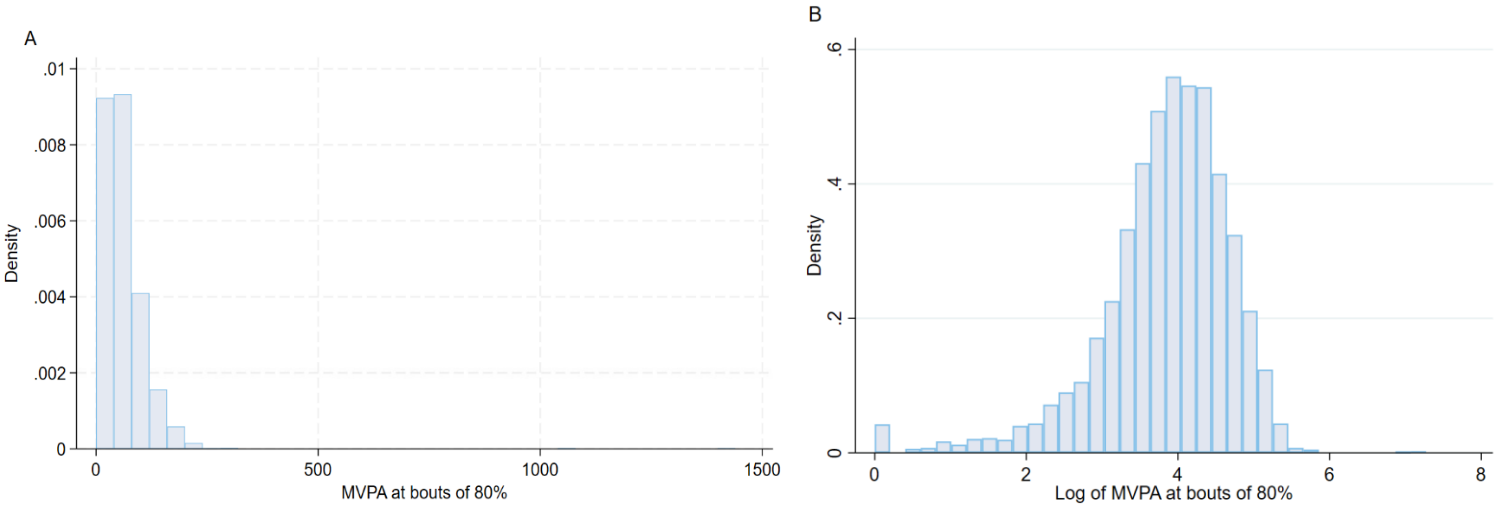

Figure 4.2 – Histogram showing distributions of mean time spent in MVPA (1-minute time windows for which 80% of 5-second epoch values were equal to or higher than the 100-mg ENMO threshold) ***A:*** *raw variable.* ***B:*** *log transformed variable*

Mean size and mean walking time to closest greenspace by income quantile

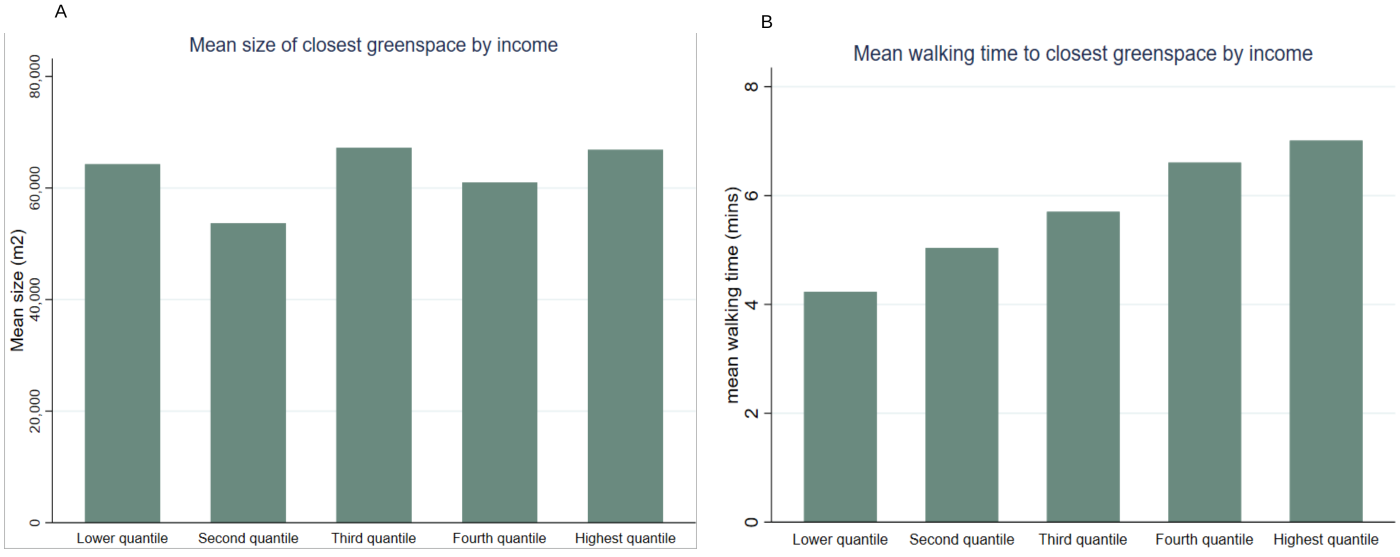

*Figure 4.3 - Bar graphs depicting mean size (**A**) and mean walking time (**B**) to closest greenspace by income.*

4.3.2 Walking time to closest greenspace (of any size) and self-reported PA

Preliminary linear regression estimated the association between every 10 minutes of walking time to greenspaces and self-reported days of PA as 0.15 (95% CI 0.08, 0.22).

The baseline multilevel model estimated the overall mean self-reported PA across all neighbourhood clusters as 3.92 days (95% CI 3.86, 3.97) and the amount of variance (calculated with VPC) in self-reported PA by neighbourhood cluster as 2.5% (95% CI 1.7, 4.0).

The unadjusted random slope model showed that every 10 minutes increase of walking time to closest greenspace was associated with 0.13 (95% CI 0.04, 0.22) increase in days of self-reported physical activity (Table 4.3). This estimate was 0.10 (95% CI 0.02, 0.19) following adjustment for overall wealth, occupational status, parental education, income (UK equivalised), and ethnicity and sex.

The VPC estimated that neighbourhood clusters account for 2.2% (95% CI 0.01, 0.04) of total residual variance in self-reported PA in the adjusted random slope model.

For males, every 10 minutes of walking time to greenspace was associated with 0.03 (95% CI -0.09, 0.16) days increase in physical activity compared to 0.17 (95% CI 0.05, 0.29) in females, adjusted for covariates (Table 4.3).

The area-level mean of walking time to nearest greenspace by neighbourhood cluster was included in the Mundlak approach. In this model, the coefficient of the “contextual effect” was estimated as -0.03 (95% CI -0.27, 0.22) indicating no mean differences in self-reported PA between neighbourhood clusters.

4.3.3 Walking time to closest greenspace (of any size) and device-measured MVPA

Preliminary linear regression estimated the association between every 10 minutes walking time to greenspaces and log-transformed MVPA as 0.06 (95% CI 0.02, 0.11).

The baseline multilevel model estimated the overall log-transformed device-measured MVPA across all neighbourhood clusters as 3.86 (95% CI 3.82, 3.90) and showed the amount of variance (calculated with VPC) in device-measured MVPA by neighbourhood cluster as 5.5% (95% CI 3.3, 8.7).

For every 10 minutes of walking time to closest greenspace, a 6% (CI 95% 2.00, 10.00) increase in device-measured MVPA was seen in our random intercept model (Table 4.4), which I found to be a better fit than the random slope model.

When adjusting for covariates, a 3% (95% CI -1.00, 7.00) increase in device-measured MVPA for every 10 minutes of walking time to closest greenspace was estimated, however, the wide confidence intervals crossing 0 indicates uncertainty around this estimate and likely no effect. The VPC of the adjusted model showed that 5% (95% CI 1.00, 1.70) of the total individual differences in physical activity might be attributed to neighbourhood cluster factors. Similarly, no associations were observed in males or females separately (Table 4.4).

There was no evidence for a "contextual effect" as measured with the Mundlak formulation and estimated as 0.00 (95% CI -0.13, 0.13).

4.3.4 Walking time to closest greenspace (minimum 2 hectares) and self-reported PA

Preliminary linear regression estimated the association between every 10 minutes of walking time to greenspaces and self-reported PA as 0.01 (95% CI 0.00, 0.02).

The unadjusted model showed that every 10 minutes of walking time to closest greenspace, that was at least 2 hectares in size, was associated with 0.03 (95% CI 0.00, 0.07) increase of self-reported PA days (Table 4.3). This association remained at 0.03 (95% CI -0.01, 0.07) with the inclusion of covariates, although the standard errors and 95% CI increased. The VPC estimated that 2.3% (95% CI 1.00, 4.00) of the variance in physical activity could be explained by neighbourhood clusters.

No associations were seen when males and females were analysed separately.

The Mundlak approach (mean of walking time to greenspace per cluster included in the model) showed there was no evidence for the "contextual effect" at 0.00 (95% CI -0.07, 0.07).

4.3.5 Walking time to closest greenspace (min 2 hectares) and device-measured MVPA

Preliminary linear regression estimated the association between every 10 minutes walking time to greenspaces and log-transformed MVPA as 0.00 (95% CI 0.00, 0.01).

For every 10 minutes of walking time to closest greenspace, a 1% (CI 95% -1.00, 2.00) increase in device-measured MVPA was seen in the unadjusted model (Table 4.4).

The adjusted model estimated a 1% decrease in device-measured MVPA minutes for every 10 minutes of walking time to closest greenspace (min 2 hectares in size). However, the confidence interval suggests that this effect is not distinct from no effect (95% CI -0.03, 0.01). No associations were seen when stratifying by sex.

The "contextual effect" included in the Mundlak formulation was estimated at 0.02 (-0.01, 0.06), indicating no mean differences in MVPA between neighbourhood clusters.

4.3.6 Secondary analysis

Table 4.5 presents adjusted random intercept models stratified by income tertiles. Results showed no clear differences in the relationships between proximity to greenspace, of any size and minimum 2 hectares, and self-reported or device-measured physical activity when stratified by income.

No associations were seen between size of closest greenspace and self-reported or device-measured physical activity. These results are displayed in Table 4.6.

4.3.7 Sensitivity analysis

No differences in the relationship between proximity to greenspace and physical activity was seen between urban and rural areas. These results are displayed in Table 4.7.

We additionally explored whether the relationship between greenspace and physical activity was non-linear by categorising walking time into groups of: <5 mins, 5-9, 10-14, 14-19, 20-29, 30-39, >40. In adjusted models, walking times greater than 40 minutes, compared to <5 mins, to closest greenspace of any size were associated with 0.49 (95% CI 0.09, 0.89) increased days of self-reported PA. Similarly, a 2.3% (95% CI 0.01, 0.45) increase in device-measured minutes of MVPA was estimated with walking times of >40 minutes to closest greenspace of any size. Evidence for an association was also seen between self-reported PA and MVPA and walking times of >30 minutes to greenspace of any size (Table 4.8). No evidence for associations were observed between other categories of walking time, compared to < 5 minutes, to greenspace and physical activity.

No associations were seen when greenspaces were minimum of 2 ha. Full modelling results are presented in Table 4.8.

Table 4.3: associations between walking time to closest greenspace (of any size and min 2ha) and self-reported physical activity at age 14

	Random Intercept Model 1 (n = 9858)			Random Slope Model 2 (n = 9858)			Adjusted Model 3 (n = 9858)		
	Coef	p value	95% CI	Coef	p value	95% CI	Coef	p value	95% CI
Greenspace any size									
PA	0.14	0.002	0.05, 0.22	0.13	0.003	0.04, 0.22	0.10	0.015	0.02, 0.19
Intercept sd	0.33	-	0.27, 0.40	0.33	-	0.14, 0.46	0.35	-	0.26, 0.47
Slope sd	-	-	-	0.25	-	0.14, 0.46	0.23	-	0.11, 0.51
Intercept-slope correlation	-	-	-	-0.30	-	-0.69, 0.22	-0.39	-	-0.75, 0.13
VPC	0.024	-	0.02, 0.04	0.021	-	0.01, 0.03	0.022	-	0.01, 0.04
Male									
	(n = 4,912)			(n = 4,912)			(n = 4850)		
PA	0.06	0.0318	-0.06, 0.18	0.065	0.434	-0.07, 0.17	0.03	0.605	-0.09, 0.16
Intercept sd	0.40	-	0.34, 0.48	0.48	-	0.36, 0.64	0.47	-	0.36, 0.63
Slope sd	-	-	-	0.32	-	0.13, 0.77	0.32	-	0.13, 0.79
Intercept-slope correlation	-	-	-	-0.62	-	-0.88, -0.07	-0.66	-	-0.89, -0.13
VPC	0.035	-	0.02, 0.05	0.034	-	0.02, 0.05	0.033	-	0.02, 0.05
Female									
	(n = 4,946)			(n = 4,946)			(n = 4,925)		
PA	0.23	0.000	0.10, 0.35	0.21	0.001	0.09, 0.33	0.17	0.006	0.05, 0.29
Intercept sd	0.44		0.38, 0.52	0.50	-	-0.35, 0.72	0.48	-	0.33, 0.70
Slope sd	-	-	-	0.41	-	0.21, 0.81	0.40	-	0.19, 0.80
Intercept-slope correlation	-	-	-	-0.48	-	-0.83, 0.15	-0.57	-	-0.87, 0.05
VPC	0.049		0.04, 0.07	0.044	-	0.03, 0.06	0.039	-	0.02, 0.06
Greenspace minimum 2 hectares									
All									
PA	0.04	0.039	-0.00, 0.07	0.03	0.079	0.00, 0.07	0.03	0.114	-0.01, 0.07
Intercept sd	0.32	-	0.27, 0.40	0.38	-	0.30, 0.47	0.39	-	0.31, 0.48
Slope sd	-	-	-	0.17	-	0.09, 0.17	0.12	-	0.09, 0.17
Intercept-slope correlation	-	-	-	-0.50	-	-0.74, -0.15	-0.61	-	-0.81,-0.27
VPC	0.024	-	0.02, 0.04	0.022	-	0.01, 0.03	0.023	-	0.01, 0,04
Male									
	(n = 4912)			(n = 4912)			(n = 4850)		
PA	0.05	0.025	0.01, 0.09	0.05	0.045	0.00, 0.09	0.04	0.072	-0.00, 0.09
Intercept sd	0.40	-	0.34, 0.48	0.49	-	0.40, 0.21	0.49	-	0.01, 41.01
Slope sd	-	-	-	0.11	-	0.06, 0.21	0.12	-	4.17 x10^{-6}, 3311
Intercept-slope correlation	-	-	-	-0.78	-	-0.97, -0.06	-0.95	-	-0.99, 0.98
VPC	0.035	-	0.02, 0.05	0.034	-	0.02, 0.05	0.032	-	0.02, 0.05
Female									
	(n = 4946)			(n = 4,946)			(n = 4,925)		
PA	0.04	0.153	-0.01, 0.09	0.04	0.114	-0.01, 0.09	0.03	0.228	-0.02, 0.08
Intercept sd	0.45	-	0.38, 0.53	0.51	-	0.41, 0.64	0.48	-	0.38, 0.61
Slope sd	-	-	-	0.16	-	0.12, 0.22	0.16	-	0.11, 0.23
Intercept-slope correlation	-	-	-	-0.50	-	-0.74, -0.15	-0.54	-	-0.77, -0.20
VPC	0.047		0.03, 0.07	0.047	-	0.03, 0.07	0.042	-	0.03, 0.06

Note: Coefficients represent the change in days of self-reported PA for every 10 minutes of walking time to greenspace. Random Intercept Model: exposure (walking time to closest greenspace) included in the model. Random Slope Model: walking time to closest greenspace included as a random slope. Random Slope Adjusted Model: covariates of parental education, parental income, occupational status and wealth plus, ethnicity and sex.

Table 4.4: associations between walking time to closest greenspace (of any size and min 2ha) and device-measured moderate to vigorous physical activity at age 14						
All						
	Random Intercept Model (n = 4078)			Random Intercept Adjusted Model (n = 4078)		
	Coef	p value	95% CI	Coef	p value	95% CI
Greenspace any size						
PA	0.06	0.005	0.02, 0.10	0.03	0.188	-0.01, 0.07
Intercept sd	0.20	-	0.15, 0.26	0.19	-	0.14, 0.26
VPC	0.054		0.03, 0.09	0.05	-	0.03, 0.09
Male						
	(n =1976)			(n = 1964)		
PA	0.06	0.0318	-0.06, 0.18	0.02	0.475	-0.04, 0.09
Intercept sd	0.40	-	0.34, 0.48	0.27	-	0.21, 0.35
VPC	0.035	-	0.02, 0.05	0.091	-	0.06, 0.14
Female						
	(n = 2102)			(n = 2089)		
PA	0.04	0.263	-0.03, 0.09	0.01	0.746	-0.05, 0.07
Intercept sd	0.21	-	0.15, 0.29	0.19	-	0.12, 0.29
VPC	0.063	-	0.03, 0.12	0.056	-	0.03, 0.11
Greenspace minimum 2 hectares						
All						
MVPA	0.01	0.524	-0.01, 0.02	0.00	0.670	-0.02, 0.14
Intercept sd	0.20	-	0.12, 0.26	0.19	-	0.14, 0.25
VPC	0.054	-	0.03, 0.09	0.05	-	0.03, 0.08
Male						
	(n = 1976)			(n = 1964)		
PA	0.02	0.145	-0.01, 0.04	0.01	0.609	-0.02, 0.03
Intercept sd	0.28	-	0.22, 0.35	0.27	-	0.21, 0.34
VPC	0.096	-	0.06, 0.14	0.090	-	0.06, 0.14
Female						
	(n = 2102)			(n = 2089)		
PA	-0.01	0.611	-0.03, 0.02	-0.02	0.233	-0.04, 0.01
Intercept sd	0.21	-	0.15, 0.29	0.18	-	0.12, 0.28
VPC	0.064	-	0.03, 0.11	0.055	-	0.02, 0.12
Note: Coefficients represent the change in minutes in device-measured MVPA (log scale) for every 10 minutes of walking time to greenspace. Random Intercept Model: exposure (walking time to closest greenspace) included in the model. Adjusted Model: covariates of parental education, parental income, occupational status and wealth plus ethnicity and sex.						

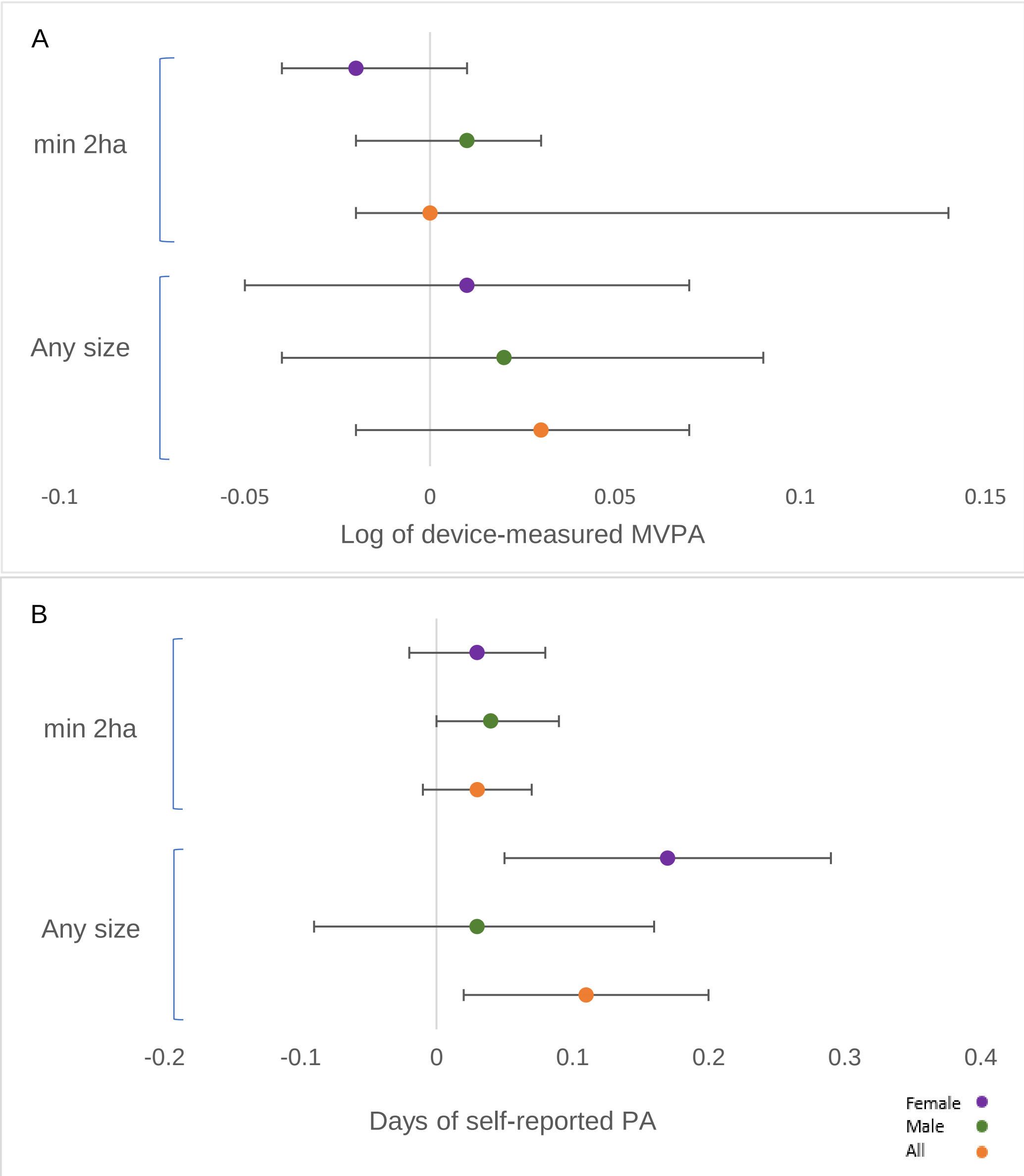

Figure 4.4 - associations between proximity to greenspace and self-reported physical activity in adjusted random slope model (A) and device-measured PA in adjusted random intercept model (B). Coefficients and 95% CIs.

Table 4.5: Adjusted Random Intercept Model of associations between walking time to closest greenspace of any size and minimum 2 ha and self-reported physical activity and device-measured MVPA at age 14, respectively, stratified by income.

	Greenspace any size Self-reported PA			Greenspace any size Device MVPA (log)			Greenspace min 2ha Self-reported PA			Greenspace min 2ha Device MVPA (log)		
Income (lowest tertile)												
	(n = 5005)			(n = 1864)			(n = 5005)			(n = 1864)		
	Coef	p value	95% CI	Coef	p value	95% CI	Coef	p value	95% CI	Coef	p value	95% CI
PA	0.01	0.852	-0.14, 0.17	0.00	0.982	-0.09, 0.09	0.05	0.118	-0.01, 0.11	0.01	0.487	-0.02, 0.04
Intercept sd	0.50	-	0.41, 0.61	0.34	-	0.27, 0.45	0.50	-	0.41, 0.61	0.35	-	0.27, 0.45
VPC	0.050	-	0.03, 0.08	0.143	-	0.09, 0.22	0.055	-	0.04, 0.08	0.143	-	0.09, 0.22
Income (middle tertile)												
	(n = 2306)			(n = 1002)			(n = 2306)			(n = 1002)		
PA	0.18	0.013	0.04, 0.32	0.03	0.451	-0.05, 0.10	0.02	0.561	-0.04, 0.08	-0.01	0.720	-0.04, 0.03
Intercept sd	0.43	-	0.32, 0.57	0.24	-	0.15, 0.38	0.43	-	0.32, 0.58	0.25	-	0.16, 0.39
VPC	0.046	-	0.03, 0.08	0.100	-	0.04, 0.22	0.045	-	0.03, 0.08	0.103	-	0.04, 0.22
Income (highest tertile)												
	(n = 2489)			(n = 1187)			(n = 2489)			(n = 1187)		
PA	0.14	0.026	0.02, 0.26	0.02	0.492	-0.04, 0.08	0.03	0.245	-0.02, 0.08	-0.03	0.034	-0.05, 0.00
Intercept sd	0.17	-	0.08, 0.40	0.01	-	0.00, 0.08	0.17	-	0.07, 0.40	0.01	-	0.00, 0.06
VPC	0.008	-	0.00, 0.04	0.017	-	0.00, 0.11	0.008	-	0.00, 0.04	0.019	-	0.00, 0.10

Note: Coefficients represent the change in days of physical activity for every 10 minutes of walking time to greenspace. Physical activity measured in days for self-report PA and minutes for device-measured MVPA (on log scale). Model adjusted for sex, ethnicity, parental education, occupational status and wealth.

Table 4.6: Adjusted random intercept models for associations between size of closest greenspace and physical activity at age 14

	Self-reported PA (n = 9763)			Device measured MVPA* (n = 4044)		
	Coef	p value	95% CI	Coef	p value	95% CI
Days of PA	-1.44 x 10^{8}	0.749	-1.03 x 10^{7}, 7.42 x10^{8}	7.01 x 108	0.007	1.92 x 10^{8}, 1.21 x10^{7}
Intercept sd	0.32	-	0.26, 0.40	0.19	-	0.14, 0.26
VPC	0.022	-	0.01, 0.04	0.052	-	0.03, 0.09
Male						
	(n = 4858)			(n = 1960)		
Days of PA	-6.07 x 10^{8}	0.480	-2.29 x 10^{7}, 1.08 x10^{7}	-8.15 x10^{8}	0.551	-3.49 x 10^{7}, 1.86 x10^{7}
Intercept sd	0.39	-	0.33, 0.47	0.27	-	0.21, 0.35
VPC	0.033	-	0.02, 0.05	0.091	-	0.05, 0.14
Female						
	(n = 4905)			(n = 2084)		
Days of PA	1.23 x10^{8}	0.838	-1.05 x 107, 1.30 x10^{7}	8.35 x10^{8}	0.000	5.32 x 10^{8}, 1.14 x10^{7}
Intercept sd	0.41	-	0.34, 50	0.19	-	0.12, 0.30
VPC	0.038	-	0.02, 0.06	0.057	-	0.00, 0.00

**Device-measured log transformed*
All models adjusted for sex, ethnicity, overall wealth, parental education, occupational status and income.

Table 4.7: Adjusted Random Intercept Model of associations between walking time to closest greenspace of any size and minimum 2 ha and self-reported physical activity and device-measured MVPA at age 14, respectively, stratified by urban/rural.

	Greenspace any size Self-reported PA			Greenspace any size Device MVPA (log)			Greenspace min 2ha Self-reported PA			Greenspace min 2ha Device MVPA (log)		
Urban												
	(n = 7394)			(n = 2934)			(n = 7394)			(n = 2934)		
	Coef	p value	95% CI	Coef	p value	95% CI	Coef	p value	95% CI	Coef	p value	95% CI
PA	0.08	0.371	-0.09, 0.25	0.01	0.850	-0.10, 0.12	0.01	0.834	-0.06, 0.07	0.01	0.961	-0.04, 0.04
Intercept sd	0.52	-	0.34, 0.80	0.19	-	0.14, 0.26	0.38	-	0.31, 0.48	0.20	-	0.15, 0.26
VPC	0.029	-	0.02, 0.05	0.051	-	0.03, 0.09	0.031	-	0.02, 0.05	0.052	-	0.02, 0.15
Rural												
	(n = 2404)			(n = 1118)			(n = 2404)			(n = 1118)		
PA	0.10	0.084	-0.01, 0.21	0.04	0.102	-0.01, 0.09	0.04	0.067	-0.01, 0.09	0.00	0.883	-0.02, 0.02
Intercept sd	0.48	-	0.13, 0.69	0.26	-	0.16, 0.44	0.46	-	0.33, 0.64	0.26	-	0.16, 0.44
VPC	0.046	-	0.02, 0.10	0.108	-	0.04, 0.26	0.053	-	0.03, 0.12	0.101	-	0.04, 0.27

Note: Coefficients represent the change in days of physical activity for every 10 minutes of walking time to greenspace. Physical activity measured in days for self-report PA and minutes for device-measured MVPA (on log scale). Model adjusted for sex, ethnicity, parental education, occupational status and wealth.

Table 4.8: associations between categories of walking time to closest greenspace (of any size and min 2ha) and physical activity at age 14						
Self-reported physical activity						
	Random Intercept Model (n = 9858)			Random Intercept Adjusted Model (n= 9,800)		
	Coef	p value	95% CI	Coef	p value	95% CI
Greenspace any size						
5-9	0.09	0.127	-0.03, 0.22	0.06	0.291	-0.05, 0.18
10-14	0.03	0.753	-0.15, 0.21	-0.03	0.716	-0.20, 0.14
15-20	0.08	0.737	-037, 0.52	0.05	0.841	-0.40, 0.49
21-29	0.24	0.434	-0.36, 0.83	0.12	0.711	-0.51, 0.74
30-39	0.61	0.018	0.11, 1.12	0.57	0.032	0.05, 1.08
≥40	0.49	0.022	0.07, 0.91	0.49	0.017	0.09, 0.89
Intercept sd	0.11	-	0.07, 0.16	0.32	-	0.26, 0.40
VPC	0.02	-	0.02, 0.04	0.024	-	0.02, 0.04
Greenspace min 2 ha						
5-9	0.01	0.909	-0.15, 0.16	0.03	0.733	-0.13, 0.18
10-14	-0.11	0.247	-0.30, 0.08	-0.11	0.239	-0.29, 0.07
15-20	0.04	0.729	-0.19, 0.26	0.08	0.459	-0.13, 0.29
21-29	0.07	0.581	-0.19, 0.34	0.09	0.502	-0.18, 0.37
30-39	0.23	0.287	-0.19, 0.65	0.14	0.478	-0.25, 0.54
≥40	0.03	0.776	-0.17, 0.23	0.05	0.597	-0.14, 0.25
Intercept sd	0.11	-	0.07, 0.16	0.32	-	0.26, 0.40
VPC	0.02		0.02, 0.04	0.024	-	0.02, 0.04
Device-measured MVPA						
Greenspace any size	n = 4063			n = 4048		
5-9	0.08	0.045	0.00, 0.15	0.06	0.105	-0.01, 0.13
10-14	0.00	0.944	-0.12, 0.13	-0.04	0.546	-0.16, 0.09
15-20	0.09	0.494	-0.17, 0.34	0.05	0.688	-0.19, 0.29
21-29	-0.06	0.586	-0.26, 0.15	-0.15	0.157	-0.35, 0.06
30-39	0.18	0.028	0.02, 0.35	0.10	0.243	-0.07, 0.27
≥40	0.34	0.005	0.10, 0.58	0.23	0.040	0.01, 0.45
Intercept sd	0.20	-	0.15, 0.26	0.19	-	0.14, 0.25
VPC	0.05	-	0.03, 0.09	0.05	-	0.03, 0.08
Greenspace min 2 ha						
5-9	0.06	0.166	-0.03, 015	0.06	0.190	-0.03, 0.14
10-14	-0.04	0.490	-0.15, 0.07	-0.05	0.402	-0.16, 0.06
15-20	-0.01	0.897	-0.17, 0.15	-0.04	0.644	-0.19, 0.06
21-29	-0.06	0.512	-0.26, 0.13	-0.07	0.463	-0.27, 0.12
30-39	0.15	0.077	-0.02 ,0.32	0.07	0.347	-0.08, 0.23
≥40	0.04	0.468	-0.07, 0.14	0.01	0.894	-0.09, 0.11
Intercept sd	0.04	-	0.02, 0.07	0.19	-	0.14, 0.25
VPC	0.05	-	0.03, 0.09	0.05	-	0.03, 0.08

Note: Coefficients represent the change in days of self-reported PA and minutes in device-measured MVPA (log scale). Random Intercept Model: exposure (walking time to closest greenspace) included in the model. Adjusted Model: covariates of parental education, parental income, occupational status and wealth plus ethnicity and sex. Reference group = 0-5 minutes walking time to greenspace (up to, not including, 5 minutes);

4.4 Discussion

Unexpectedly, results from this study showed that greater distance to greenspace of any size, measured in walking time, was associated with a small increase in self-reported, but not device-measured, physical activity. The Mundlak formulation showed no contextual effects. No associations were seen between distance to greenspaces of at least 2 hectares in size and physical activity. Sensitivity analysis indicated that associations between greater walking times to greenspace and increased physical activity (both self-reported and device-measured) only emerged after >30 minutes compared to <5 minutes walking time.

Results of associations between greenspace and physical activity in the existing literature are inconsistent. A systematic review of US studies found that nine out of twenty included studies reported no association between proximity to parks and physical activity, with a further six reporting mixed results (Bancroft et al., 2015). A Dutch study, which measured greenspace via total percentage of land cover, concluded that the amount of greenspace in 1km and 3km radii from home had no influence on self-reported physical activity in adults (Maas et al., 2008). This study further reported that adults living in greener environments undertook walking and cycling less often. The authors of this study pointed out that the attractiveness of the area was not investigated, which could help explain this finding. Another Dutch cross-sectional study, focussed on adolescents, reported that the frequency of visits to greenspaces was not associated with the quantity of residential greenspace (Bloemsma et al., 2018). In this case, perceived importance of greenspace was a predictor of greenspace use.

Furthermore, a study using English cross-sectional data on adults reported counterintuitive results, with living in the greenest areas associated with an increased risk of overweight and obesity that was not mediated by physical activity (Cummins & Fagg, 2012). The authors suggest that the common hypothesis in the literature that more physically active people move to greener areas may not be the case.

A study from Washington, US, showed that increased number of neighbourhood parks close to home was associated with physical activity taken place in parks further from the home neighbourhood (O. Stewart et al., 2018). The authors posited that the presence of parks in one’s neighbourhood may facilitate active travel to other parks beyond the neighbourhood. This could mean that individuals travel to parks further away from home to take part in physical activity and sports. Our study did not ask participants to specify the location of their physical activity, meaning they may be using greenspaces and other facilities away from their immediate environment, which may help to explain our finding that walking times of >30 and >40 minutes were associated with increased physical activity. Similarly, it is important to note that the self-reported PA survey question used in the collection of this data asked participants to report on moderate to vigorous exercise, with swimming, running and cycling given as examples. However, with self-report measures it is not possible to verify exactly what each participant themselves considered as moderate to vigorous exercise. It may be that adolescents considered walking to their nearest greenspace as physical activity, hence living further away from a greenspace, and walking to that greenspace would contribute to their PA levels.

Results from our study suggest that close proximity to greenspace alone is not sufficient to facilitate physical activity. Sensitivity analysis indicated a relationship between proximity to greenspace and physical activity, with walking times greater than 30 minutes to greenspaces associated with increased physical activity compared with those that lived within 5 minutes' walk of a greenspace. Therefore, it may be necessary to consider the quality and design of greenspaces in addition to type of greenspace. Greenspaces vary in terms of objective 'good' qualities, for example, the presence of footpaths and amenities, cleanliness, and size (Nguyen et al., 2021). A case study from Tottenham, London, highlights how proximity and size of greenspace is often not enough to encourage usage. The Lordship Rec, Tottenham's largest public park, was rarely used in the early 2000s due to its poor quality, despite a lack of private garden space for residents in the local vicinity (Friends of the Earth, 2020). Increased funding since 2012 has led to dramatically improved facilities, better maintenance of buildings, introduction of flowerbeds and trees, paths resurfaced plus a new cycling track and renovation of the sports pitch (Friends of Lordship Recreation Ground, n.d.). Usage of the park has since tripled and over 20 groups promoting sports, fitness and events have been created.

It may also be that other factors contribute to the relationship between greenspace and physical activity that we did not account for. For example, we didn't consider access to other fitness facilities, as although participants may live far from greenspaces, they may live close to gyms or sports facilities.

Moreover, our results suggest that considering the totality of neighbourhood characteristics on health behaviours is important. It may be the case that other geographical influences play a role in the relationship between greenspaces and physical activity, and that proximity to a greenspace alone is not adequate to capture the complexities around this relationship. Prior work has indicated that health behaviours reflect access to a diverse range of neighbourhood elements and should not be considered in isolation (Meyer et al., 2015). Although we used network distance to accurately measure the walking time and distance to participant's closest greenspace, this approach does not consider the aesthetics of the walking route or perceptions of the neighbourhood. Other spatial considerations worth exploring include safety and street connectively. Previous research has concluded that youth with increased concerns about personal safety and traffic safety are less likely to walk to destinations (Panter et al., 2008). As found in Chapter Three, MCS participants that reported feeling very safe at age 11 and those that lived in a lower crime area, measured with the IMD crime domain, self-reported more frequent physical activity at age 14.

Contrary to existing literature (The Ramblers, 2020), proximity to greenspace did not differ by income bands, used as a proxy indicator of socioeconomic status. When stratifying by income, we observed no differences between those in the highest, middle and lowest income tertiles and associations between greenspace proximity and physical activity.

Descriptive statistics showed those within higher income quantiles lived further away from their closest greenspace (Figure 4.3). There is some existing research that has similarly shown mixed or counterintuitive findings on socioeconomic indicators and access to neighbourhood features. Research undertaken in Bristol, UK, concluded that respondents in more deprived areas lived closer to greenspaces (A. Jones et al., 2009). A recent cross-sectional study of Scottish children reported that children living in the most deprived areas tended to have better access to amenities, including greenspaces, within an 800m buffer of home address (Olsen et al., 2023). However, children living in deprived areas also had a greater number of health harming features, such as the presence of major roads. A study from New Zealand also highlighted the co-occurrence of environmental health-promoting and health-constraining characteristics and indicated that some deprived neighbourhoods have better access to physical activity facilities (Marek et al., 2021).

Evidence from the UK highlights the nuance in the relationship between greenspace and deprivation. Results from a network analysis study conducted in Sheffield, UK, reported that more income-deprived households lived closer to publicly available greenspaces (Barbosa et al., 2007). A later study repeated this work, using different measures of deprivation and greenspaces, and similarly reported that overall distribution of greenspaces is greater in deprived areas of the city (Mears et al., 2019). However, when considering quality of the greenspaces and the potential for overcrowding, more deprived households were in a less favourable situation (Mears et al., 2019).

Furthermore, the urban development history of Britain over the past century has meant green and open spaces tended to be built close to deprived areas (Dreher, 1993). The rapid growth and urbanisation of British cities in the 19th century led to overcrowding and unsanitary conditions for the poorest citizens. In response to this urban health crisis, public health reformers campaigned for public parks and the Public Health Act 1848 gave local authorities power to purchase land for public use to improve health of its residents (Dreher, 1993). To achieve this, parks were located within walking distance of working-class neighbourhoods. Mears & Brindley (2019) report that modern-day accessibility of greenspaces favours those in more deprived areas of Sheffield, influenced by the spatial dimension of socioeconomic conditions in the Victorian era. Indeed, research suggests that spatial patterns of social deprivation and health have remained static over the last century (Dorling et al., 2000). Furthermore, a report produced by the Friends of the Earth similarly highlight the historical importance of public parks built in densely populated areas to partly explain that areas with a lower average income have a greater proportion of their population within 5-minutes walk of greenspaces than wealthier areas (de Zylva et al., 2020). This was also attributed to the higher density population in these areas.

4.4.1 Strengths and limitations

This study has several strengths including the use of a nationally representative longitudinal dataset and use of both subjective and device-measured physical activity, as in Chapter Three.

This study also benefits from geocoded participant postcodes and the use of network analysis to accurately measure distance from a greenspace access point and postcode centroid, using real-world walking routes. We also excluded greenspace types that are not relevant to physical activity in adolescence. This is an improvement from studies that use crude measures of greenspace, such as green land coverage, for physical activity outcomes do not account for real world usage of greenspaces.

Limitations of this study include the usage of postcode centroids instead of participant address data, which was not available due to confidentiality and privacy implications. UK postcodes are based on number of addresses not spatial area; individual postcodes contain an average of 15 properties with some holding up to 100. Therefore, rural postcodes cover a much larger area than urban postcodes meaning that our GIS network analysis routes will be less accurate for larger, rural postcodes, as discussed in Chapter Two. Whilst our multilevel models can account for hierarchical structures and clusters at the electoral ward level, precise spatial location was not included in the models.

I was also unable to capture participant perceptions of their neighbourhood greenspaces due to this not being collected in the MCS. Social meaning attached to greenspace may be an important driver of health rather than proximity or physical access.

4.5 Conclusion

In summary, this study found that greater distance to greenspace of any size, measured in walking time, was associated with a small increase in self-reported, but not device-measured, physical activity. No associations were seen between greenspaces of a minimum of 2 hectares and physical activity. Although these findings were unexpected, they do fit with the generally mixed evidence in this research area. Similar to Chapter Three, results differed between objective and subjective measures of physical activity. This study suggests it is necessary to move beyond only considering proximity as a predictor of greenspace use in adolescents. Future work should incorporate measures of quality and perceptions, including safety, of greenspaces given findings from Chapter Three that indicated safety is associated with self-reported physical activity.

Chapter Five – Proximity to high streets and indicators of social isolation and social support

This chapter forms the basis of a submitted manuscript, currently under review:

Constable Fernandez, C., Maddock, J., Patalay, P., Fett, A., Pitman, A., Vaughan, L. & Krenz, K. (2024). Proximity to high streets, social isolation and social support in British adolescents: a longitudinal analysis of socio-spatial influences on social connectedness using geospatial data.

5.1 Introduction

In the previous chapters I examined associations between neighbourhood crime, safety and greenspaces and physical activity. In this chapter, I explore a further aspect of the neighbourhood, namely proximity to high streets. High streets are an under-explored feature of the environment which may exert an important influence in the social lives of adolescents. This chapter moves away from physical activity outcomes and focuses on social isolation and social support. Whilst physical activity remains an important health outcome, social isolation and lack of social support can have equally detrimental effects on mental health. Social isolation and loneliness in adolescence is a growing public health concern which this chapter aims to address. To my knowledge, no previous studies have explored high street access and indicators of social isolation making this chapter a novel contribution to the literature.

Social isolation in young people is associated with negative mental health outcomes such as depression (Matthews et al., 2016) and suicidal thoughts (Armstrong & Manion, 2006). As previously discussed, adolescence represents a sensitive phase in life, marked by significant changes in social bonds and heightened risk of developing mental health issues (Solmi et al., 2022). Tackling social isolation in adolescence is an obvious target for intervention at a societal, community and individual level, yet we lack an understanding of the determinants of social isolation in young people.

Defining social isolation in young people is challenging. Social isolation is generally considered an objective measure based on the quantity of social connections, typically assessed through the size of social networks and the number of significant ties (Wang et al., 2017). In adults this is typically assessed as the size of social networks, or number and frequency of social interactions (Holt-Lunstad & Steptoe, 2022) or most crudely as living alone, providing a proxy for limited social interactions with others. Such objective indicators show clear associations with poor mental health in older adults (Cornwell & Waite, 2009;

Fakoya et al., 2020). However, for children and adolescents, who typically live with carers, indicators such as cohabitation status mean very little and fail to capture differences in opportunities to interact with others, and the developmental opportunities that arise from peer relationships and friendships. During early childhood the company of a friend is important, whilst in adolescence the need to feel accepted by peer groups becomes more valuable followed by a shift in desire for more intimate relationships into adulthood (Qualter et al., 2015). These shifts in social needs and priorities during childhood and adolescence take place against transitions through education and puberty. Social isolation can also occur involuntarily, for example through peer victimisation and rejection (Bowker et al., 2021). This study therefore utilises frequency of social activities and social contact as indicators of social isolation.

Estimates of the prevalence of social isolation in children and young people have used indicators such as number of close friends or degree of social support. Such work demonstrates that 5% of 11-15 year olds in Scotland have fewer than three close friends and 43% do not perceive high levels of peer support (Teuton, 2018). Survey data from the US shows that in-person social interaction time among young people (whether at home or in the community) declined significantly over the period 2006-2017 (Twenge et al., 2019). Comparing social isolation patterns across age groups is complicated by differing definitions. Nevertheless, a study using harmonised indicators in the UK revealed that younger cohorts are less likely to be members of clubs or organisations (Mansfield et al., 2023). For this study I defined social isolation as the extent of a young person's social activities in their local community, which takes into account social connectedness beyond the household. This acknowledged the importance of developmental opportunities available outside the immediate family.

Social isolation is distinct from loneliness, which is defined subjectively as the distressing mismatch between a person's desired and perceived quantity and/or quality of social relationships (De Jong Gierveld, 1998) or as the subjective feeling of being alone and unsupported (Hämmig, 2019). The two are correlated in adolescents (Matthews et al., 2016) but it is possible to feel lonely but not experience social isolation and vice versa (Holt-Lunstad et al., 2015b). Both concepts are also distinct from social support, which can be described as the subjective availability of care and assistance (Scardera et al., 2020). Higher perceived social support has been linked with better health outcomes in adults, through lower loneliness (Segrin & Domschke, 2011). Among adolescents, perceived social support is associated with fewer depressive symptoms, with specifically family, friend and teacher support important (Rueger et al., 2016). A longitudinal study from Denmark concluded that perceived social support from friends at age 14/15 years was positively associated with indicators of mental health, including wellbeing, at age 20/21 years (Jakobsen et al., 2022). There is a specific evidence gap in relation to understanding the impacts of social isolation in adolescence on mental health (Qualter et al., 2022) in order to consider appropriate interventions.

Opportunities for young people to connect with others and nurture friendships must be considered in their wider (built) environmental contexts, including local areas where they might congregate with peers. High streets, traditionally the heart of urban communities, offer unique settings for social engagement and community integration (Joseph Rowntree Foundation, 2007). Social wellbeing is a key dimension of high streets as they can foster social interactions and a sense of community by acting as an accessible social space (Daly & Allen, 2018). Young people have less control over their home or school environment, so depend on socialising in outdoor and public spaces (Pearson et al., 2008). Investigating the relationship between these places of social interaction and social isolation and support and can provide vital insights into how urban environments can influence adolescent well-being. With increasing concerns about social isolation in younger populations, particularly in the context of rapid urbanisation and digitalisation, understanding the impact of physical social spaces like high streets on adolescent social health becomes critical.

Considerable research has examined social isolation and loneliness in the ageing population whilst noticeably fewer studies have focused on young people. One reason for this may be common experiences in the elderly, such as bereavement or reduced mobility, can often have an impact on social isolation (Savikko et al., 2005). Previous research in older people has shown that indicators of social isolation such as living alone, having a small social network and infrequent social contacts are associated with poorer mental health (Cornwell & Waite, 2009; Fakoya et al., 2020). Nevertheless, the factors that make young people vulnerable to social isolation are increasingly coming into research and policy focus (Qualter et al., 2022). Indeed, social needs and priorities differ throughout the life-course. During early childhood the company of a friend is important, whilst in adolescence the need to feel accepted by peer groups becomes more valuable followed by a shift in desire for more intimate relationships into adulthood (Qualter et al., 2015). These shifts in social needs during childhood and adolescence take place against transitions through education and puberty. The experience of social isolation is therefore likely to be felt very differently between young people and older adults. Among young people, social isolation often appears in the context of friendships and peer relationships. Survey data from NHS Scotland (11-15 year olds) suggests that peer support is lower amongst older children and therefore older children may be more vulnerable to social isolation (Teuton, 2018). Social isolation can occur involuntarily, for example through peer victimisation and rejection. Peer victimisation, including physical, verbal or cyber bullying, is an indicator of social isolation (Bowker et al., 2021).

Research indicates that young adults at age 18 who are socially isolated are more likely to experience symptoms of depression (Matthews et al., 2016). Literature also suggests that being isolated from friends during adolescence increases the risk of emotional and psychological problems (Copeland et al., 2018; Högnäs et al., 2020). Results from a Danish population-based study concluded that social isolation in adolescents and young adults (mean age of 22 years) was associated with increased risk of long-term mental illness (Christiansen et al., 2021). Studies that have focused on children have reported associations between childhood social isolation and elevated age-related-disease risk in adulthood.

Previous research has suggested a link between spatial factors that provide opportunities for social interactions, including local amenities and public spaces, and social isolation and loneliness (MacIntyre & Hewings, 2022). Research from older adults in the US concluded that those who lived closer to a city centre were less likely to report social isolation (Finlay & Kobayashi, 2018) whilst UK research has highlighted that high streets are important for social participation in the older adults (Phillips et al., 2021). However, to our knowledge, no previous study has explored the association between high street proximity and diversity and social isolation outcomes in UK adolescents.

The role of the high street is varied; high streets bring people together for many different reasons including to socialise, for healthcare and travelling through to work (Vaughan, 2022). High streets work as part of a network of streets that are highly accessible to other parts of the town or city which therefore generates activity as people utilise them as a part of regular routes to take somewhere else (Vaughan, 2015). Therefore, distance of key facilities, such as shops, healthcare or leisure facilities, can prevent people from participating in the social life of the community (A. Church et al., 2000). High streets offer an array of functions, with users valuing a mix of products, stores and social experiences alongside practical features such as efficient transport (A. Hill & Cheshire, 2023). Accessibility to the high street can provide adolescents with freedom of mobility without depending on parents or others for transport. Lacking their own spaces, young people often visit public spaces in groups to 'hang out' and gather without adult supervision (Pyyry & Tani, 2015). These public spaces are opportunities for young people to make spaces of their own and develop a sense of identity and belongingness (Pickering et al., 2012). Some research indicates that adolescents prefer commercial areas, shopping centres and green spaces close to home and that these areas support social interaction behaviours (C. Clark & Uzzell, 2002). However, the use of public spaces by young people is increasingly regulated and often seen as problematic (Gray & Manning, 2022).

This study aimed to investigate the relationship between proximity to high streets at age 14, as a proxy for social opportunities, and social isolation and perceived social support in adolescents at age 17. I also aimed to investigate whether the diversity of high streets is associated with social isolation and social support.

5.2 Methods

5.2.1 Participants

As with Chapters Three and Four, I analysed data from MCS. The study design for MCS is described in detail in Chapter 2.1. For this chapter, I used data from sweeps 6 (age 14) and 7 (age 17).

At age 17, 6,828 participants from England, Wales, Scotland and Northern Ireland completed an online self-completion questionnaire, which included responses to questions about social isolation. Participants from Northern Ireland were excluded due to lack of high street data. The analytical sample (n=5582) was compromised of participants with postcode data available, and successfully linked to high street, and with any outcome measure at age 17.

5.2.2 Proximity to High Streets

This study measured proximity to the nearest high street as the shortest path through the street network between the participants' postcode centroid (i.e. the geographically central address of a postcode unit) at age 14 years and the nearest start, end, or intersection of a high street.

Precise, vector-based geospatial data were used from Ordnance Survey (OS) i.e., OS Highways Roads and Path (Ordnance Survey, 2023b) and OS Retail Geographies – High Streets (Kingston, 2019). These datasets offer a detailed, current snapshot of the urban road network for England, Wales, and Scotland (excluding Northern Ireland), including alleys and paths, the spatial extent of high streets, and their land uses.

The 2019 OS High streets data iteration was utilised, however, there are no high streets that either emerged or disappeared in or after 2015 (when age 14 postcodes were collected).

OS defines high streets through a stepwise selection process (Office for National Statistics & Ordnance Survey, 2019). Initially, retail activity clusters are identified, each necessitating at least 15 retail addresses within a 150-meter radius. Subsequently, non-high street retail clusters (such as retail, business, or industrial parks) are filtered out by categorising address types and street names, enforcing building-to-address ratio limits, and the absence of residential land uses. This restrictive definition excludes smaller high streets (having fewer than 15 land uses) and shopping centres. In this study I sought to offer a surrogate indicator for sites potentially hosting social activities, and locations where young people were likely to mingle with other people living or working in their neighbourhoods. High streets are consistently identified as the most interconnected locales within a community, thereby increasing the likelihood of their use as routes to and from residences (Griffiths et al., 2008).

Distance between cohort member's postcode to their closest high street was initially calculated in metres and re-scaled to kilometres for analysis.

Distance Decay

In addition to proximity to high streets, we also examined an exponential distance decay function (Vale & Pereira, 2017). This function allows for the effect of decreasing likelihood of interaction between an individual and their surrounding environment - whether making a purchase in a shop or visiting a leisure centre or park - namely the decreasing importance of an urban feature (in this case high streets) to a person with an increasing distance from it (Krenz et al., 2023). This yields a demonstrably better estimate of actual exposure than using circular buffers or aggregate estimates by census unit (Sadler & Lafreniere, 2017, p. 194). Distance decay functions continuously decrease values until converging to zero (when rounded), rather than an abrupt cut-off at pre-set distances, as is common in built environment health studies distance decay function at varying parameters equating to approximately 2000m, 1400m and 800m from each cohort member's postcode (Figure 5.1a-b), based on precedent (Ortegon-Sanchez et al., 2021).

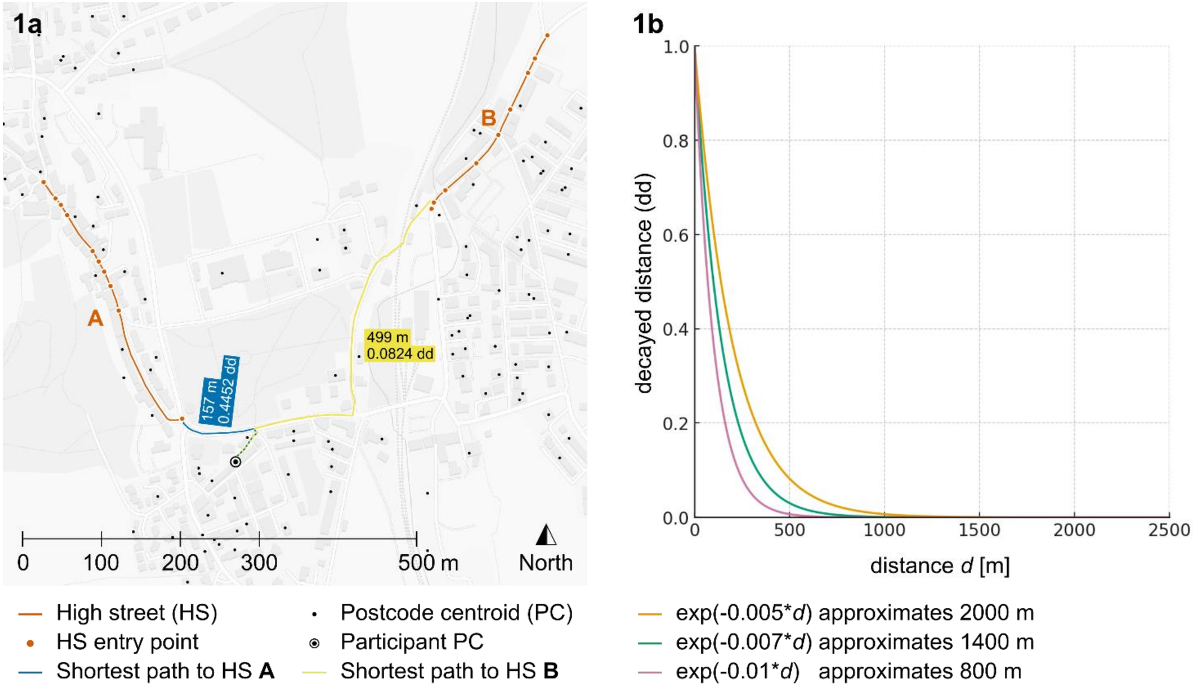

Figure 5.1 a) Visualisation of a hypothetical participant's postcode and two shortest paths to the nearest high street entry points (showing distance in meters and decayed distance value dd). Contains data from © Ordnance Survey Limited 2019 and CartoDB; b) Visualisation of three distance decay functions. Each line corresponds to a decay model, illustrating the variation in decayed distance (0 to 1) as a function of the initial distance (in meters)

5.2.3 Diversity of High Streets

Differences in high street character were captured through measuring land use diversity using Shannon's Diversity Index (Shannon, 1948), which provides an indicator of the number of different land uses present, as well as their distribution. We used the number of unique addresses classified into one of five land use classes (i.e., residential, leisure, office, retail and community) for each high street. Diversity was measured on a scale that takes account of the theoretical presence of all five land uses along any single high street, namely 0-1.609 with a theoretical maximum of 1.609 indicating highest land use mix and therefore greatest diversity. The following formula was used:

$$H' = -\sum_{i=1}^{R} (p_i \cdot \ln(p_i))$$

Where: H' is Shannon's Diversity Index. R is the total number of different land uses. p_i is the proportion of the total number of land uses belonging to the i th category. Calculated as $n_i \,/\, N$, where n_i is the number of entities in the i th category and N is the total number of land uses across all categories.

5.2.4 Social Isolation

At age 17, as part of the online self-completion questionnaire, participants were asked about the frequency of their social activities in the community. The questions captured how often they:

- Go to a party, dance, house party or nightclub
- Go to the theatre (for example to see a play, pantomime or opera)
- Go to watch live sport (for example at a stadium)
- Sing in a choir or play in a band or orchestra
- Go to a live music concert or gig
- Go to youth clubs, explorer scouts, senior guides or other organised activities
- Go to a library
- Go to museums or galleries, visit a historic place or stately home
- Do voluntary or community work
- Go to a political meeting, march, rally or demonstration
- Attend a religious service

The response options were: Most days, At least once a week, At least once a month, Several times a year, Once a year or less, Never or almost never. We combined and coded into three categories, whereby the lowest category reflected minimal social activity (responded Never, Once a year or less, or Several times a year to all activities), the middle category corresponded engaging in any activity for At least once a month and the highest corresponded to high social activity with frequency of At least once a week or Most days to any activity.

Participants were also asked about the frequency of contact with friends outside of school or work. Response options were: Most days, At least once a week, At least once a month, Several times a year, Once a year or less, Never or almost never. I combined these into three categories where the lowest category reflected lowest frequency of contact.

5.2.5 Social Support

The Social Provisions Scale (SPS) was used to measure perceived social support. At age 17, three items were included from the 10-item Social Provisions Scale in the online self-completion questionnaire. Young people were asked to choose responses to the following:

- I have family and friends who help me feel safe, secure and happy
- There is someone I trust whom I would turn to for advice if I were having problems
- There is no one I feel close to

Response options were: very true, partly true, or not at all true. The three variables were averaged together to create one continuous variable with a mean value and higher scores indicating higher social support.

5.2.6 Covariates

5.2.7 Statistical Analysis

I presented descriptive statistics as frequencies and means with standard deviations. Distributions of sex, ethnicity, parental education and income of the sample that completed the face-to-face interview compared with the sample that completed the online questionnaire at age 17 can be found in Appendix 2.

Proximity to and diversity of high streets was captured for the built environment characteristics at age 14 and three outcomes of social isolation were measured at age 17, to measure prolonged exposure and capture longitudinal/temporal associations. 9% (n=512) of participants in the analytic sample changed address between ages 14 and 17.

A random intercept multilevel regression was used to assess associations between proximity to high streets and the three social isolation outcome variables considered separately (social activities, frequency of contact with friends and social support). Multilevel modelling can account for neighbourhood clustering i.e. individuals nested within the same geographical areas are likely to have correlated observations. This was important as the MCS is geographically clustered by electoral wards.

Linear multilevel models were used to estimate associations between distance to closest high street and the continuous social support outcome variable, while the logistic multilevel model was used to estimate associations with the frequency of contact with friends and social activities outcome variables (reference group of lowest categories coded as 0).

I first estimated the proportion of variance in social isolation outcomes accounted for by neighbourhood clusters as a baseline reference. The Variance Partition Coefficient (VPC) measures how much variation in the independent variable (social isolation or social support) is accounted for by clustering.

In separate models I examined associations with 1) distance to closest high street and 2) diversity of land use. I first ran each model unadjusted, then adjusted for sex, ethnicity, parental education, occupational status, overall wealth and income. I stratified adjusted models by sex; results are presented stratified.

5.2.7.1 Sensitivity Analysis

Non-linearity

I tested for potential non-linearity in the relationship between distance to closest high street and all three outcomes by first including a quadratic term in the adjusted models (i.e., a squared term for proximity to high street). Adding a quadratic function captures a parabolic, U-shaped or inverted U-shaped relationship. I used visual plots, ROC curves and AIC/BIC to investigate fit between the models with and without the quadratic term. Akaike's information criterion (AIC) and Bayesian information criterion (BIC) are mathematical methods for evaluating how well the model fits the data. A ROC curve shows the performance of a model; the AUC measures the area under the ROC curve and provides a measure of performance, with higher AUC values indicating the model is better at classifying outcomes.

I additionally used a second approach to account for potential non-linearity, applying a decay function to spatial distances (Figure 5.1a–b). We conducted analysis exploring associations between decayed distance at varying parameters of approximately 2000m, 1400m and 800m and indicators of social support and social isolation. This was achieved by adding an exponential decay function to the distance variable. The result is that with the increase in *actual* distance, the *value* of the distance decay variable decreases accordingly, eventually rounding down to zero.

Average diversity of high streets

I also explored associations between the average diversity of high streets within distance decayed radii of 2000m, 1400m and 800m and social isolation and support outcomes. The diversity index is an indicator on the number of different land-uses present; high streets with a greater mix of land uses are considered to feature a higher potential of social interaction.

High street size

I hypothesised that high street size may potentially affect the number and variety of social venues available, therefore impacting social interactions. I included a measure of size of the closest high street as a covariate into models examining associations between distance to closest high street and the three outcomes.

I additionally included size of high streets within the radii of 2000m, 1400m and 800m and included these into the respective 2000m, 1400m and 800m distance decay models.

5.2.7.2 Missing data

For missing information within the analytic sample, multiple imputation with chained equations was used with 10 imputations. To account for non-response and adjust for attrition, combined survey and non-response weights were used (Fitzsimons et al., 2020). Further information on the assumptions of multiple imputation can be found in Chapter Two - 2.2.1.

5.3 Results

Table 5.1 shows the descriptive characteristics of the analytic sample (n = 5582). 56% of the sample were female and 44% were male. The sample was also mostly white (80%). There were no sociodemographic differences between our analytic sample and the full MCS sweep 7 sample that completed the face-to-face interview (Appendix Table 2.1).

Tables 5.2 and 5.3 show the distribution of responses for the frequency of social contact, social activities and social support. At age 17, 55% and 69% of participants reported participating in social activity or contact with friends respectively at least once a week or every day. 63% reported the highest level of social support.

Between ages 14 and 17, 9% (n=512) of participants in the analytic sample changed address. Sensitivity analysis showed no difference in main analysis results between those remaining at the same address between survey sweeps and the total analytic sample.

The mean distance to the closest high street was 2.23 km (min = 0.0002 km; max = 160.49 km); 2,024 participants (36%) lived within 800m (around a 10-minute walk) of their closest high street whilst 617 (11%) participants lived over 5km away from a high street. I found that 3.1% (95% CI 1.9, 4.9) of the variance in social contact with friends, 8% (95% CI 6.1, 10.8) of the variance in frequency of social activity and 1.2% (95% CI 0.4, 3.3) of the variance in social support was due to differences in neighbourhood clusters.

Table 5.1: Study sample characteristics (n=5582)

Sex	**Frequency**	**Percent**
Female	3123	55.95
Male	2459	44.05
Total	5582	100.00
Highest Parental Education		
NVQ level 1 (CSE below grade 1/GCSE or O Level below grade C, SCE Standard, Ordinary grades below grade 3 or Junior Certificate below grade C)	100	2.00
NVQ level 2 (O Level or GCSE grade A-C, SCE Standard, Ordinary grades 1-3 or Junior Certificate grade A-C)	722	14.46
NVQ level 3 (A/AS/S levels, SCE Higher, Scottish Certificate Sixth Year Studies, Leaving Certificate)	656	13.14
NVQ level 4 (first degree, diplomas in higher education, teaching qualifications for schools or further education)	2107	42.20
NVQ level 5 (higher degree, postgraduate qualification, certificate or diploma)	1178	23.59
Other academic qualifications (incl. overseas)	230	4.61
Total	4993	100.00
Missing	*589*	
Ethnicity		
White	4472	80.13
Mixed	249	4.46
Indian	168	3.01
Pakistani and Bangladeshi	379	6.79
Black or Black British	170	3.05
Other ethnic group (inc Chinese, other)	143	2.56
Total	5581	100.00
Missing	*1*	
Income Quintile		
First quintile	686	12.30
Second quintile	747	13.40
Third quintile	1037	18.60
Fourth quintile	1436	25.75
Highest quintile	1670	29.95
Total	5576	100.00
Missing	*6*	
ONS Rural/Urban classification		
Rural	1399	25.09
Urban	4177	74.91
Total	5576	100.00
Missing	*6*	
Occupational status		
Not in work	1339	24.18
Semi-routine and routine	904	16.32
Lower supervisory and technical	142	2.56
Small employers/self-employed	373	6.74
Intermediate	971	17.53
Higher managerial	1809	32.67
Total	5538	100.00
Missing	*44*	

Table 5.2: Distributions of indicators of social isolation at age 17 years												
	Frequency of contact with friends						Social activities					
	All (n=5577)		Male (n=2458)		Female (n=3119)		All (n=5577)		Male (n=2455)		Female (n=3122)	
Lowest category *(never, once a year or less, or several times a year)*	605	10.85%	292	11.88%	313	10.04%	1259	22.57%	584	23.79%	675	21.62%
Middle category *(at least once a month)*	1100	19.72%	424	17.25%	676	21.67%	1271	22.79%	547	22.28%	724	23.19%
Highest category *(at least once a week or every day)*	3872	69.43%	1742	70.87%	2130	68.29%	3047	54.67%	1324	53.93%	1723	55.19%

Note: Participants were asked about the frequency of contact with friends outside of school or work and about the frequency of their social activities in the community.

Table 5.3: Distributions of Social Provisions Scale (SPS) items used to capture social support, age 17 years

		Frequency	Percent
I have family and friends who help me feel safe, secure and happy			
Not true at all		81	1.49
Partly true		1061	19.48
Very true		4306	79.04
	Total	5448	100.00
	Missing	*134*	
There is someone I trust whom I would turn to for advice if I were having problems			
Not true at all		191	3.51
Partly true		906	16.64
Very true		4349	79.86
	Total	5446	100.00
	Missing	*136*	
There is no one I feel close to			
Not true at all		4260	78.37
Partly true		966	17.77
Very true		210	3.86
	Total	5436	100.00
	Missing	*146*	

Note: for analysis variables were combined and averaged to create one continuous variable with lower scores indicating lower social support.
Analytic sample (n = 5582)

5.3.1 Distance to closest high street

Frequency of social activities

The odds of being in the highest category of frequency of social activities, compared to the lowest, were 1.01 (95% CI 0.98, 1.03) times larger for each additional km in our fully adjusted model (Table 5.4). However, the confidence interval suggests that this effect is not distinct from no effect, as the interval includes 1.00. The VPC estimated that neighbourhood clusters account for 6.1% (95% CI 3.83, 9.76) of total residual variance in highest category of social activities frequency.

Frequency of contact with friends

I found no associations between participant’s distance (km) to closest high street at age 14 and frequency of contact with friends at age 17 in unadjusted or adjusted models in either males or females (Table 5.4). The VPC estimated that neighbourhood clusters account for 9.1% (95% CI 5.34, 15.19) of total residual variance in the highest category of social contact with friends.

Social support

I found no associations between participant’s distance (km) to closest high street at age 14 and social support at age 17, in either females or males (Table 5.4). The VPC estimated that neighbourhood clusters accounted for 0.9% (95% CI 0.25, 3.45) of total residual variance in social support.

Table 5.4: Associations between distance (km) to closest high street and indicators of social isolation and social support						
Frequency of social activities OR (95% CI)						
	All (n = 5577)		Male (n = 2455)		Female (n=3119)	
Middle category (compared to lowest)						
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Distance	1.01 (0.97, 1.05)	1.00 (0.98, 1.03)	1.06 (1.00, 1.11)	1.04 (0.99, 1.09)	1.00 (0.98, 1.03)	1.00 (0.98, 1.02)
VPC	10.0% (7.59, 1.53)	7.6% (4.49, 12.91)	13.3% (7.69, 2.22)	10.5% (5.26, 20.20)	13.4% (7.69, 22.24)	10.2% (5.12, 19.40)
Highest category (compared to lowest)						
Distance	1.01 (0.97, 1.04)	1.01 (0.98, 1.03)	1.04 (1.00, 1.09)	1.04 (1.00, 1.08)	1.00 (0.97, 1.02)	0.99 (0.97, 1.02)
VPC	9.5% (6.58, 1.36)	6.1% (3.83, 9.76)	11.2% (7.26, 16.9)	7.6% (3.83,14.24)	12.7% (7.10, 21.76)	10.0% (5.93,17.15)
Frequency of social contact OR (95% CI)						
Middle category (compared to lowest)						
	All (n = 5577)		Male (n=2458)		Female (n=3119)	
Distance	1.01 (0.99, 1.03)	1.00 (0.99, 1.02)	0.99 (0.97, 1.02)	0.99 (0.97, 1.01)	1.03 (0.98, 1.08)	1.02 (0.99, 1.04)
VPC	10.2% (6.38, 15.88)	10.3% (6.45, 16.17)	18.8% (9.96, 32.59)	18.1% (9.41, 32.45)	20.4% (12.82, 30.85)	20.4% (11.76, 34.85)
Highest category (compared to lowest)						
Distance	0.99 (0.97, 1.01)	0.98 (0.96, 1.00)	0.98 (0.96, 1.00)	0.98 (0.95, 1.00)	1.01 (0.95, 1.08)	0.98 (0.93, 1.04)
VPC	9.44% (6.08,14.37)	9.1% (5.34, 15.19)	12.9% (7.51, 21.33)	13.1% (7,57, 21.85)	16.3% (10.37, 24.64)	15.5% (8.72, 27.18)
Social support coef (95% CI)						
	All (n = 5450)		Male (n = 2397)		Female (n = 3053)	
Distance	0.001 (-0.001, 0.003)	0.00 (-0.002, 0.002)	-0.001 (-0.004, 0.002)	-0.001 (-0.005, 0.002)	0.003 (-0.001, 0.01)	0.002 (0.00, 0.00)
VPC	1.2% (0.44, 3.42)	0.9% (0.25, 3.45)	2.8% (1,23, 6.41)	3.1% (1.41, 6.72)	2.4% (0.79, 6.83)	1.9% (0.52, 6.62)
Note: Logistic random intercept multilevel regression used to estimate relationships with frequency of social activities and social contact, OR (Odds ratio). Linear random intercept multilevel regression used to estimate association with social support. Model 1 unadjusted. Model 2 adjusted for overall wealth, occupational status, income, parental education, sex and ethnicity. VPC = Variance Partition Coefficient. Lowest category = responded never, once a year or less, or several times a year to all activities. Middle category = responded at least once a month to any activity. Highest category = at least once a week or every day to any activity. Social support variable was compromised of 3 items from the Social Provisions Scale; higher scores indicate higher social support.						

5.3.2 Diversity index of land uses of the closest high street

I found no associations between the diversity of participants closest high street and frequency of social activities, contact with friends or social support, in either males or females in unadjusted or adjusted models (Table 5.5).

Table 5.5: Associations between diversity of land use of closest high street and indicators of social isolation and social support

Frequency of social activities OR						
	All (n = 5577)		Male (n = 2455)		Female (n=3119)	
Middle category (compared to lowest)						
Diversity	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Fixed effects Intercept	1.82 (1.06, 3.14)	1.59 (0.92, 2.75)	2.50 (1.22, 5.10)	1.93 (0.95, 3.93)	1.58 (0.81, 3.10)	1.57 (0.79, 3.12)
VPC	9.3% (5.87, 14.39)	7.1% (4.09, 12.40)	12.3% (6.73, 21.40)	9.8% (4.72, 19.69)	11.9% (6.41, 21.05)	9.5% (4.59, 18.81)
Category 3 (compared to lowest)						
Diversity	1.49 (0.90, 2.47)	1.33 (0.79, 2.25)	1.69 (0.90, 3.17)	1.32 (0.71, 2.49)	1.47 (0.74, 2.91)	1.65 (0.80, 3.42)
VPC	9.3% (6.32, 13.37)	6.0% (3.66, 9.69)	10.9% (6.99, 16.72)	7.7% (3.83, 14.49)	12.9% (8.16, 20.04)	9.9% (5.80,17.10)
Frequency of social contact OR						
Middle category (compared to lowest)						
	All (n = 5577)		Male (n=2458)		Female (n=3119)	
Diversity	1.27 (0.63, 2.54)	1.04 (0.52, 2.06)	2.18 (0.80, 5.92)	1.42 (0.53, 3.83)	0.77 (0.30, 1.96)	0.76 (0.28, 2.02)
VPC	10.1% (6.31, 15.70)	10.3% (6.43, 16)	0.19 (0.60, 1.26)	18.0% (9.26, 32.49)	0.20 (0.13, 0.30)	19.8% (11.26, 34.30)
Category 3 (compared to lowest)						
Diversity	0.97 (0.55, 1.71)	0.83 (0.47, 1.48)	1.25 (0.59, 2.62)	1.08 (0.50, 2.35)	0.68 (0.29, 1.60)	0.62 (0.25, 1.51)
VPC	9.5% (6.10, 14.41)	9.4% (5.5, 15.60)	0.13 (0.07, 0.21)	13.2% (7.69, 21.91)	0.17 (0.11, 0.25)	16.2% (9.04, 28.36)
Social support						
	All (n = 5450)		Male (n = 2397)		Female (n = 3053)	
Diversity	-0.003 (-0.07, 0.06)	-0.03 (-0.09, 0.04)	-0.003 (-0.10, 0.09)	-0.02 (-0.12, 0.08)	-0.01 (-0.10, 0.08)	-0.03 (-0.12, 0.06)
VPC	1.2% (0.44, 3.43)	1.0% (0.26, 3.43)	2.9% (1.23, 6.46)	3.1% (1.43, 6.82)	2.4% (0.80, 6.82)	1.9% (0.53, 6.54)

Note: Logistic random intercept multilevel regression used to estimate relationships with frequency of social activities and social contact, OR (Odds ratio). Linear random intercept multilevel regression. Model 1 unadjusted.
Model 2 adjusted for overall wealth, occupational status, income, parental education, sex and ethnicity. VPC = Variance Partition Coefficient. Lowest category = responded never, once a year or less, or several times a year to all activities. Middle category = responded at least once a month to any activity. Highest category = at least once a week or every day to any activity. Social support variable was compromised of 3 items from the Social Provisions Scale; higher scores indicate higher social support.

5.3.3 Sensitivity Analyses

Non-linearity

I explored non-linearity firstly with the inclusion of a quadratic term within all models. There was no evidence that including a quadratic term improved model fit.

I also modelled distance decayed at radii cutoffs of approximately 2000m, 1400m and 800m; which did not show evidence of better model fit. Full modelling results are presented in Appendix 2 Tables A2.4 – A2.6.

Average diversity of all high streets

I found no associations between average diversity of all high streets within radii of 800m, 1400m and 2000m and frequency of social activities, frequency of contact with friends or social support. Full modelling results can be found in Appendix 2 Tables A2.8-10.

High street size

I included the size of the closest high street as an additional covariate to the distance to closest high street and social isolation and support models. This covariate measured the number of addresses of the closest high street, capturing the size. Results did not change with the inclusion of high street size.

These results can be found in Appendix 2 Tables A2.11-12.

5.4 Discussion

Main findings

I hypothesised that greater proximity to high streets at age 14 years, acting as a proxy for opportunities for social encounters, would be associated with lower social isolation (i.e. lack of social activities and contact with friends) and poor perceived support in adolescents at age 17. I also considered that exposure to high streets with low diversity at age 14 would be associated with higher social isolation at age 17. Contrary to expectations, this study revealed no associations between proximity to high streets or diversity of closest high streets with the frequency of various social activities, contact with friends or social support in adolescents. These findings may indicate that proximity to and land use diversity of high streets are not significant for participation in social activities and social contact and perceived support in this age group in Britain.

Previous research has reported that adolescent males experience greater social isolation than females (Umberson et al., 2022). However, this data revealed no differences between males and females in their frequency of social activities and social contact. 24% of males, compared to 22% of females, responded never, once a year or less, or several times to participating in any social activity. 12% of males reported never, once a year or less, or several times a year to seeing friends outside of school or work compared to 10% of females. However, our analytic sample was relatively smaller than this study (n=14,056 and 22,156) (Umberson et al., 2022).

Findings in the context of other studies

Results estimated that 8% (95% CI 6.1, 10.8) of the variance in social activity could be accounted for by neighbourhood clusters, in this case electoral wards. This is similar to previous research that reported UK geographic regions accounted for 5-8% of variation in loneliness in young people (Marquez et al., 2023).

There is limited existing research examining proximity to high streets and social isolation indicators, making it difficult to compare our findings with other studies. The role of the high street in social participation appears to be important for older adults (Phillips et al., 2021), but our findings indicate that the distance to high streets may not be as important for social activities, social contact and social support for adolescents as we had hypothesised. It is possible that younger individuals can overcome these distances more easily due to higher mobility and better access to transport, as compared to older individuals and that the proxy of distance to the high street therefore becomes less relevant. Further, some of the social activities we investigated at age 17 included going to a club, theatre, stadium, museum or gig, for which young people might be willing to travel longer distances. Other social activities that we investigated, such as attending a religious service or explorer scouts might, in turn, be less related to distance to high street (British Youth Council, 2012; Collings et al., 2023).

Alternatively, it might be is possible that adolescents socialise in spaces other than around the high street, including online, and that distances to high streets are therefore less relevant as a proxy. In the current study social contact was measured as how often the respondent sees friends outside of school or work, but we did not include communication via social media, gaming, or mobile phones. This approach overlooks the extent to which adolescents use social media to maintain social relationships. Indeed, some research has suggested that increased social media use leads to the displacement of face-to-face interactions among adolescents (Winstone et al., 2021). Furthermore, other spaces may be meaningful for adolescent social interaction, which may include green spaces as indicated in the existing literature (Hind et al., 2021; Lyons et al., 2022). Some research indicates that adolescents prefer indoor shopping centres and green spaces close to home and that these areas support social interaction behaviours (C. Clark & Uzzell, 2002). A case study of 48 participants from London reported that young people (16-24 year olds) felt most socially connected in parks, religious places and places they could engage in activities (G. Moore et al., 2023).

In this study I did not consider the quality and character of high streets. Although a greater mix of land uses, as captured through Shannon's diversity index, is indicative of a healthier high street (Daly & Allen, 2018), it does not measure local crime, aesthetics, places to sit or other important features of high streets which may impact their usage. For example, research has shown that crime, such as street robbery, can limit resident's social activities and negatively impact mental health (Dustmann & Fasani, 2016; T. Jones et al., 1987). Increased levels of litter, fly-tipping and graffiti also reduce the amount of time people spend visiting those areas (Daly & Allen, 2018). Moreover, high streets with carefully placed seating provide opportunities for people to gather and talk, which may be particularly important for adolescents that often rely on public spaces to socialise (Department for Communities and Local Government, 2012; Pearson et al., 2008).

In this current study I did not consider neighbourhood perceptions. Marquez et. al., (2023) reported that young people aged 16-24 years experienced less loneliness if they felt a greater sense of belonging to their neighbourhood and had higher perceived neighbourhood quality. Similarly, Moore et al. (2023) highlighted the important role of young people's views and experiences of their neighbourhood with regards to feelings of social connectedness.

Whilst high street proximity and diversity may be important, participant perceptions of their local area could be a salient factor in levels of social isolation that we did not consider.

Strengths and limitations

Strengths of this study include a large sample size and the use of nationally representative, demographically diverse longitudinal data on a sample of adolescents. Another key strength is the use of diverse disciplinary perspectives in building our hypotheses, linking the datasets, and interpreting findings. Rather than conflating social isolation, social ties and loneliness (Valtorta et al., 2016) this study conceptualised social isolation as an objective lack of social contact, operationalised by measuring the frequency of social activities and social contact. The study used geographically detailed measures of high street proximity, taking account both of the closest and those within walking distance (including using distance decay measures) from the high street.

Limitations of this study included that the frequency of social activities variable included components such as frequency of attending a youth club, religious service, music gig or party. The aggregation of these social activities lacked specificity and may have obscured possible effects. However, it was not computationally possible to run each model with every individual components of the activity exposure. I measured perceived social support with three items from the 10-item Social Provisions Scale (Cutrona & Russell, 1987); a validated and widely used measure of social support. However, the inclusion of only three items in the MCS may have limited the scale's ability to represent social support. Such measures also failed to capture the digital connectivity of adolescents or acknowledge that social media and gaming is an important mode of communication.

The data did not allow us to assess the exact provisions and amenities in the local areas of cohort members. Although the land use diversity index would, to some extent, capture the availability of facilities such as parks, religious places or other places they could engage in activities, we were limited by the diversity index to land use categories of residential, leisure, office, retail, and community and did not include green spaces. I therefore was not able to specify whether particular features of the high street were significant for social isolation in adolescents.

As address level data was not available due to confidentiality, the study utilised participant postcodes which was not a precise measure of their home location. The administrative classifications of postcodes may lead to scaling issues; MAUP and ecological fallacy in particular (Sadler & Lafreniere, 2017).

Furthermore, I used a standard OS definition of a high street, which only includes high streets with a minimum of 15 retail addresses. It is possible that the importance of smaller high streets, particularly in coastal and rural areas, was therefore overlooked.

Research and policy implications

The null findings in this cohort of adolescents suggests that proximity to high streets may not especially important for adolescents in Britain. Further qualitative work, including walking interviews and GPS-based tracking of participants, is needed to understand which spaces offer opportunities for young people to encounter and congregate with others, and which features of the sociospatial environment attract such encounters in rural and urban environments. It would also be important to understand if, and how, young people may be able to overcome greater distances to high streets. It would be important to conduct similar quantitative work to investigate our hypotheses in older cohorts and compare findings, as high street proximity may be important for other age groups.

5.5 Conclusions

This study sought to improve understanding of the effects of proximity to high streets and social isolation in adolescents. I did not find evidence for associations between proximity or diversity of closest high streets and either social isolation or perceived social support. Further research focusing on quality and perceptions of high streets is warranted, including in other age groups.

Chapter Six – Discussion

The overarching aim of this thesis was to investigate the significance of features of the neighbourhood, namely safety and crime, greenspaces and high streets, and physical activity and social isolation in adolescents. The thesis aimed to achieve this by bringing together the disciplines of health epidemiology and spatial research. The following chapter discusses the findings of the thesis in terms of three key themes: measurement, UK perspectives and adolescence. The strengths and limitations of the data and methods, and implications for future research will then be discussed.

6.1 Overall Findings

Results from Chapter Three indicate varying associations between subjective and objective measures of crime, safety and physical activity and suggest that crime and subjective safety may impede adolescents from participating in physical activity. The subcategory of violent and sexual offences, as measured with Data.Police.UK, was associated with fewer days of self-reported physical activity. I found no associations between proximity to greenspace and physical activity in Chapter Four, suggesting that it is necessary to consider other features of greenspaces, not just proximity, in terms of its association with physical activity in adolescents. There were also no associations when males and females were considered separately. In Chapter Five, there was no evidence for an association between proximity to or diversity of closest high street and social isolation or social support in males or females. These results suggest that high streets may either not significantly influence adolescent social engagement or that young people are willing to travel greater distances to socialise.

6.2 Measurement

Objective and subjective measures

Throughout this thesis I have used objective and subjective measures where possible. In Chapters Three and Four I captured physical activity using both self-reported (subjective) and device-measured (objective) measures. Chapter Three additionally used two objective measures of crime in the neighbourhood and a perceived safety measure. In Chapter Five I also captured the objective construct of social isolation in addition to the perceived feeling of social support. Using both self-reported and objective measures is a strength of the studies in this thesis.

Findings from Chapters Three and Four highlight the complexities of objective and subjective measures of physical activity. For example, there was an association between perceived safety and self-reported physical activity but not with physical activity measured with accelerometers. It therefore cannot be assumed that self-reported and device-measured physical activity are interchangeable or will provide the same results as each other for adolescents. The integration of both types of measures allows for a more comprehensive understanding of adolescent physical activity.

All three studies presented in this thesis incorporated objective neighbourhood measures, geo-linked to participant postcodes. However, it was not possible to include subjective measures of the neighbourhood in Chapters Four and Five. As briefly discussed in the respective chapters, a limitation of not using subjective measures is that the potential importance of perceptions of greenspaces or high streets could not be explored which may explain the null associations. Indeed, previous research has indicated that there is poor agreement between objective and subjective greenspace measures (Lackey & Kaczynski, 2009). Although we were able to capture high street size and diversity and size of greenspaces, subjective measures are potentially better at capturing the quality of these features. Individuals will make a judgement about the quality, amenities, and facilities as is important to their needs and preferences. It is, however, time-intensive to measure quality via surveys, especially for a large sample size.

Measurement of neighbourhood features

This thesis included the use of GIS-generated measures in Chapters Four and Five. GIS-generated measures include accurate walking time and distance variables between access points of greenspaces or high streets and participants residence. Such measures have the benefit of greater spatial precision especially with the use of network distance variables which incorporate real world walking routes. Epidemiological urban health studies have traditionally focused on simple, area-aggregated associations between, for example land use, and an indicator of health or wellbeing. This thesis used a variety of variables to capture neighbourhood features which expands on previous studies that have used crude neighbourhood measures, such as proportion of greenspace within an administrative area.

As discussed in Chapter One, there are a wide variety of methods to measure and operationalise the neighbourhood, but measurements focused on the adolescent population are needed. It has been suggested that older adolescence is associated with decreased social and physical bonds to the residential neighbourhood (Skelton, 2013) and that ‘activity space’ should be explored in addition to exposures in the residential neighbourhood. An ‘activity space’ refers to the locations an individual has contact with on a daily basis. Technological advances in research mean that future studies may be able to determine objective, individually-tailored neighbourhood measures based on activity spaces (Boruff et al., 2012). Previous research has indeed highlighted how neighbourhood classification and measurement of spatial accessibility is important in accurately capturing the environmental exposures to youth (Duncan et al., 2014). Address level data, rather than postcodes for example, may be necessary to understand the spatial realities of adolescents.

6.3 Neighbourhoods and heath from a UK perspective

This thesis adds to the literature on neighbourhoods and health in the context of adolescence in the UK. A large majority of previous research has been conducted in North America, which although provides useful background information, is not directly comparable to the UK due to the different spatial landscapes. British and European cities tend to be high-density and more compact. In contrast, American cities are known for low-density development and increased urban sprawl with dependency on private cars (Richardson & Bae, 2017).

Chapter Five measured proximity and diversity of high streets, a predominantly UK phenomenon. Although a high street could be roughly translated to 'Main Street' in a North American context, high streets represent a spatial construct distinctive to the UK. As argued in Chapter Five, UK high streets do not merely function for retail purposes but also form part of the community fabric of towns and cities. It has also been argued that suburban high streets are uniquely British, due to the historical pattern of suburban growth not seen in North America (Griffiths, 2018). Many suburban high streets were formed in an unplanned way along roads that originally connected a marketplace and centre of a settlement (Griffiths et al., 2010). The retail environment in the US differs in that cities often contain out-of-town shopping centres and planned retail strips (Guy, 1991; C. Jones, 2021). Although retail parks and shopping centres have increased in Britain, the city centre remains a focal point for retail and businesses. As such, high streets are thought of as key spaces for social encounters, partly due to the well-connected street networks around them and access to transport. Although Chapter Five did not support the hypothesis that proximity to high streets is associated with social isolation in adolescents, this finding importantly contributes to the minimal evidence that exists for this topic.

Similarly, the spatial distribution and usage of greenspaces is distinct in the UK from North America and even Europe. For example, the distribution of urban greenspaces in the US has been shaped by historical ethno-racial inequalities (Byrne & Wolch, 2009). Until 1948, people of colour were legally confined to limited areas within US cities and many states continued the practice of segregated park systems until the 1960s (Gotham, 2000; Nickel, 1997). US researchers have argued that the effects of segregation prevail today, impacting park usage (Byrne, 2012).

The spatial landscapes of the UK and Europe, although historically more similar than North America, still differ. Indeed, greenspace provision differs considerably across Europe. Whilst in England the average provision of greenspace per person is 29m^2, it is significantly lower in Southern and Eastern Europe with Spain, for example, averaging 4m^4 to 5m^2 per person (Yukhnovskyi & Zibtseva, 2019). Meanwhile, northern European countries enjoy a greater provision of greenspace per person (European Environment Agency, 2022; Fuller & Gaston, 2009). Furthermore, whilst greenspaces make up a third, on average, of urban areas in Britain, this is 42% in European cities (European Environment Agency, 2023; Office for National Statistics, 2018). This highlights how caution should be taken when drawing on spatial research from other countries and that findings cannot be generalised to a UK setting.

Other examples of spatial differences between the UK and Europe include transportation. The public transport infrastructure in Western European differs to Britain, with 67% of European city residents able to reach their city centre within 30 minutes compared to 40% of British people (Rodrigues & Breach, 2021). This has been partly attributed to the increased density typical of Western European cities. The availability and efficiency of transportation may be especially important in adolescence, as this age group often rely on public transport to meet friends and attend activities (British Youth Council, 2012; Collings et al., 2023).

This thesis importantly adds to the literature of neighbourhood effects and health in a UK context, which is distinct from North America and Europe where a large proportion of the existing research has been conducted.

6.4 Adolescence

This thesis has discussed how adolescents, due partly to financial and mobility constraints, may be particularly influenced by their neighbourhood. The null findings between proximity to greenspace and physical activity and access to high streets and social isolation may indicate that standard approaches to neighbourhood research may not always be relevant to an adolescent population. The level of autonomy and mobility of an adolescent determines how much they are exposed to their neighbourhood (Crosnoe & Johnson, 2011). It is also possible that, for example greenspaces, affect adolescents at different ages differently. Across the period of adolescence, individuals experience several developmental stages, including social and cognitive changes. Adolescents at ages 11, 14 and 17 (MCS sweeps 5-7) may express different interests and needs and make use of their neighbourhood in different ways. It therefore may not be possible to extrapolate findings from early to late adolescence, or vice versa. In Chapters Three and Four we looked at data from age 14 in the MCS, at this age adolescents are likely to spend more time with peers away from home but still depend on guardians for transportation and permission to participate in activities outside of school. At age 17, our social isolation and support outcome age in Chapter Five, adolescents are likely to move around their neighbourhoods, and further afield, unsupervised.

Furthermore, Chapters Four and Five highlight that proximity to a neighbourhood feature is unlikely to capture a rounded picture of their effect in adolescents. In Chapter Four I measured proximity to a greenspace whilst in Chapter Five I explored distance to high streets. Indeed, the null associations in Chapters Four and Five may highlight the fact that the mechanistic pathways between the neighbourhood and health outcomes might operate in a complex system. It may well be that proximity alone to either neighbourhood feature is not enough to entice adolescents. Public spaces that offer features such as benches and places to congregate without supervision from adults may be more important to adolescents. Future studies should consider incorporating information on characteristics of the public space of interest.

6.5 Strengths and Limitations

Each of the studies presented in this thesis contributes to the growing literature on the role of neighbourhood environment and health outcomes in adolescence in a UK landscape. This thesis also highlights the challenges and inconsistencies in the field of neighbourhood health research in relation to adolescent health and wellbeing. Chapter Five in particular makes a unique contribution to the literature by researching proximity to high streets and social isolation, a previously unexplored feature of UK neighbourhoods. The thesis further benefits from the inter-disciplinary approach taken. With expertise from the fields of built environment, urban planning, epidemiology and quantitative statistics the thesis was informed by a multitude of disciplines. It was therefore possible to examine neighbourhood features from both a spatial and health perspective. The multidisciplinary approach of this thesis, drawing together spatial and health sciences, is novel in that it combines an understanding of the multifaceted nature of the neighbourhood and adolescent health.

Furthermore, the thesis also benefits from the variety of statistical approaches taken. In Chapters Four and Five I employed multilevel modelling techniques which allows the measurement of variation in outcomes between individuals whilst accounting for contextual effects. As described in these chapters, a multilevel framework recognises that data can have a hierarchical structure. A benefit of using multilevel modelling is that standard errors of regression coefficients are likely to be more accurate over traditional multiple regressions which treat units of analysis as independent observations and ignore hierarchical structures and grouping. I also employed the Mundlak formulation in Chapter Four, which estimates the "contextual effect", or the neighbourhood effect once individual-level characteristics are accounted for (Bell et al., 2019), and is not often employed in health epidemiology studies representing a novel aspect of this thesis. Furthermore, throughout the thesis results are presented stratified by sex, enabling consideration of differences such as in fear of crime and crime rates influencing levels of physical activity in girls.

An important strength of this thesis is the use of a large cohort study with a rich set of variables. The MCS recruited a representative sample of the UK in a contemporary adolescent population. The rich dataset allowed for adjustment of important socioeconomic and demographic factors.

However, we were limited in that we could only investigate variables that were collected within the cohort. As with any cohort study, all participants are given the same questionnaires and data are collected without a specific purpose and with the intention it can be utilised by a variety of disciplines. For example, the MCS did not collect any information on what specific features of the neighbourhood adolescents perceived as unsafe or if they were more likely to be physically active in a greenspace or not, as discussed above.

I was interested in specifically exploring prospective associations in Chapters Three and Five to allow for the observation of medium-term effects, hence the three-year time lag between exposure and outcome. However, this time difference may not be appropriate considering the lack of evidence around optimal time of exposure to a neighbourhood feature and health outcomes. Indeed, adolescent's perceptions and interactions with neighbourhood features may change during this time, therefore, a cross-sectional analysis may be an important alternative approach.

I conducted sensitivity analyses of non-movers in Chapters Three and Five which found no differences. This implies that any confounding effect of residential mobility was minimal. However, this sensitivity analysis would not account for potential selective migration of participants and their families. Selective migration suggests that individuals select neighbourhoods based on pre-existing preferences, for example, those that enjoy greenspaces are more likely to move to areas with greenspaces. Nonetheless, this is less relevant for adolescents who likely have little autonomy in deciding living arrangements. Moreover, in this thesis it was not possible to analyse whether those that changed address moved to areas with greater proximity to greenspaces or high streets. Future analyses may investigate proximity to greenspaces and physical activity in the sample of those that moved address.

Other limitations that are important to note include that address level data was not available, meaning postcode centroids were utilised for cohort member residence. Although this is typically the most granular level of data available in UK studies, it may over or underestimate distances. As discussed in Research Aims and Objectives

The overall aim of this thesis is to explore whether the features of the neighbourhood environment influence physical activity and social isolation outcomes in an adolescent population.

To achieve this aim, I use epidemiological methods alongside aspects of spatial and urban science and health geography. By employing a multidisciplinary approach, I aim to bring relevant aspects of these disciplines together to inform research questions, analytical methods, and better understand the UK spatial landscape in a health context. For example, I used geo-coded data and uses measures generated from Geographical Information Software (GIS) to better capture the neighbourhood features of interest.

This thesis recognises that the neighbourhood is multidimensional. The following chapters explore how the neighbourhood exposures of crime and safety, greenspace, and high streets may be important for adolescence. This thesis focuses on outcomes in adolescence, specifically, physical activity and social isolation and social support outcomes.

Research objectives:

13) To explore how neighbourhood crime and perceived safety impact physical activity behaviours. This study also explores the complexities around using objective and subjective measures for both exposure and outcomes.
14) To explore whether greenspace plays a role in physical activity behaviours, whilst carefully considering socio-economic confounding factors.
15) To investigate whether high streets, as a proxy for areas of social encounter, activity, and interaction, are important for social isolation and social support.

Results from this thesis will offer important insight into the UK neighbourhood environment, relevant to health in adolescence.

Chapter Two – Data and Methods, this is especially true in rural areas.

Whilst all three studies in this thesis attempted to carefully control for socioeconomic confounding factors, it is possible that further individual or area level characteristics important in the relationship between neighbourhood features and physical activity or social isolation were not accounted for. For example, we did not account for access to a private garden in Chapter Four which some research has linked to increased physical activity in adults (de Bell et al., 2020).

6.6 Considerations for future research

Adolescence may be better understood when viewed from a life course perspective; looking back into childhood and forward into adulthood may help better understand the role of neighbourhood features during adolescence. The use of longitudinal cohort data to explore how neighbourhoods can influence health outcomes over the life course would be valuable. Such research should ideally make use of cohorts followed through from childhood to adulthood and examine repeated measures of, for example, physical activity and social isolation, along with repeated measures of the neighbourhood environment.

As previously mentioned, null findings in Chapters Four and Five may point towards the need for a complex systems approach in addressing questions around the impact of the neighbourhood on health. A complex systems approach consists of a focus on the pathways between interdependent elements within a connected whole, rather than considering isolated linear cause-and-effect pathways (Rutter et al., 2017). In other words, a complex system model appreciates that the determinants of health work within a dynamic system with many characteristics influencing each other. It is unlikely that neighbourhood risk factors act independently on health outcomes. Complex systems computational modelling makes use of computer algorithms to model complex and dynamic interactions between individuals within and across different levels within a simulated population (Galea et al., 2009).

As discussed throughout this thesis, the concept of the neighbourhood is multifaceted and not straightforward to define or operationalise. It is also not possible to create a definition or measure for neighbourhoods that will be appropriate for all. Depending on many factors including age group, socioeconomic background or cultural affiliation, a neighbourhood will mean different things to different people. Advances in GIS and GPS technology, which make it possible to track individuals' movements and activities, could be used to gauge neighbourhood scales in representative samples of sociodemographic groups. This could offer important insights into how different age groups, for example, use their local and residential areas.

Qualitative data may provide important insights into why and when adolescents use public spaces in their neighbourhood. Qualitative studies offer in-depth exploration of narrative data and are useful in unpicking complex relationships. Qualitative studies seek to gather the perspectives and experiences from the point of view of research participants, offering rich insight into the research question (Bannister-Tyrrell & Meiqari, 2020). This would be particularly useful to expand our knowledge on perceptions of neighbourhood features in early and late adolescents.

It may be that other health outcomes and behaviours are likely to be influenced by the neighbourhood in adolescence beyond physical activity and social isolation. For example, mental health outcomes have been linked to contextual conditions, including the neighbourhood environment. The neighbourhood may influence the type and level of stressors that people are exposed to and the resources available to cope with stressors (Snedker & Herting, 2016). The stress process is a framework for understanding the mechanisms by which stressors can impact mental health; it is posited that neighbourhoods can influence the stress process in three different ways (Cutrona et al., 2006). Firstly, characteristics of the neighbourhood can influence the level of daily stress on those who live there. Physical features of the neighbourhood, such as low-quality housing, traffic density, crime and lack of greenspaces, may impose stress on residents. Secondly, the neighbourhood may impact the vulnerability to mental disorders of its residents. For example, a negative life event is more likely to trigger poor mental health for an individual living in an adverse neighbourhood compared to a good-quality neighbourhood. Thirdly, the characteristics of a neighbourhood effect the social bonds and ties amongst people. Research suggests that residents tend not to form social ties with other residents in neighbourhoods high in social disorder (Hill et al., 2005). The impact of neighbourhood features explored in this thesis on mental health outcomes in adolescents would be an interesting topic of further research.

6.7 Conclusion

This thesis contributes to the literature by utilising geo-linked, longitudinal data and methods to answer novel research questions around the neighbourhood and health outcomes in adolescence. The thesis has been able to offer some future research considerations such as considering research on adolescence health from a life course perspective and integrating qualitative data to explore how adolescence interact with their neighbourhoods.

References

Alcock, I., White, M. P., Wheeler, B. W., Fleming, L. E., & Depledge, M. H. (2014). Longitudinal effects on mental health of moving to greener and less green urban areas. *Environmental Science and Technology*. https://doi.org/10.1021/es403688w

Algren, M. H., Ekholm, O., Nielsen, L., Ersbøll, A. K., Bak, C. K., & Andersen, P. T. (2020). Social isolation, loneliness, socioeconomic status, and health-risk behaviour in deprived neighbourhoods in Denmark: A cross-sectional study. *SSM - Population Health*, *10*. https://doi.org/10.1016/j.ssmph.2020.100546

Allen, R., & Balfour, R. (2014). *Natural Solutions to Tackling Health Inequalities*.

Almeida, I., Rego, J. F., Teixeira, A. C. G., & Moreira, M. R. (2021). Social isolation and its impact on child and adolescent development: a systematic review. *Revista Paulista de Pediatria : Orgao Oficial Da Sociedade de Pediatria de Sao Paulo*, *40*. https://doi.org/10.1590/1984-0462/2022/40/2020385

Alsadoun, D. A., Alotaibi, H. S., Alanazi, A. I., Almohsen, L. A., Almarhoum, N. N., & Mahboub, S. (2023). Social isolation among adolescents and its association with depression symptoms. *Middle East Current Psychiatry*, *30*(1). https://doi.org/10.1186/s43045-023-00314-4

Andresen, M. A. (2006). A spatial analysis of crime in Vancouver, British Columbia: A synthesis of social disorganization and routine activity theory. *Canadian Geographer*. https://doi.org/10.1111/j.1541-0064.2006.00159.x

Armstrong, L. L., & Manion, I. G. (2006). Suicidal ideation in young males living in rural communities: Distance from school as a risk factor, youth engagement as a protective factor. *Vulnerable Children and Youth Studies*, *1*(1). https://doi.org/10.1080/17450120600659010

Atkin, A. J., Gorely, T., Clemes, S. A., Yates, T., Edwardson, C., Brage, S., Salmon, J., Marshall, S. J., & Biddle, S. J. H. (2012). Methods of measurement in epidemiology: Sedentary behaviour. *International Journal of Epidemiology*. https://doi.org/10.1093/ije/dys118

Babey, S. H., Hastert, T. A., Yu, H., & Brown, E. R. (2008). Physical Activity Among Adolescents. When Do Parks Matter? *American Journal of Preventive Medicine*, *34*(4). https://doi.org/10.1016/j.amepre.2008.01.020

Baffoe, G. (2019). Understanding the Neighbourhood Concept and Its Evolution: A Review. *Environment and Urbanization ASIA*, *10*(2). https://doi.org/10.1177/0975425319859115

Bancroft, C., Joshi, S., Rundle, A., Hutson, M., Chong, C., Weiss, C. C., Genkinger, J., Neckerman, K., & Lovasi, G. (2015). Association of proximity and density of parks and objectively measured physical activity in the United States: A systematic review. In *Social Science and Medicine* (Vol. 138). https://doi.org/10.1016/j.socscimed.2015.05.034

Bannister-Tyrrell, M., & Meiqari, L. (2020). Qualitative research in epidemiology: theoretical and methodological perspectives. In *Annals of Epidemiology* (Vol. 49). https://doi.org/10.1016/j.annepidem.2020.07.008

Baranyi, G. (2020). *Neighbourhood effects, local crime and mental health: Longitudinal analyses over the life course*. University of Edinburgh.

Barbosa, O., Tratalos, J. A., Armsworth, P. R., Davies, R. G., Fuller, R. A., Johnson, P., & Gaston, K. J. (2007). Who benefits from access to green space? A case study from Sheffield, UK. *Landscape and Urban Planning*, *83*(2–3). https://doi.org/10.1016/j.landurbplan.2007.04.004

Barton, J., & Rogerson, M. (2017). The importance of greenspace for mental health. *BJPsych. International*. https://doi.org/10.1192/s2056474000002051

Bélanger, M., Gray-Donald, K., O'loughlin, J., Paradis, G., & Hanley, J. (2009). Influence of Weather Conditions and Season on Physical Activity in Adolescents. *Annals of Epidemiology*. https://doi.org/10.1016/j.annepidem.2008.12.008

Bell, A., Fairbrother, M., & Jones, K. (2019). Fixed and random effects models: making an informed choice. *Quality and Quantity*, *53*(2). https://doi.org/10.1007/s11135-018-0802-x

Bennett, G. G., McNeill, L. H., Wolin, K. Y., Duncan, D. T., Puleo, E., & Emmons, K. M. (2007). Safe to walk? Neighborhood safety and physical activity among public housing residents. *PLoS Medicine*. https://doi.org/10.1371/journal.pmed.0040306

Berger, N., Lewis, D., Quartagno, M., Njagi, E. N., & Cummins, S. (2019). Longitudinal associations between perceptions of the neighbourhood environment and physical activity in adolescents: Evidence from the Olympic Regeneration in East London (ORiEL) study. *BMC Public Health*. https://doi.org/10.1186/s12889-019-8003-7

Berger, N., Lewis, D., Quartagno, M., Njagi, E. N., & Cummins, S. (2020). Longitudinal associations between neighbourhood trust, social support and physical activity in adolescents: Evidence from the Olympic Regeneration in East London (ORiEL) study. *Journal of Epidemiology and Community Health*, *74*(9). https://doi.org/10.1136/jech-2019-213412

Bloemsma, L. D., Gehring, U., Klompmaker, J. O., Hoek, G., Janssen, N. A. H., Smit, H. A., Vonk, J. M., Brunekreef, B., Lebret, E., & Wijga, A. H. (2018). Green space visits among adolescents: Frequency and predictors in the PIAMA birth cohort study. *Environmental Health Perspectives*, *126*(4). https://doi.org/10.1289/EHP2429

Boruff, B. J., Nathan, A., & Nijënstein, S. (2012). Using GPS technology to (re)-examine operational definitions of 'neighbourhood' in place-based health research. *International Journal of Health Geographics*. https://doi.org/10.1186/1476-072X-11-22

Bowker, J., White, H., & Etkin, R. (2021). Social Withdrawal During Adolescence: The Role of Peers. In R. Coplan, J. Bowker, & L. Nelson (Eds.), *The Handbook of Solitude: Psychological Perspectives on Social Isolation, Social Withdrawal, and Being Alone* (Second). John Wiley & Sons, Inc.

Braveman, P. A., Cubbin, C., Egerter, S., Chideya, S., Marchi, K. S., Metzler, M., & Posner, S. (2005). Socioeconomic status in health research: One size does not fit all. *JAMA*, *294*(22). https://doi.org/10.1001/jama.294.22.2879

British Heart Foundation National Centre. (2014). *Evidence Briefing Physical Activity for Children and Young People*.

British Youth Council. (2012). *Youth Select Committee. Transport and Young People*.

Brown, B. B., Werner, C. M., Smith, K. R., Tribby, C. P., & Miller, H. J. (2014). Physical activity mediates the relationship between perceived crime safety and obesity. *Preventive Medicine*. https://doi.org/10.1016/j.ypmed.2014.06.021

Brown, M., Goodman, A., Peters, A., Ploubidis, G. B., Sanchez, A., Silverwood, R., & Smith, K. (2021). *COVID-19 Survey in Five National Longitudinal Studies: Waves 1, 2 and 3 User Guide (Version 3)*.

Brownson, R. C., Hoehner, C. M., Day, K., Forsyth, A., & Sallis, J. F. (2009). Measuring the Built Environment for Physical Activity. State of the Science. In *American Journal of Preventive Medicine* (Vol. 36, Issue 4 SUPPL.). https://doi.org/10.1016/j.amepre.2009.01.005

Brunton-Smith, I. (2011). Untangling the relationship between fear of crime and perceptions of disorder: Evidence from a longitudinal study of young people in England and Wales. *British Journal of Criminology*. https://doi.org/10.1093/bjc/azr064

Brunton-Smith, I., & Sturgis, P. (2011). Do Neighborhoods Generate Fear Of Crime? An Empirical Test Using The British Crime Survey. *Criminology*, *49*(2), 331–369. https://doi.org/10.1111/J.1745-9125.2011.00228.X

Brunton-Smith, I., Sutherland, A., & Jackson, J. (2013). The role of neighbourhoods in shaping crime and perceptions of crime. In *Neighbourhood Effects or Neighbourhood Based Problems?: A Policy Context*. https://doi.org/10.1007/978-94-007-6695-2_4

Burbidge, S. K., & Goulias, K. G. (2009). Evaluating the impact of neighborhood trail development on active travel behavior and overall physical activity of suburban residents. *Transportation Research Record*, *2135*. https://doi.org/10.3141/2135-10

Burden, A., Fry, R., Rodgers, S., & Grinnell, D. (2014). *Using address data to compare accuracy of accessibility to health services*. GIS Research UK . https://www.gla.ac.uk/media/Media_401733_smxx.pdf

Burrough, P., McDonnell, R., & Lloyd, C. (2015). *Principles of geographical information systems* (Third). Oxford University Press.

Butcher, M. (2020). Feminist City: Claiming Space in a Man-made World. *Gender & Development*. https://doi.org/10.1080/13552074.2020.1832387

Byrne, J. (2012). When green is White: The cultural politics of race, nature and social exclusion in a Los Angeles urban national park. *Geoforum*, *43*(3). https://doi.org/10.1016/j.geoforum.2011.10.002

Byrne, J., & Wolch, J. (2009). Nature, race, and parks: Past research and future directions for geographic research. *Progress in Human Geography*, *33*(6). https://doi.org/10.1177/0309132509103156

Cacioppo, J. T., Cacioppo, S., Capitanio, J. P., & Cole, S. W. (2015). The neuroendocrinology of social isolation. *Annual Review of Psychology*, *66*. https://doi.org/10.1146/annurev-psych-010814-015240

Cacioppo, J. T., & Hawkley, L. C. (2003). Social Isolation and Health, with an Emphasis on Underlying Mechanisms. *Perspectives in Biology and Medicine*, *46*(3). https://doi.org/10.1353/pbm.2003.0049

Cairney, J., Kwan, M. Y. W., Velduizen, S., Hay, J., Bray, S. R., & Faught, B. E. (2012). Gender, perceived competence and the enjoyment of physical education in children: A longitudinal examination. *International Journal of Behavioral Nutrition and Physical Activity*. https://doi.org/10.1186/1479-5868-9-26

Campbell, E., Henly, J. R., Elliott, D. S., & Irwin, K. (2009). Subjective constructions of neighborhood boundaries: Lessons from a qualitative study of four neighborhoods. *Journal of Urban Affairs*. https://doi.org/10.1111/j.1467-9906.2009.00450.x

Carmona, M. (2015). London's local high streets: The problems, potential and complexities of mixed street corridors. *Progress in Planning*, *100*(1–84). https://doi.org/10.1016/j.progress.2014.03.001

Carro, D., Valera, S., & Vidal, T. (2010). Perceived insecurity in the public space: Personal, social and environmental variables. *Quality and Quantity*. https://doi.org/10.1007/s11135-008-9200-0

Carver, A., Timperio, A., & Crawford, D. (2008). Playing it safe: The influence of neighbourhood safety on children's physical activity-A review. *Health and Place*. https://doi.org/10.1016/j.healthplace.2007.06.004

Caspi, A., Harrington, H. L., Moffitt, T. E., Milne, B. J., & Poulton, R. (2006). Socially isolated children 20 years later: Risk of cardiovascular disease. *Archives of Pediatrics and Adolescent Medicine*, *160*(8). https://doi.org/10.1001/archpedi.160.8.805

Ceccato, V. (2012). The urban fabric of crime and fear. In *The Urban Fabric of Crime and Fear*. https://doi.org/10.1007/978-94-007-4210-9_1

Centre for Longitudinal Studies. (2020a). *Millennium Cohort Study: Sixth Survey 2015-2016: Vol. 2nd ed*.

Centre for Longitudinal Studies. (2020b). *Millennium Cohort Study User Guide (Surveys 1 – 5)*.

Chandola, T., & Jenkinson, C. (2000). The new UK National Statistics Socio-Economic Classification (NS-SEC); Investigating social class differences in self-reported health status. *Journal of Public Health Medicine*, *22*(2). https://doi.org/10.1093/pubmed/22.2.182

Chaparro, M. P., Bilfield, A., & Theall, K. P. (2019). Exposure to Neighborhood Crime Is Associated with Lower Levels of Physical Activity and Higher Obesity Risk among Adolescent Girls, but Not Boys. *Childhood Obesity*. https://doi.org/10.1089/chi.2018.0165

Christiansen, J., Qualter, P., Friis, K., Pedersen, S. S., Lund, R., Andersen, C. M., Bekker-Jeppesen, M., & Lasgaard, M. (2021). Associations of loneliness and social isolation with physical and mental health among adolescents and young adults. In *Perspectives in Public Health* (Vol. 141, Issue 4). https://doi.org/10.1177/17579139211016077

Church, A., Frost, M., & Sullivan, K. (2000). Transport and social exclusion in London. *Transport Policy*, *7*(3), 195–205. https://doi.org/10.1016/S0967-070X(00)00024-X

Church, D. (2015). *Millennium Cohort Study Guide to geographic identifiers*.

Clark, C., & Uzzell, D. L. (2002). *THE AFFORDANCES OF THE HOME, NEIGHBOURHOOD, SCHOOL AND TOWN CENTRE FOR ADOLESCENTS*. https://doi.org/10.1006/jevp.2001.0242

Clark, S. (2015). Running into trouble: constructions of danger and risk in girls' access to outdoor space and physical activity. *Sport, Education and Society*. https://doi.org/10.1080/13573322.2013.866548

Cohen, L. E., & Felson, M. (1979). Social Change and Crime Rate Trends: A Routine Activity Approach. *American Sociological Review*. https://doi.org/10.2307/2094589

Collings, S., Chatterjee, K., Cope, A., Burns, T., & Adeel, M. (2023). *Transport to Thrive. Why we shouldn't ignore the transport needs of young people*.

Community First Oxfordshire. (2022). *Rural Isolation in Oxfordshire Survey Report*.

Connelly, R., & Platt, L. (2014). Cohort profile: UK Millennium Cohort Study (mcs). *International Journal of Epidemiology*, *43*(6). https://doi.org/10.1093/ije/dyu001

Constable Fernandez, C., Patalay, P., Vaughan, L., Church, D., Hamer, M., & Maddock, J. (2023). Subjective and objective indicators of neighbourhood safety and physical activity among UK adolescents. *Health and Place*, *83*. https://doi.org/10.1016/j.healthplace.2023.103050

Consumer Data Research Centre. (n.d.). *Note on Active and Passive Green Spaces (v2)*. Retrieved 13 June 2023, from https://data.cdrc.ac.uk/dataset/access-healthy-assets-hazards-ahah/resource/note-active-and-passive-green-spaces-v2

Coombes, E., Jones, A., Cooper, A., & Page, A. (2017). Does home neighbourhood supportiveness influence the location more than volume of adolescent's physical activity? An observational study using global positioning systems. *International Journal of Behavioral Nutrition and Physical Activity*, *14*(1). https://doi.org/10.1186/s12966-017-0607-7

Copeland, M., Fisher, J. C., Moody, J., & Feinberg, M. E. (2018). Different Kinds of Lonely: Dimensions of Isolation and Substance Use in Adolescence. *Journal of Youth and Adolescence*, *47*(8). https://doi.org/10.1007/s10964-018-0860-3

Corcoran, R., Mansfield, R., de Bezenac, C., Anderson, E., Overbury, K., & Marshall, G. (2018). Perceived neighbourhood affluence, mental health and wellbeing influence judgements of threat and trust on our streets: An urban walking study. *PLoS ONE*. https://doi.org/10.1371/journal.pone.0202412

Corder, K., Sharp, S. J., Atkin, A. J., Griffin, S. J., Jones, A. P., Ekelund, U., & Van Sluijs, E. M. F. (2015). Change in objectively measured physical activity during the transition to adolescence. *British Journal of Sports Medicine*, *49*(11). https://doi.org/10.1136/bjsports-2013-093190

Cornwell, E. Y., & Waite, L. J. (2009). Social disconnectedness, perceived isolation, and health among older adults. *Journal of Health and Social Behavior*, *50*(1). https://doi.org/10.1177/002214650905000103

Cox, W. (2022). Demographia World Urban Areas, 18th Annual Edition: July 2022. *Demograpgia*, *18*.

Crosnoe, R., & Johnson, M. K. (2011). Research on adolescence in the twenty-first century. In *Annual Review of Sociology* (Vol. 37). https://doi.org/10.1146/annurev-soc-081309-150008

Cummins, S., & Fagg, J. (2012). Does greener mean thinner Associations between neighbourhood greenspace and weight status among adults in England. *International Journal of Obesity*, *36*(8). https://doi.org/10.1038/ijo.2011.195

Curiel, R. P., & Bishop, S. R. (2016). A metric of the difference between perception of security and victimisation rates. *Crime Science*. https://doi.org/10.1186/s40163-016-0060-y

Cutrona, C., & Russell, D. (1987). The provisions of social support and adaptation to stress. *Advance in Personal Relationships*, 37–67.

Cutrona, C., Wallace, G., & Wesner, K. A. (2006). Neighborhood characteristics and depression an examination of stress processes. *Current Directions in Psychological Science*, *15*(4). https://doi.org/10.1111/j.1467-8721.2006.00433.x

da Silva, I., van Hees, V., Ramires, V. V., Knuth, A. G., Bielemann, R. M., Ekelund, U., Brage, S., & Hallal, P. C. (2014). Physical activity levels in three Brazilian birth cohorts as assessed with raw triaxial wrist accelerometry. *International Journal of Epidemiology*. https://doi.org/10.1093/ije/dyu203

Daly, S., & Allen, J. (2018). *Healthy High Streets: Good place-making in an urban setting*.

Danese, A., Moffitt, T. E., Harrington, H., Milne, B. J., Polanczyk, G., Pariante, C. M., Poulton, R., & Caspi, A. (2009). Adverse childhood experiences predict adult risk factors for age-related disease: Depression, inflammation, and clustering of metabolic risk markers. *Brain, Behavior, and Immunity*, *23*. https://doi.org/10.1016/j.bbi.2009.06.032

Daras, K., Green, M. A., Davies, A., Barr, B., & Singleton, A. (2019). Open data on health-related neighbourhood features in Great Britain. *Scientific Data*, *6*(1). https://doi.org/10.1038/s41597-019-0114-6

Darlington, F., Norman, P., Ballas, D., & Exeter, D. J. (2015). Exploring ethnic inequalities in health: Evidence from the Health Survey for England, 1998-2011. *Diversity and Equality in Health and Care*, *12*(2). https://doi.org/10.21767/2049-5471.100032

Davies, D. S. C., Atherton, F., McBride, M., & Calderwood, C. (2019). UK Chief Medical Officers' Physical Activity Guidelines. *Department of Health and Social Care*.

Davison, K. K., & Lawson, C. T. (2006). Do attributes in the physical environment influence children's physical activity? A review of the literature. In *International Journal of Behavioral Nutrition and Physical Activity* (Vol. 3). https://doi.org/10.1186/1479-5868-3-19

de Bell, White, M., Griffiths, A., Darlow, A., Taylor, T., Wheeler, B., & Lovell, R. (2020). Spending time in the garden is positively associated with health and wellbeing: Results from a national survey in England. *Landscape and Urban Planning*, *200*. https://doi.org/10.1016/j.landurbplan.2020.103836

De Jong Gierveld, J. (1998). A review of loneliness: Concept and definitions, determinants and consequences. In *Reviews in Clinical Gerontology* (Vol. 8, Issue 1). https://doi.org/10.1017/S0959259898008090

De Koning, J. L., Stathi, A., & Richards, S. (2017). Predictors of loneliness and different types of social isolation of rural-living older adults in the United Kingdom. In *Ageing and Society* (Vol. 37, Issue 10). https://doi.org/10.1017/S0144686X16000696

de Zylva, P., Gordon-Smith, C., & Childs, M. (2020). *England's green space gap How to end green space deprivation in England*.

Delmelle, E. M., Desjardins, M. R., Jung, P., Owusu, C., Lan, Y., Hohl, A., & Dony, C. (2022). Uncertainty in geospatial health: challenges and opportunities ahead. *Annals of Epidemiology*, *65*, 15–30. https://doi.org/10.1016/j.annepidem.2021.10.002

Dennis, M., & James, P. (2017). Evaluating the relative influence on population health of domestic gardens and green space along a rural-urban gradient. *Landscape and Urban Planning*. https://doi.org/10.1016/j.landurbplan.2016.08.009

Department for Communities and Local Government. (2012). *Re-imagining urban spaces to help revitalise our high streets*.

Desjardins, M. R., Murray, E. T., Hobbs, M., & Curtis, S. (2023). Improving longitudinal research in geospatial health: An agenda. *Health & Place*, *80*, 102994. https://doi.org/10.1016/j.healthplace.2023.102994

Diemer, E. W., Hudson, J. I., & Javaras, K. N. (2021). More (Adjustment) Is Not Always Better: How Directed Acyclic Graphs Can Help Researchers Decide Which Covariates to Include in Models for the Causal Relationship between an Exposure and an Outcome in Observational Research. *Psychotherapy and Psychosomatics*, *90*(5). https://doi.org/10.1159/000517104

Ding, D., Sallis, J. F., Kerr, J., Lee, S., & Rosenberg, D. E. (2011). Neighborhood environment and physical activity among youth: A review. *American Journal of Preventive Medicine*, *41*(4). https://doi.org/10.1016/j.amepre.2011.06.036

Do, D. P., Diez Roux, A. V., Hajat, A., Auchincloss, A. H., Merkin, S. S., Ranjit, N., Shea, S., & Seeman, T. (2011). Circadian rhythm of cortisol and neighborhood characteristics in a population-based sample: The Multi-Ethnic Study of Atherosclerosis. *Health and Place*, *17*(2). https://doi.org/10.1016/j.healthplace.2010.12.019

Dorling, D., Mitchell, R., Shaw, M., Orford, S., & Smith, G. D. (2000). The ghost of christmas past: Health effects of poverty in London in 1896 and 1991. *British Medical Journal*, *321*(7276). https://doi.org/10.1136/bmj.321.7276.1547

Dreher, N. H. (1993). *Public Parks in Urban Britain, 1870-1920: Creating a New Public Culture*. University of Pennsylvania.

Dubourg, R., Hamed, J., & Thorns, J. (2003). The Economic and Social Costs of Crime Against Individuals and Households 2003/04. *Home Office Online Report*.

Duncan, D. T., & Kawachi, I. (2018). Neighborhoods and Health. In *Neighborhoods and Health*. https://doi.org/10.1097/01.ede.0000121553.93692.6c

Duncan, D. T., Kawachi, I., Subramanian, S. V., Aldstadt, J., Melly, S. J., & Williams, D. R. (2014). Examination of how neighborhood definition influences measurements of youths' access to tobacco retailers: A methodological note on spatial misclassification. *American Journal of Epidemiology*, *179*(3). https://doi.org/10.1093/aje/kwt251

Dustmann, C., & Fasani, F. (2016). The Effect of Local Area Crime on Mental Health. *Economic Journal*, *126*(593). https://doi.org/10.1111/ecoj.12205

Ekelund, U., Luan, J., Sherar, L. B., Esliger, D. W., Griew, P., & Cooper, A. (2012). Moderate to vigorous physical activity and sedentary time and cardiometabolic risk factors in children and adolescents. *JAMA - Journal of the American Medical Association*. https://doi.org/10.1001/jama.2012.156

Elliott, P., Wakefield, J., Best, N., & Briggs, B. (2001). *Spatial Epidemiology: Methods and Applications*. Oxford University Press.

Enders, C. K. (2010). Applied missing data analysis. *Guilford Press*.

European Environment Agency. (2022). Who benefits from nature in cities? Social inequalities in access to urban green and blue spaces across Europe. *Briefing No. 15/2021*.

European Environment Agency. (2023). *How Green Are European Cities? Green Space Key to Well-Being – but Access Varies — European Environment Agency*. European Environment Agency (EEA).

Evans, B. (2006). 'I'd feel ashamed': Girls' bodies and sports participation. *Gender, Place and Culture*. https://doi.org/10.1080/09663690600858952

Evans, G. W., Jones-Rounds, M. L., Belojevic, G., & Vermeylen, F. (2012). Family income and childhood obesity in eight European cities: The mediating roles of Neighborhood characteristics and physical activity. *Social Science and Medicine*. https://doi.org/10.1016/j.socscimed.2012.03.037

Eyre, E. L. J., Duncan, M. J., Birch, S. L., & Cox, V. M. (2014). Low socio-economic environmental determinants of children's physical activity in Coventry, UK: A Qualitative study in parents. *Preventive Medicine Reports*, *1*. https://doi.org/10.1016/j.pmedr.2014.09.002

Fakoya, O. A., McCorry, N. K., & Donnelly, M. (2020). Loneliness and social isolation interventions for older adults: A scoping review of reviews. *BMC Public Health*, *20*(1). https://doi.org/10.1186/s12889-020-8251-6

Ferraro, K. F. (1996). Fear of Crime: Interpreting Victimization Risk. *Contemporary Sociology*. https://doi.org/10.2307/2077214

Finlay, J. M., & Kobayashi, L. C. (2018). Social isolation and loneliness in later life: A parallel convergent mixed-methods case study of older adults and their residential contexts in the Minneapolis metropolitan area, USA. *Social Science and Medicine*, *208*. https://doi.org/10.1016/j.socscimed.2018.05.010

Fitzsimons, E. (2020). *Millennium Cohort Study Sixth Survey 2015-2016 User Guide (Second Edition)*.

Fitzsimons, E., Haselden, L., Smith, K., Agalioti-Sgompou, V., Veeravalli, S., Silverwood, R., & Ploubidis, G. (2020). *Millennium Cohort Study Age 17 Sweep (MCS7): User Guide.*

Foster, S., Giles-Corti, B., & Knuiman, M. (2010). Neighbourhood design and fear of crime: A social-ecological examination of the correlates of residents' fear in new suburban housing developments. *Health and Place*, *16*(6), 1156–1165. https://doi.org/10.1016/j.healthplace.2010.07.007

Friends of Lordship Recreation Ground. (n.d.). *The Community-Led Transformation of Lordship Rec*. Retrieved 11 September 2023, from https://lordshiprec.org.uk/works/

Friends of the Earth. (2020). *England's green space gap*.

Fuller, R. A., & Gaston, K. J. (2009). The scaling of green space coverage in European cities. *Biology Letters*, *5*(3). https://doi.org/10.1098/rsbl.2009.0010

Galea, S., Hall, C., & Kaplan, G. A. (2009). Social epidemiology and complex system dynamic modelling as applied to health behaviour and drug use research. *International Journal of Drug Policy*, *20*(3). https://doi.org/10.1016/j.drugpo.2008.08.005

Gardsjord, H. S., Tveit, M. S., & Nordh, H. (2014). Promoting Youth's Physical Activity through Park Design: Linking Theory and Practice in a Public Health Perspective. *Landscape Research*, *39*(1), 70–81. https://doi.org/10.1080/01426397.2013.793764

Gidlow, C., Johnston, L. H., Crone, D., Ellis, N., & James, D. (2006). A systematic review of the relationship between socio-economic position and physical activity. In *Health Education Journal*. https://doi.org/10.1177/0017896906069378

Gilbert, B., Datta, A., Casey, J., & Ogburn, E. (2023). A causal inference framework for spatial confounding. *ArXiv*.

Gordon, M. T., & Riger, S. (1989). *The Female Fear*. The Free Press.

Gotham, K. F. (2000). Urban space, restrictive covenants and the origins of racial residential segregation in a US city, 1900-50. *International Journal of Urban and Regional Research*, *24*(3). https://doi.org/10.1111/1468-2427.00268

Gottlieb, B. H., & Bergen, A. E. (2010). Social support concepts and measures. In *Journal of Psychosomatic Research* (Vol. 69, Issue 5). https://doi.org/10.1016/j.jpsychores.2009.10.001

Graham, J. W. (2009). Missing data analysis: Making it work in the real world. In *Annual Review of Psychology* (Vol. 60). https://doi.org/10.1146/annurev.psych.58.110405.085530

Gray, D., & Manning, R. (2022). Constructing the places of young people in public space: Conflict, belonging and identity. *British Journal of Social Psychology*, *61*(4), 1400–1417. https://doi.org/10.1111/BJSO.12542

Griffith, G. J., & Jones, K. (2020). When does geography matter most? Age-specific geographical effects in the patterning of, and relationship between, mental wellbeing and mental illness. *Health and Place*. https://doi.org/10.1016/j.healthplace.2020.102401

Griffiths, S. (2018). The High Street as a Morphological Event. In *Suburban Urbanities*. https://doi.org/10.2307/j.ctt1g69z0m.10

Griffiths, S., Jones, C. E., Vaughan, L., & Haklay, M. (2010). The persistence of suburban centres in Greater London: Combining Conzenian and space syntax approaches. *Urban Morphology*, *14*(2). https://doi.org/10.51347/jum.v14i2.3955

Griffiths, S., Vaughan, L., Haklay, M. M., & Emma Jones, C. (2008). The Sustainable Suburban High Street: A Review of Themes and Approaches. *Geography Compass*, *2*(4). https://doi.org/10.1111/j.1749-8198.2008.00117.x

Guy, C. M. (1991). Comparative Retail Structure of British and American cities: Cardiff (UK) and Charlotte (USA). *The International Review of Retail, Distribution and Consumer Research*, *1*(4). https://doi.org/10.1080/09593969100000001

Hajat, A., Kaufman, J. S., Rose, K. M., Siddiqi, A., & Thomas, J. C. (2010). Do the wealthy have a health advantage? Cardiovascular disease risk factors and wealth. *Social Science and Medicine*, *71*(11). https://doi.org/10.1016/j.socscimed.2010.09.027

Hajat, A., Maclehose, R. F., Rosofsky, A., Walker, K. D., & Clougherty, J. E. (2021). Confounding by socioeconomic status in epidemiological studies of air pollution and health: Challenges and opportunities. *Environmental Health Perspectives*, *129*(6). https://doi.org/10.1289/EHP7980

Hale, C. (1996). Fear of crime: A review of the literature. In *International Review of Victimology*. https://doi.org/10.1177/026975809600400201

Hämmig, O. (2019). Health risks associated with social isolation in general and in young, middle and old age. *PLoS ONE*, *14*(7). https://doi.org/10.1371/journal.pone.0219663

Harden, J. (2000). There's no place like home: The public/private distinction in children's theorizing of risk and safety. *Childhood*, *7*(1). https://doi.org/10.1177/0907568200007001005

Harrison, R. A., Gemmell, I., & Heller, R. F. (2007). The population effect of crime and neighbourhood on physical activity: An analysis of 15 461 adults. *Journal of Epidemiology and Community Health*. https://doi.org/10.1136/jech.2006.048389

Hayes, G., Dowd, K. P., MacDonncha, C., & Donnelly, A. E. (2019). Tracking of Physical Activity and Sedentary Behavior From Adolescence to Young Adulthood: A Systematic Literature Review. In *Journal of Adolescent Health* (Vol. 65, Issue 4). https://doi.org/10.1016/j.jadohealth.2019.03.013

Heinrichs, M., Baumgartner, T., Kirschbaum, C., & Ehlert, U. (2003). Social support and oxytocin interact to suppress cortisol and subjective responses to psychosocial stress. *Biological Psychiatry*. https://doi.org/10.1016/S0006-3223(03)00465-7

Hendry, L. B., Shucksmith, J., Love, J. G., & Glendinning, A. (1993). *Young People's Leisure and Lifestyles.* Routledge.

Hernández, D. (2014). Affording Housing at the Expense of Health: Exploring the Housing and Neighborhood Strategies of Poor Families. *Journal of Family Issues*, *37*(7). https://doi.org/10.1177/0192513X14530970

Hewitt, R. J., Pera, F. A., García-Martín, M., Gaudry-Sada, K. H., Hernández-Jiménez, V., & Bieling, C. (2020). Mapping Adolescents' Sense of Place and Perceptions of Change in an Urban–Rural Transition Area. *Environmental Management*, *65*(3). https://doi.org/10.1007/s00267-019-01249-5

Hill, A., & Cheshire, J. (2023). An Investigation of the Impact and Resilience of British High Streets Following the COVID-19 Lockdown Restrictions. *Applied Spatial Analysis and Policy*, *16*(2). https://doi.org/10.1007/s12061-022-09494-8

Hill, T. D., Ross, C. E., & Angel, R. J. (2005). Neighborhood disorder, psychophysiological distress, and health. *Journal of Health and Social Behavior*, *46*(2). https://doi.org/10.1177/002214650504600204

Hillier, B. (1999). Centrality as a process: Accounting for attraction inequalities in deformed grids. *Urban Design International*, *4*(3–4). https://doi.org/10.1057/udi.1999.19

Hind, K., de Bell, S., Lovell, R., Abrahams, R., & Wheeler, B. W. (2021). *More than just a skate park? A review and practical guide on how to make urban green space more accessible to adolescents to support health and wellbeing*.

Hirvensalo, M., & Lintunen, T. (2011). Life-course perspective for physical activity and sports participation. In *European Review of Aging and Physical Activity*. https://doi.org/10.1007/s11556-010-0076-3

Högnäs, R. S., Almquist, Y. B., & Modin, B. (2020). Adolescent social isolation and premature mortality in a Swedish birth cohort. *Journal of Population Research*, *37*(1). https://doi.org/10.1007/s12546-019-09237-6

Holgate, H. (2020). *High streets in Great Britain: March, 2020*.

Holland, S., Burgess, S., Grogan-Kaylor, A., & Delva, J. (2011). Understanding neighbourhoods, communities and environments: New approaches for social work research. *British Journal of Social Work*, *41*(4). https://doi.org/10.1093/bjsw/bcq123

Holt-Lunstad, J., Smith, T. B., Baker, M., Harris, T., & Stephenson, D. (2015a). Loneliness and Social Isolation as Risk Factors for Mortality: A Meta-Analytic Review. *Perspectives on Psychological Science*. https://doi.org/10.1177/1745691614568352

Holt-Lunstad, J., Smith, T. B., Baker, M., Harris, T., & Stephenson, D. (2015b). Loneliness and Social Isolation as Risk Factors for Mortality: A Meta-Analytic Review. *Perspectives on Psychological Science*, *10*(2), 227–237. https://doi.org/10.1177/1745691614568352

Holt-Lunstad, J., & Steptoe, A. (2022). Social isolation: An underappreciated determinant of physical health. *Current Opinion in Psychology*, *43*, 232–237. https://doi.org/10.1016/J.COPSYC.2021.07.012

Huotari, P., Nupponen, H., Mikkelsson, L., Laakso, L., & Kujala, U. (2011). Adolescent physical fitness and activity as predictors of adulthood activity. *Journal of Sports Sciences*, *29*(11). https://doi.org/10.1080/02640414.2011.585166

Jacobs, J. (1961). *The Death and Life of Great American Cities*. Vintage.

Jakobsen, A. L., Hansen, C. D., & Andersen, J. H. (2022). The association between perceived social support in adolescence and positive mental health outcomes in early adulthood: a prospective cohort study. *Scandinavian Journal of Public Health*, *50*(3). https://doi.org/10.1177/1403494821993718

Janke, K., Propper, C., & Shields, M. A. (2016). Assaults, murders and walkers: The impact of violent crime on physical activity. *Journal of Health Economics*, *47*, 34–49. https://doi.org/10.1016/J.JHEALECO.2016.01.006

Janssen, I. (2014). Crime and perceptions of safety in the home neighborhood are independently associated with physical activity among 11-15year olds. *Preventive Medicine*. https://doi.org/10.1016/j.ypmed.2014.06.016

Janssen, I., & LeBlanc, A. G. (2010). Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. In *International Journal of Behavioral Nutrition and Physical Activity* (Vol. 7). https://doi.org/10.1186/1479-5868-7-40

Janz, K. F., Lutuchy, E. M., Wenthe, P., & Levy, S. M. (2008). Measuring activity in children and adolescents using self-report: PAQ-C and PAQ-A. *Medicine and Science in Sports and Exercise*. https://doi.org/10.1249/MSS.0b013e3181620ed1

Johnson, J., Joshi, H., Calderwood, L., Jones, E., McDonald, J., Shepherd, P., Platt, L., & Rosenberg, R. (2012). *Millennium Cohort Study User Guide (Surveys 1 – 5)*.

Jones, A., Hillsdon, M., & Coombes, E. (2009). Greenspace access, use, and physical activity: understanding the effects of area deprivation. *Preventive Medicine*, 500–505. https://doi.org/10.1016/j.ypmed.2009.10.012

Jones, C. (2021). Reframing the intra-urban retail hierarchy. *Cities*, *109*. https://doi.org/10.1016/j.cities.2020.103037

Jones, P., Roberts, M., & Morris, L. (2007). *Rediscovering mixed-use streets. The contribution of local high streets to sustainable communities*.

Jones, T., MacLean, B., & Young, J. (1987). The Islington Crime Survey (Crime, Victimization and Policing in Inner-City London). *The Police Journal: Theory, Practice and Principles*, *60*(3). https://doi.org/10.1177/0032258x8706000318

Joseph Rowntree Foundation. (2007). *The social value of public spaces*.

Kaczynski, A. T., & Henderson, K. A. (2007). Environmental correlates of physical activity: A review of evidence about parks and recreation. In *Leisure Sciences*. https://doi.org/10.1080/01490400701394865

Kaczynski, A. T., Potwarka, L. R., Smale, B. J. A., & Havitz, M. F. (2009). Association of Parkland proximity with neighborhood and park-based physical activity: Variations by gender and age. *Leisure Sciences*, *31*(2). https://doi.org/10.1080/01490400802686045

Kantomaa, M. T., Tammelin, T. H., Näyhä, S., & Taanila, A. M. (2007). Adolescents' physical activity in relation to family income and parents' education. *Preventive Medicine*. https://doi.org/10.1016/j.ypmed.2007.01.008

Kessler, R. C., Berglund, P., Demler, O., Jin, R., Merikangas, K. R., & Walters, E. E. (2005). Lifetime prevalence and age-of-onset distributions of DSM-IV disorders in the national comorbidity survey replication. In *Archives of General Psychiatry* (Vol. 62, Issue 6). https://doi.org/10.1001/archpsyc.62.6.593

Ketende, S. (2010). *Millennium Cohort Study Technical Report on Response Third Edition*.

Kilgour, L., & Parker, A. (2013). Gender, physical activity and fear: Women, exercise and the great outdoors. *Qualitative Research in Sport, Exercise and Health*, *5*(1). https://doi.org/10.1080/2159676X.2012.718619

Killen, M., Mulvey, K. L., & Hitti, A. (2013). Social Exclusion in Childhood: A Developmental Intergroup Perspective. *Child Development*, *84*(3). https://doi.org/10.1111/cdev.12012

Kingston, S. (2019). *Retail Geographies - High Streets Dataset Technical Specification*.

Kirby, R. S., Delmelle, E., & Eberth, J. M. (2017). Advances in spatial epidemiology and geographic information systems. *Annals of Epidemiology*, *27*(1). https://doi.org/10.1016/j.annepidem.2016.12.001

Kirkbride, J. B., Anglin, D. M., Colman, I., Dykxhoorn, J., Jones, P. B., Patalay, P., Pitman, A., Soneson, E., Steare, T., Wright, T., & Griffiths, S. L. (2024). The social determinants of mental health and disorder: evidence, prevention and recommendations. *World Psychiatry*, *23*(1). https://doi.org/10.1002/wps.21160

Kontopantelis, E., Mamas, M. A., Van Marwijk, H., Ryan, A. M., Buchan, I. E., Ashcroft, D. M., & Doran, T. (2018). Geographical epidemiology of health and overall deprivation in England, its changes and persistence from 2004 to 2015: A longitudinal spatial population study. *Journal of Epidemiology and Community Health*, *72*(2). https://doi.org/10.1136/jech-2017-209999

Krenz, K., Dhanani, A., McEachan, R. R. C., Sohal, K., Wright, J., & Vaughan, L. (2023). Linking the Urban Environment and Health: An Innovative Methodology for Measuring Individual-Level Environmental Exposures. *International Journal of Environmental Research and Public Health*, *20*(3). https://doi.org/10.3390/ijerph20031953

Kubrin, C. E. (2000). Racial Heterogeneity and Crime: Measuring Static and Dynamic Effects. *Research in Community Sociology*, *10*, 189–219.

Kubrin, C. E. (2009). *Social Disorganization Theory: Then, Now, and in the Future*. https://doi.org/10.1007/978-1-4419-0245-0_12

Kumar, B., Robinson, R., & Till, S. (2015). Physical activity and health in adolescence. *Clinical Medicine, Journal of the Royal College of Physicians of London*. https://doi.org/10.7861/clinmedicine.15-3-267

Kung, C. S. J., Pudney, S. E., & Shields, M. A. (2022). Economic gradients in loneliness, social isolation and social support: Evidence from the UK Biobank. *Social Science and Medicine*, *306*. https://doi.org/10.1016/j.socscimed.2022.115122

Lachowycz, K., & Jones, A. P. (2013). Towards A Better Understanding Of The Relationship Between Greenspace And Health: Development Of A Theoretical Framework. *Landscape and Urban Planning*, *118*. https://doi.org/10.1016/j.landurbplan.2012.10.012

Lachowycz, K., Jones, A. P., Page, A. S., Wheeler, B. W., & Cooper, A. R. (2012). What can global positioning systems tell us about the contribution of different types of urban greenspace to children's physical activity? *Health and Place*, *18*(3). https://doi.org/10.1016/j.healthplace.2012.01.006

Lackey, J. L., & Kaczynski, A. T. (2009). Correspondence of perceived vs. objective proximity to parks and their relationship to park-based physical activity. *International Journal of Behavioral Nutrition and Physical Activity*, *6*. https://doi.org/10.1186/1479-5868-6-53

Lai, K. Y., Kumari, S., Webster, C., Gallacher, J., & Sarkar, C. (2021). Associations of neighbourhood housing density with loneliness and social isolation: a cross-sectional study using UK Biobank data. *The Lancet*, *398*. https://doi.org/10.1016/s0140-6736(21)02603-9

Lamb, K. E., Thornton, L. E., King, T. L., Ball, K., White, S. R., Bentley, R., Coffee, N. T., & Daniel, M. (2020). Methods for accounting for neighbourhood self-selection in physical activity and dietary behaviour research: A systematic review. In *International Journal of Behavioral Nutrition and Physical Activity* (Vol. 17, Issue 1). https://doi.org/10.1186/s12966-020-00947-2

Lane, J. (2015). Theoretical explanations for gender differences in fear of crime. In *Routledge International Handbook of Crime and Gender Studies*. https://doi.org/10.4324/9780203832516.ch3

Lenhart, C. M., Wiemken, A., Hanlon, A., Perkett, M., & Patterson, F. (2017). Perceived neighborhood safety related to physical activity but not recreational screen-based sedentary behavior in adolescents. *BMC Public Health*. https://doi.org/10.1186/s12889-017-4756-z

Leyland, A. H., & Groenewegen, P. P. (2020). Context, Composition and How Their Influences Vary. In *Multilevel Modelling for Public Health and Health Services Research*. https://doi.org/10.1007/978-3-030-34801-4_7

Libuy, N., & Church, D. (2019). *Geo-linkages scoping review* .

Loades, M. E., Chatburn, E., Higson-Sweeney, N., Reynolds, S., Shafran, R., Brigden, A., Linney, C., McManus, M. N., Borwick, C., & Crawley, E. (2020). Rapid Systematic Review: The Impact of Social Isolation and Loneliness on the Mental Health of Children and Adolescents in the Context of COVID-19. In *Journal of the American Academy of Child and Adolescent Psychiatry* (Vol. 59, Issue 11). https://doi.org/10.1016/j.jaac.2020.05.009

Loh, V. H. Y., Veitch, J., Salmon, J., Cerin, E., Thornton, L., Mavoa, S., Villanueva, K., & Timperio, A. (2019). Built environment and physical activity among adolescents: The moderating effects of neighborhood safety and social support. *International Journal of Behavioral Nutrition and Physical Activity*, *16*(1), 1–8. https://doi.org/10.1186/s12966-019-0898-y

Long, D. L., Preisser, J. S., Herring, A. H., & Golin, C. E. (2014). A marginalized zero-inflated Poisson regression model with overall exposure effects. *Statistics in Medicine*, *33*(29). https://doi.org/10.1002/sim.6293

Lopes, B., Kamau, C., & Jaspal, R. (2019). The Roles of Socioeconomic Status, Occupational Health and Job Rank on the Epidemiology of Different Psychiatric Symptoms in a Sample of UK Workers. *Community Mental Health Journal*, *55*(2). https://doi.org/10.1007/s10597-018-0259-3

Lorenc, T., Clayton, S., Neary, D., Whitehead, M., Petticrew, M., Thomson, H., Cummins, S., Sowden, A., & Renton, A. (2012). Crime, fear of crime, environment, and mental health and wellbeing: Mapping review of theories and causal pathways. *Health and Place*. https://doi.org/10.1016/j.healthplace.2012.04.001

Lorenc, T., Petticrew, M., Whitehead, M., Neary, D., Clayton, S., Wright, K., Thomson, H., Cummins, S., Sowden, A., & Renton, A. (2013). Fear of crime and the environment: Systematic review of UK qualitative evidence. *BMC Public Health*. https://doi.org/10.1186/1471-2458-13-496

Lorenc, T., Petticrew, M., Whitehead, M., Neary, D., Clayton, S., Wright, K., Thomson, H., Cummins, S., Sowden, A., & Renton, A. (2014). Crime, fear of crime and mental health:

synthesis of theory and systematic reviews of interventions and qualitative evidence. *Public Health Research*. https://doi.org/10.3310/phr02020

Lovasi, G. S., Goh, C. E., Pearson, A. L., & Breetzke, G. (2014). The independent associations of recorded crime and perceived safety with physical health in a nationally representative cross-sectional survey of men and women in New Zealand. *BMJ Open*. https://doi.org/10.1136/bmjopen-2013-004058

Lymperopoulou, K., Bannister, J., & Krzemieniewska-Nandwani, K. (2022). Inequality in Exposure to Crime, Social Disorganization and Collective Efficacy: Evidence from Greater Manchester, United Kingdom. *British Journal of Criminology*, *62*(4). https://doi.org/10.1093/bjc/azab106

Lyons, R., Colbert, A., Browning, M., & Jakub, K. (2022). Urban greenspace use among adolescents and young adults: An integrative review. In *Public Health Nursing* (Vol. 39, Issue 3). https://doi.org/10.1111/phn.13010

Maas, J., van Dillen, S. M. E., Verheij, R. A., & Groenewegen, P. P. (2009). Social contacts as a possible mechanism behind the relation between green space and health. *Health and Place*. https://doi.org/10.1016/j.healthplace.2008.09.006

Maas, J., Verheij, R. A., Spreeuwenberg, P., & Groenewegen, P. P. (2008). Physical activity as a possible mechanism behind the relationship between green space and health: A multilevel analysis. *BMC Public Health*, *8*. https://doi.org/10.1186/1471-2458-8-206

MacIntyre, H., & Hewings, R. (2022). *Tackling loneliness through the built environment*.

Mansfield, R., Henderson, M., Richards, M., Ploubidis, G., & Patalay, P. (2023). Lifecourse Trajectories and Cross-generation Trends in Social Isolation: Findings from Five Successive British Birth Cohort Studies (preprint). *SocArXiv*.

Marek, L., Hobbs, M., Wiki, J., Kingham, S., & Campbell, M. (2021). The good, the bad, and the environment: developing an area-based measure of access to health-promoting and health-constraining environments in New Zealand. *International Journal of Health Geographics*, *20*(1). https://doi.org/10.1186/s12942-021-00269-x

Markevych, I., Schoierer, J., Hartig, T., Chudnovsky, A., Hystad, P., Dzhambov, A. M., de Vries, S., Triguero-Mas, M., Brauer, M., Nieuwenhuijsen, M. J., Lupp, G., Richardson, E. A., Astell-Burt, T., Dimitrova, D., Feng, X., Sadeh, M., Standl, M., Heinrich, J., & Fuertes, E. (2017). Exploring pathways linking greenspace to health: Theoretical and methodological guidance. In *Environmental Research*. https://doi.org/10.1016/j.envres.2017.06.028

Marquez, J., Goodfellow, C., Hardoon, D., Inchley, J., Leyland, A. H., Qualter, P., Simpson, S. A., & Long, E. (2023). Loneliness in young people: a multilevel exploration of social ecological influences and geographic variation. *Journal of Public Health (Oxford, England)*, *45*(1). https://doi.org/10.1093/pubmed/fdab402

Martins, J., Marques, A., Sarmento, H., & Carreiro Da Costa, F. (2014). Adolescents' perspectives on the barriers and facilitators of physical activity: A systematic review of qualitative studies. *Health Education Research*. https://doi.org/10.1093/her/cyv042

Mason, P., Kearns, A., & Livingston, M. (2013). 'Safe Going': The influence of crime rates and perceived crime and safety on walking in deprived neighbourhoods. *Social Science and Medicine*. https://doi.org/10.1016/j.socscimed.2013.04.011

Matthews, T., Danese, A., Wertz, J., Odgers, C. L., Ambler, A., Moffitt, T. E., & Arseneault, L. (2016). Social isolation, loneliness and depression in young adulthood: a behavioural genetic analysis. *Social Psychiatry and Psychiatric Epidemiology*, *51*(3). https://doi.org/10.1007/s00127-016-1178-7

Mattocks, C., Ness, A., Leary, S., Tilling, K., Blair, S. N., Shield, J., Deere, K., Saunders, J., Kirkby, J., Smith, G. D., Wells, J., Wareham, N., Reilly, J., & Riddoch, C. (2008). Use of accelerometers in a large field-based study of children: Protocols, design issues, and effects on precision. *Journal of Physical Activity and Health*, *5*(SUPPL. 1). https://doi.org/10.1123/jpah.5.s1.s98

McCormack, G. R., Rock, M., Toohey, A. M., & Hignell, D. (2010). Characteristics of urban parks associated with park use and physical activity: A review of qualitative research. *Health and Place*. https://doi.org/10.1016/j.healthplace.2010.03.003

McGinn, A. P., Evenson, K. R., Herring, A. H., Huston, S. L., & Rodriguez, D. A. (2008). The association of perceived and objectively measured crime with physical activity: A cross-sectional analysis. *Journal of Physical Activity and Health*, *5*(1). https://doi.org/10.1123/jpah.5.1.117

McGrath, B., Brennan, M. A., Dolan, P., & Barnett, R. (2009). Adolescent well-being and supporting contexts: A comparison of adolescents in Ireland and Florida. *Journal of Community and Applied Social Psychology*, *19*(4). https://doi.org/10.1002/casp.998

McLay, L., Jamieson, H. A., France, K. G., & Schluter, P. J. (2021). Loneliness and social isolation is associated with sleep problems among older community dwelling women and men with complex needs. *Scientific Reports*, *11*(1). https://doi.org/10.1038/s41598-021-83778-w

McLennan, D., Barnes, H., Noble, M., Davies, J., & Garratt, E. (2011). The English Indices of Deprivation 2010 - technical report. In *Social Policy*. https://doi.org/http://dx.doi.org/http://www.communities.gov.uk/publications/corporate/statistics/indices2010technicalreport

Mears, M., & Brindley, P. (2019). Measuring urban greenspace distribution equity: The importance of appropriate methodological approaches. *ISPRS International Journal of Geo-Information*. https://doi.org/10.3390/ijgi8060286

Mears, M., Brindley, P., Maheswaran, R., & Jorgensen, A. (2019). Understanding the socioeconomic equity of publicly accessible greenspace distribution: The example of Sheffield, UK. *Geoforum*, *103*. https://doi.org/10.1016/j.geoforum.2019.04.016

Mehta, V. (2009). Look closely and you will see, listen carefully and you will hear: Urban design and social interaction on streets. *Journal of Urban Design*, *14*(1). https://doi.org/10.1080/13574800802452658

Meltzer, H., Bebbington, P., Dennis, M. S., Jenkins, R., McManus, S., & Brugha, T. S. (2013). Feelings of loneliness among adults with mental disorder. *Social Psychiatry and Psychiatric Epidemiology*, *48*(1). https://doi.org/10.1007/s00127-012-0515-8

Meyer, K. A., Boone-Heinonen, J., Duffey, K. J., Rodriguez, D. A., Kiefe, C. I., Lewis, C. E., & Gordon-Larsen, P. (2015). Combined measure of neighborhood food and physical activity environments and weight-related outcomes: The CARDIA study. *Health and Place*, *33*. https://doi.org/10.1016/j.healthplace.2015.01.004

Ministry of Justice, Home Office, & The Office of National Statistics. (2013). *An Overview of Sexual Offending in England and Wales*.

Miró, F. (2014). Routine Activity Theory. In *The Encyclopedia of Theoretical Criminology*. https://doi.org/10.1002/9781118517390.wbetc198

Mitáš, J., Sas-Nowosielski, K., Groffik, D., & Frömel, K. (2018). The safety of the neighborhood environment and physical activity in Czech and Polish adolescents. *International Journal of Environmental Research and Public Health*. https://doi.org/10.3390/ijerph15010126

Mocnik, F. B. (2022). Putting Geographical Information Science in Place – Towards Theories of Platial Information and Platial Information Systems. *Progress in Human Geography*, *46*(3). https://doi.org/10.1177/03091325221074023

Molnar, B. E., Gortmaker, S. L., Bull, F. C., & Buka, S. L. (2004). Unsafe to Play? Neighborhood Disorder and Lack of Safety Predict Reduced Physical Activity among

Urban Children and Adolescents. *American Journal of Health Promotion*. https://doi.org/10.4278/0890-1171-18.5.378

Moore, G., Fardghassemi, S., & Joffe, H. (2023). Wellbeing in the city: Young adults' sense of loneliness and social connection in deprived urban neighbourhoods. *Wellbeing, Space and Society*, *5*. https://doi.org/10.1016/j.wss.2023.100172

Moore, J. B., Beets, M. W., Kaczynski, A. T., Besenyi, G. M., Morris, S. F., & Kolbe, M. B. (2014). Sex moderates associations between perceptions of the physical and social environments and physical activity in youth. *American Journal of Health Promotion*. https://doi.org/10.4278/ajhp.121023-ARB-516

Moore, T., Kesten, J. M., López-López, J. A., Ijaz, S., McAleenan, A., Richards, A., Gray, S., Savović, J., & Audrey, S. (2018). The effects of changes to the built environment on the mental health and well-being of adults: Systematic review. In *Health and Place* (Vol. 53). https://doi.org/10.1016/j.healthplace.2018.07.012

Moudon, A. V., Lee, C., Cheadle, A. D., Garvin, C., Johnson, D., Schmid, T. L., Weathers, R. D., & Lin, L. (2016). Operational Definitions of Walkable Neighborhood: Theoretical and Empirical Insights. *Journal of Physical Activity and Health*, *3*(s1). https://doi.org/10.1123/jpah.3.s1.s99

Moulton, V., Goodman, A., Nasim, B., Ploubidis, G. B., & Gambaro, L. (2021). Parental Wealth and Children's Cognitive Ability, Mental, and Physical Health: Evidence From the UK Millennium Cohort Study. *Child Development*, *92*(1). https://doi.org/10.1111/cdev.13413

Mouratidis, K. (2020). Neighborhood characteristics, neighborhood satisfaction, and well-being: The links with neighborhood deprivation. *Land Use Policy*, *99*. https://doi.org/10.1016/j.landusepol.2020.104886

Mullan, E. (2003). Do you think that your local area is a good place for young people to grow up? The effects of traffic and car parking on young people's views. *Health & Place*, *9*, 351–360. https://doi.org/10.1016/S1353-8292(02)00069-2

Mundlak, Y. (1978). On the Pooling of Time Series and Cross Section Data. *Econometrica*, *46*(1). https://doi.org/10.2307/1913646

Mytton, O. T., Townsend, N., Rutter, H., & Foster, C. (2012). Green space and physical activity: An observational study using Health Survey for England data. *Health and Place*. https://doi.org/10.1016/j.healthplace.2012.06.003

Natural England. (2023). *Green Infrastructure Standards for England-Summary Green Infrastructure Framework-Principles and Standards for England*.

Nazmi, A., Diez Roux, A., Ranjit, N., Seeman, T. E., & Jenny, N. S. (2010). Cross-sectional and longitudinal associations of neighborhood characteristics with inflammatory markers: Findings from the multi-ethnic study of atherosclerosis. *Health and Place*, *16*(6). https://doi.org/10.1016/j.healthplace.2010.07.001

Nguyen, P. Y., Astell-Burt, T., Rahimi-Ardabili, H., & Feng, X. (2021). Green space quality and health: A systematic review. In *International Journal of Environmental Research and Public Health* (Vol. 18, Issue 21). https://doi.org/10.3390/ijerph182111028

Nickel, J. W. (1997). The liberty dimension of historic and contemporary segregation. *Law and Philosophy*, *16*(3). https://doi.org/10.2307/3504873

Noble, M., Wright, G., Smith, G., & Dibben, C. (2006). Measuring multiple deprivation at the small-area level. *Environment and Planning A*. https://doi.org/10.1068/a37168

Office for National Statistics. (2015). Chapter 3: Equivalised income. In *Compendium: Family Spending: 2015. A report on the Living Costs and Food Survey 2014.*

Office for National Statistics. (2018). *UK natural capital: ecosystem accounts for urban areas*.

Office for National Statistics. (2022). *The impact of crime on victims and society: March 2022*. *March*, 1–9.

Office for National Statistics, & Ordnance Survey. (2019). *High streets in Great Britain*.

Oh, W., Rubin, K. H., Bowker, J. C., Booth-LaForce, C., Rose-Krasnor, L., & Laursen, B. (2008). Trajectories of social withdrawal from middle childhood to early adolescence. *Journal of Abnormal Child Psychology*, *36*(4). https://doi.org/10.1007/s10802-007-9199-z

Olsen, J., Caryl, F., Nicholls, N., Smith, M., McCrorie, P., & Mitchell, R. (2023). Inequalities in neighbourhood features within children's 20-minute neighbourhoods and variation in time spent locally, measured using GPS. *Wellbeing, Space and Society*, *5*(100174).

Openshaw, S., & Taylor, P. J. (1979). A million or so correlation coefficients: three experiments on the modifiable areal unit problem. In *Statistical Applications in the Spatial Sciences*.

Orben, A., Tomova, L., & Blakemore, S. J. (2020). The effects of social deprivation on adolescent development and mental health. *The Lancet. Child & Adolescent Health*, *4*(8), 634. https://doi.org/10.1016/S2352-4642(20)30186-3

Ordnance Survey. (2022). *OS MASTERMAP GREENSPACE LAYER – OVERVIEW*.

Ordnance Survey. (2023a). *OS MASTERMAP HIGHWAYS NETWORK – PATHS™ – TECHNICAL SPECIFICATION*.

Ordnance Survey. (2023b). *OS MASTERMAP HIGHWAYS NETWORK – PRODUCT GUIDE*.

Ortegon-Sanchez, A., McEachan, R. R. C., Albert, A., Cartwright, C., Christie, N., Dhanani, A., Islam, S., Ucci, M., & Vaughan, L. (2021). Measuring the built environment in studies of child health—a meta-narrative review of associations. *International Journal of Environmental Research and Public Health*, *18*(20), 10741. https://doi.org/10.3390/IJERPH182010741/S1

Osmane, S., Brennan, M., & Dolan, P. (2021). Understanding and assessing construct validity of the social provisions scale: Implications for youth development. *Journal of Youth Development*, *16*(4). https://doi.org/10.5195/jyd.2021.925

Owen, G., Harris, R., & Jones, K. (2016). Under examination: Multilevel models, geography and health research. *Progress in Human Geography*, *40*(3). https://doi.org/10.1177/0309132515580814

Ozbay, F., Johnson, D. C., Dimoulas, E., Morgan, C. A., Charney, D., & Southwick, S. (2007). Social Support and Resilience to Stress. *Psychiatry (Edgmont)*, *4*(5).

Palumbo, C., Volpe, U., Matanov, A., Priebe, S., & Giacco, D. (2015). Social networks of patients with psychosis: A systematic review Psychiatry. In *BMC Research Notes* (Vol. 8, Issue 1). https://doi.org/10.1186/s13104-015-1528-7

Panter, J. R., Jones, A. P., & van Sluijs, E. M. F. (2008). Environmental determinants of active travel in youth: A review and framework for future research. In *International Journal of Behavioral Nutrition and Physical Activity* (Vol. 5). https://doi.org/10.1186/1479-5868-5-34

Park, B. J., Tsunetsugu, Y., Kasetani, T., Kagawa, T., & Miyazaki, Y. (2010). The physiological effects of Shinrin-yoku (taking in the forest atmosphere or forest bathing): Evidence from field experiments in 24 forests across Japan. In *Environmental Health and Preventive Medicine*. https://doi.org/10.1007/s12199-009-0086-9

Payne, R. a, & Abel, G. a. (2012). UK indices of multiple deprivation - a way to make comparisons across constituent countries easier. *Health Statistics Quarterly / Office for National Statistics*.

Pearson, C., Levi, D., & del Rio, V. (2008). Implications of Adolescents' Perceptions and Values for Planning and Design. *Journal of Planning Education and Research*, *28*(1), 5–122.

Pedersen, M. R. L., Bredahl, T. V. G., Elmose-Østerlund, K., & Hansen, A. F. (2022). Motives and Barriers Related to Physical Activity within Different Types of Built Environments: Implications for Health Promotion. *International Journal of Environmental Research and Public Health*, *19*(15). https://doi.org/10.3390/ijerph19159000

Perchoux, C., Chaix, B., Cummins, S., & Kestens, Y. (2013). Conceptualization and measurement of environmental exposure in epidemiology: Accounting for activity space related to daily mobility. *Health and Place*. https://doi.org/10.1016/j.healthplace.2013.01.005

Perlman, D., & Peplau, L. A. (1984). Loneliness research: A survey of empirical findings. In *Preventing the harmful consequences of severe and persistent loneliness*.

Phillips, J., Walford, N., Hockey, A., & Sparks, L. (2021). Older People, Town Centres and the Revival of the 'High Street'. *Planning Theory and Practice*, *22*(1). https://doi.org/10.1080/14649357.2021.1875030

Pickering, J., Kintrea, K., & Bannister, J. (2012). Invisible walls and visible youth: Territoriality among young people in British cities. *Urban Studies*, *49*(5). https://doi.org/10.1177/0042098011411939

Platt, B., Kadosh, K. C., & Lau, J. Y. F. (2013). The role of peer rejection in adolescent depression. In *Depression and Anxiety* (Vol. 30, Issue 9). https://doi.org/10.1002/da.22120

Platt, L. (2009). Social activity, social isolation and ethnicity. In *Sociological Review* (Vol. 57, Issue 4). https://doi.org/10.1111/j.1467-954X.2009.01867.x

Plewis, I. (2007). *The Millennium Cohort Study: Technical Report on Sampling 4th Edition*. www.ioe.ac.uk/bedfordgroup

Pollack, C. E., Cubbin, C., Sania, A., Hayward, M., Vallone, D., Flaherty, B., & Braveman, P. A. (2013). Do wealth disparities contribute to health disparities within racial/ethnic groups? *Journal of Epidemiology and Community Health*, *67*(5). https://doi.org/10.1136/jech-2012-200999

Propper, C., Burgess, S., Bolster, A., Leckie, G., Jones, K., & Johnston, R. (2007). The impact of neighbourhood on the income and mental health of British social renters. *Urban Studies*, *44*(2). https://doi.org/10.1080/00420980601075067

Pyyry, N., & Tani, S. (2015). Young People's Play with Urban Public Space: Geographies of Hanging Out. In *Play, Recreation, Health and Well Being*. https://doi.org/10.1007/978-981-4585-96-5_8-1

Qualter, P., Arsenault, L., Barreto, M., Fett, A.-K., Hey, N., Johnson, S., Kharicha, K., Matthews. T, McDaid, D., Pearce, E., Pitman, A., & Victor, C. (2022). *Tackling loneliness evidence review*.

Qualter, P., Vanhalst, J., Harris, R., Van Roekel, E., Lodder, G., Bangee, M., Maes, M., & Verhagen, M. (2015). Loneliness Across the Life Span. *Perspectives on Psychological Science*, *10*(2). https://doi.org/10.1177/1745691615568999

Reid, L. W., & Konrad, M. (2004). The gender gap in fear: Assessing the interactive effects of gender and perceived risk on fear of crime. *Sociological Spectrum*. https://doi.org/10.1080/02732170490431331

Rey Gozalo, G., Barrigón Morillas, J. M., & Montes González, D. (2019). Perceptions and use of urban green spaces on the basis of size. *Urban Forestry and Urban Greening*, *46*. https://doi.org/10.1016/j.ufug.2019.126470

Richards, L., & Paskov, M. (2016). Social class, employment status and inequality in psychological well-being in the UK: Cross-sectional and fixed effects analyses over two decades. *Social Science and Medicine*, *167*. https://doi.org/10.1016/j.socscimed.2016.08.042

Richardson, H. W., & Bae, C. H. C. (2017). Urban sprawl in Western Europe and the United States. In *Urban Sprawl in Western Europe and the United States*. https://doi.org/10.4324/9781315235226

Ries, A. V., Gittelsohn, J., Voorhees, C. C., Roche, K. M., Clifton, K. J., & Astone, N. M. (2008). The environment and urban adolescents' use of recreational facilities for physical activity: A qualitative study. *American Journal of Health Promotion*. https://doi.org/10.4278/ajhp.07043042

Rodrigues, G., & Breach, A. (2021). *Measuring up: Comparing public transport in the UK and Europe's biggest cities*. Centre for Cities.

Rook, G. A. (2013). Regulation of the immune system by biodiversity from the natural environment: An ecosystem service essential to health. In *Proceedings of the National Academy of Sciences of the United States of America*. https://doi.org/10.1073/pnas.1313731110

Royal Society for Public Health. (2015). *Health on the High Street*.

Royal Society for Public Health. (2018). *Health on the High Street: Running on Empty*.

Rubin, D. B. (1987). Multiple imputation for nonresponse in surveys. In *MULTIPLE IMPUTATION FOR NONRESPONSE IN SURVEYS*. Wiley.

Rueger, S. Y., Malecki, C. K., Pyun, Y., Aycock, C., & Coyle, S. (2016). A meta-analytic review of the association between perceived social support and depression in childhood and adolescence. *Psychological Bulletin*, *142*(10). https://doi.org/10.1037/bul0000058

Russell, D. W. (1996). UCLA Loneliness Scale (Version 3): Reliability, validity, and factor structure. *Journal of Personality Assessment*, *66*(1). https://doi.org/10.1207/s15327752jpa6601_2

Rutter, H., Savona, N., Glonti, K., Bibby, J., Cummins, S., Finegood, D. T., Greaves, F., Harper, L., Hawe, P., Moore, L., Petticrew, M., Rehfuess, E., Shiell, A., Thomas, J., & White, M. (2017). The need for a complex systems model of evidence for public health. In *The Lancet* (Vol. 390, Issue 10112). https://doi.org/10.1016/S0140-6736(17)31267-9

Sadler, R. C., & Lafreniere, D. J. (2017). You are where you live: Methodological challenges to measuring children's exposure to hazards. *Journal of Children and Poverty*, *23*(2). https://doi.org/10.1080/10796126.2017.1336705

Salvo, G., Lashewicz, B. M., Doyle-Baker, P. K., & McCormack, G. R. (2018). Neighbourhood built environment influences on physical activity among adults: A systematized review of qualitative evidence. In *International Journal of Environmental Research and Public Health* (Vol. 15, Issue 5). https://doi.org/10.3390/ijerph15050897

Sander, H. A., Ghosh, D., & Hodson, C. B. (2017). Varying age-gender associations between body mass index and urban greenspace. *Urban Forestry and Urban Greening*, *26*. https://doi.org/10.1016/j.ufug.2017.05.016

Sander, H. A., Ghosh, D., van Riper, D., & Manson, S. M. (2010). How do you measure distance in spatial models? an example using open-space valuation. *Environment and Planning B: Planning and Design*, *37*(5). https://doi.org/10.1068/b35126

Santini, Z. I., Jose, P. E., Koyanagi, A., Meilstrup, C., Nielsen, L., Madsen, K. R., Hinrichsen, C., Dunbar, R. I. M., & Koushede, V. (2021). The moderating role of social network size in the temporal association between formal social participation and mental health: a longitudinal analysis using two consecutive waves of the Survey of Health, Ageing and Retirement in Europe (SHARE). *Social Psychiatry and Psychiatric Epidemiology*, *56*(3). https://doi.org/10.1007/s00127-020-01961-2

Savikko, N., Routasalo, P., Tilvis, R. S., Strandberg, T. E., & Pitkälä, K. H. (2005). Predictors and subjective causes of loneliness in an aged population. *Archives of Gerontology and Geriatrics*, *41*(3). https://doi.org/10.1016/j.archger.2005.03.002

Sawyer, S. M., Afifi, R. A., Bearinger, L. H., Blakemore, S. J., Dick, B., Ezeh, A. C., & Patton, G. C. (2012). Adolescence: A foundation for future health. In *The Lancet* (Vol. 379, Issue 9826). https://doi.org/10.1016/S0140-6736(12)60072-5

Scardera, S., Perret, L. C., Ouellet-Morin, I., Gariépy, G., Juster, R. P., Boivin, M., Turecki, G., Tremblay, R. E., Côté, S., & Geoffroy, M. C. (2020). Association of social support during adolescence with depression, anxiety, and suicidal ideation in young adults. *JAMA Network Open*, *3*(12). https://doi.org/10.1001/jamanetworkopen.2020.27491

Schiavo, R. S. (1988). Age differences in assessment and use of a suburban neighborhood among children and adolescents. *Children's Environments Quarterly*, *5*(2).

Schüle, S. A., Hilz, L. K., Dreger, S., & Bolte, G. (2019). Social inequalities in environmental resources of green and blue spaces: A review of evidence in the WHO European region. In *International Journal of Environmental Research and Public Health* (Vol. 16, Issue 7). https://doi.org/10.3390/ijerph16071216

Segrin, C., & Domschke, T. (2011). Social support, loneliness, recuperative processes, and their direct and indirect effects on health. *Health Communication*, *26*(3). https://doi.org/10.1080/10410236.2010.546771

Shannon, C. E. (1948). A Mathematical Theory of Communication. *Bell System Technical Journal*, *27*(3). https://doi.org/10.1002/j.1538-7305.1948.tb01338.x

Shaw, C. R., & McKay, H. D. (1942). Juvenile delinquency and urban areas. In *Juvenile delinquency and urban areas.* University of Chicago Press.

Shinew, K. J., Stodolska, M., Roman, C. G., & Yahner, J. (2013). Crime, physical activity and outdoor recreation among Latino adolescents in Chicago. *Preventive Medicine*. https://doi.org/10.1016/j.ypmed.2013.07.008

Skelton, T. (2013). Young People's Urban Im/Mobilities: Relationality and Identity Formation. *Urban Studies*, *50*(3). https://doi.org/10.1177/0042098012468893

Smith, A. L., Troped, P. J., McDonough, M. H., & DeFreese, J. D. (2015). Youth perceptions of how neighborhood physical environment and peers affect physical activity: A focus group study. *International Journal of Behavioral Nutrition and Physical Activity*. https://doi.org/10.1186/s12966-015-0246-9

Smith, G. D., Chaturvedi, N., Harding, S., Nazroo, J., & Williams, R. (2000). Ethnic inequalities in health: A review of UK epidemiological evidence. In *Critical Public Health* (Vol. 10, Issue 4). https://doi.org/10.1080/09581590010005331

Smith, W., Frazee, S. G., & Davison, E. L. (2000). Furthering the integration of routine activity and social disorganization theories: Small units of analysis and the study of street robbery as a diffusion process. *Criminology*, *38*(2), 489–524. https://doi.org/10.1111/j.1745-9125.2000.tb00897.x

Smith, W., & Torstensson, M. (1997). Gender differences in risk perception and neutralizing fear of crime: Toward resolving the paradoxes. *British Journal of Criminology*. https://doi.org/10.1093/oxfordjournals.bjc.a014201

Snedker, K. A. (2012). Explaining the Gender Gap in Fear of Crime: Assessments of Risk and Vulnerability Among New York City Residents. *Feminist Criminology*. https://doi.org/10.1177/1557085111424405

Snedker, K. A., & Herting, J. R. (2016). Adolescent Mental Health: Neighborhood Stress and Emotional Distress. *Youth and Society*, *48*(5). https://doi.org/10.1177/0044118X13512335

Solmi, M., Radua, J., Olivola, M., Croce, E., Soardo, L., Salazar de Pablo, G., Il Shin, J., Kirkbride, J. B., Jones, P., Kim, J. H., Kim, J. Y., Carvalho, A. F., Seeman, M. V., Correll, C. U., & Fusar-Poli, P. (2022). Age at onset of mental disorders worldwide: large-scale meta-analysis of 192 epidemiological studies. In *Molecular Psychiatry* (Vol. 27, Issue 1). https://doi.org/10.1038/s41380-021-01161-7

Sport England. (2020). Active Lives Adult Survey November 2018/19 Report. In *Sport England*.

Sport England. (2021). *Active Lives Adult Survey May 2020/21 Report*.

Sport England. (2022). *Table 5a, Active Lives Children and Young People Survey Academic year 2021-22*.

Sport Scotland. (2006). *Sports Participation: Bowls Fact Sheet*.

Stafford, M., Chandola, T., & Marmot, M. (2007). Association between fear of crime and mental health and physical functioning. *American Journal of Public Health*. https://doi.org/10.2105/AJPH.2006.097154

Stafford, M., & Marmot, M. (2003). Neighbourhood deprivation and health: does it affect us all equally? *International Journal of Epidemiology*, *32*(3), 357–366. https://doi.org/10.1093/ije/dyg084

Stanko. (1993a). Ordinary fear: Women, violence and personal safety. In P. B. Bart & E. G. Moran (Eds.), *Violence against women: The Bloody Footprints* (pp. 155–164). Sage Publications.

Stanko, E. (1993b). The case of fearful women: Gender, personal safety and fear of crime. *Women and Criminal Justice*. https://doi.org/10.1300/J012v04n01_06

Stein, R. E. (2014). Neighborhood Scale and Collective Efficacy: Does Size Matter? *Sociology Compass*. https://doi.org/10.1111/soc4.12127

Sterne, J. A. C., White, I. R., Carlin, J. B., Spratt, M., Royston, P., Kenward, M. G., Wood, A. M., & Carpenter, J. R. (2009). Multiple imputation for missing data in epidemiological and clinical research: Potential and pitfalls. In *BMJ (Online)* (Vol. 339, Issue 7713). https://doi.org/10.1136/bmj.b2393

Stewart, M., Makwarimba, E., Reutter, L. I., Veenstra, G., Raphael, D., & Love, R. (2009). Poverty, sense of belonging and experiences of social isolation. *Journal of Poverty*, *13*(2). https://doi.org/10.1080/10875540902841762

Stewart, O., Moudon, A. V., Littman, A. J., Seto, E., & Saelens, B. E. (2018). Why neighborhood park proximity is not associated with total physical activity. *Health and Place*, *52*. https://doi.org/10.1016/j.healthplace.2018.05.011

Stice, E., Ragan, J., & Randall, P. (2004). Prospective Relations between Social Support and Depression: Differential Direction of Effects for Parent and Peer Support? *Journal of Abnormal Psychology*, *113*(1). https://doi.org/10.1037/0021-843X.113.1.155

Stodolska, M., Shinew, K. J., Acevedo, J. C., & Roman, C. G. (2013). 'I Was Born in the Hood': Fear of Crime, Outdoor Recreation and Physical Activity Among Mexican-American Urban Adolescents. *Leisure Sciences*. https://doi.org/10.1080/01490400.2013.739867

Su, M. D., Lin, M. C., & Wen, T. H. (2011). Spatial Mapping and Environmental Risk Identification. In *Encyclopedia of Environmental Health*. https://doi.org/10.1016/B978-0-444-52272-6.00636-X

Telama, R., Yang, X., Viikari, J., Välimäki, I., Wanne, O., & Raitakari, O. (2005). Physical activity from childhood to adulthood: A 21-year tracking study. *American Journal of Preventive Medicine*. https://doi.org/10.1016/j.amepre.2004.12.003

Teuton, J. (2018). *Social isolation and loneliness in Scotland: a review of prevalence and trends*.

The Lancet Public Health. (2019). Time to tackle the physical activity gender gap. In *The Lancet Public Health*. https://doi.org/10.1016/S2468-2667(19)30135-5

The Ramblers. (2020). *The grass isn't greener for everyone: why access to green space matters*.

Thompson Coon, J., Boddy, K., Stein, K., Whear, R., Barton, J., & Depledge, M. H. (2011). Does participating in physical activity in outdoor natural environments have a greater effect on physical and mental wellbeing than physical activity indoors? A systematic review. In *Environmental Science and Technology*. https://doi.org/10.1021/es102947t

Tinsley, J., & Jacobs, M. (2006). Deprivation and Ethnicity in England: A Regional Perspective. *Regional Trends*.

Tseloni, A. (2006). Multilevel Modelling of the Number of Property Crimes: Household and Area Effects. *Journal of the Royal Statistical Society Series A: Statistics in Society*, *169*(2), 205–233. https://doi.org/10.1111/j.1467-985X.2005.00388.x

Tseloni, A. (2007). Fear of crime, perceived disorders and property crime: A multivariate analysis at the area level. In *Imagination for Crime Prevention: Essays in Honour of Ken Pease.*

Tung, E. L., Hawkley, L. C., Cagney, K. A., & Peek, M. E. (2019). Social isolation, loneliness, and violence exposure in urban adults. *Health Affairs*, *38*(10). https://doi.org/10.1377/hlthaff.2019.00563

Twenge, J. M., Spitzberg, B. H., & Campbell, W. K. (2019). Less in-person social interaction with peers among U.S. adolescents in the 21st century and links to loneliness. *Journal of Social and Personal Relationships*, *36*(6). https://doi.org/10.1177/0265407519836170

Twohig-Bennett, C., & Jones, A. (2018). The health benefits of the great outdoors: A systematic review and meta-analysis of greenspace exposure and health outcomes. *Environmental Research*. https://doi.org/10.1016/j.envres.2018.06.030

Umberson, D., & Karas Montez, J. (2010). Social Relationships and Health: A Flashpoint for Health Policy. *Journal of Health and Social Behavior*, *51*(1_suppl). https://doi.org/10.1177/0022146510383501

Umberson, D., Lin, Z., & Cha, H. (2022). Gender and Social Isolation across the Life Course. *Journal of Health and Social Behavior*, *63*(3). https://doi.org/10.1177/00221465221109634

Vale, D. S., & Pereira, M. (2017). The influence of the impedance function on gravity-based pedestrian accessibility measures: A comparative analysis. *Environment and Planning B: Urban Analytics and City Science*, *44*(4). https://doi.org/10.1177/0265813516641685

Valtorta, N. K., Kanaan, M., Gilbody, S., & Hanratty, B. (2016). Loneliness, social isolation and social relationships: What are we measuring? A novel framework for classifying and comparing tools. *BMJ Open*, *6*(4). https://doi.org/10.1136/bmjopen-2015-010799

Van Harmelen, A. L., Kievit, R. A., Ioannidis, K., Neufeld, S., Jones, P. B., Bullmore, E., Dolan, R., Fonagy, P., & Goodyer, I. (2017). Adolescent friendships predict later resilient functioning across psychosocial domains in a healthy community cohort. *Psychological Medicine*, *47*(13). https://doi.org/10.1017/S0033291717000836

Van Hecke, L., Ghekiere, A., Veitch, J., Van Dyck, D., Van Cauwenberg, J., Clarys, P., & Deforche, B. (2018). Public open space characteristics influencing adolescents' use and physical activity: A systematic literature review of qualitative and quantitative studies. *Health and Place*, *51*, 158–173. https://doi.org/10.1016/J.HEALTHPLACE.2018.03.008

Vaughan, L. (2015). High Street Diversity. In *Suburban Urbanities: Suburbs and the Life of the High Street* (pp. 153–174). UCL Press. https://doi.org/10.2307/j.ctt1g69z0m.15

Vaughan, L. (2022). Butcher, baker, candlestick-maker and… healthcare centre? *Journal of Urban Design*, *27*(1), 69–72. https://doi.org/10.1080/13574809.2022.1994772

Viner. (2013). Life stage: Adolescence. In C. Lemer (Ed.), *Annual Report of the Chief Medical Officer 2012, Our Children Deserve Better: Prevention Pays*.

Viner, R. M., Ross, D., Hardy, R., Kuh, D., Power, C., Johnson, A., Wellings, K., McCambridge, J., Cole, T. J., Kelly, Y., & Batty, G. D. (2015). Life course epidemiology: Recognising the importance of adolescence. In *Journal of Epidemiology and Community Health*. https://doi.org/10.1136/jech-2014-205300

Wang, J., Lloyd-Evans, B., Giacco, D., Forsyth, R., Nebo, C., Mann, F., & Johnson, S. (2017). Social isolation in mental health: a conceptual and methodological review. In *Social Psychiatry and Psychiatric Epidemiology* (Vol. 52, Issue 12). https://doi.org/10.1007/s00127-017-1446-1

We Made That, & LSE Cities. (2017). *High Streets for All* .

Weiss, R. (1974). The Provisions of Social Relationships. In *Doing Unto Others*.

WHO Regional Office for Europe. (2016). Urban green spaces and health: A review of evidence. In *WHO Regional Office for Europe*.

WHO/Europe. (2009). *Addressing gender inequities in health and environment; Report of the VI Forum on gender and health*.

Winstone, L., Mars, B., Haworth, C. M. A., & Kidger, J. (2021). Social media use and social connectedness among adolescents in the United Kingdom: a qualitative exploration of displacement and stimulation. *BMC Public Health*, *21*(1). https://doi.org/10.1186/s12889-021-11802-9

Witten, K., Pearce, J., & Day, P. (2011). Neighbourhood Destination Accessibility Index: A GIS Tool for Measuring Infrastructure Support for Neighbourhood Physical Activity. *Environment and Planning* , *43*(1), 205–223.

Wolf, L. J., Anselin, L., Arribas-Bel, D., & Mobley, L. R. (2021). On Spatial and Platial Dependence: Examining Shrinkage in Spatially Dependent Multilevel Models. *Annals of the American Association of Geographers*, *111*(6). https://doi.org/10.1080/24694452.2020.1841602

Women's Sport and Fitness Foundation. (2008). Barriers to sports participation for women and girls. In *Women's Sport and Fitness Foundation*.

Wood, L., Hooper, P., Foster, S., & Bull, F. (2017). Public green spaces and positive mental health – investigating the relationship between access, quantity and types of parks and mental wellbeing. *Health and Place*. https://doi.org/10.1016/j.healthplace.2017.09.002

World Health Organisation. (2014). *Health for the World's Adolescents. A second chance in the second decade*.

World Health Organization. (2016). *Urban green spaces and health.*

World Health Organization. (2022). *Global status report on physical activity 2022*.

Yakubovich, A. R., Heron, J., & Humphreys, D. K. (2020). How do perceived and objective measures of neighbourhood disadvantage vary over time? Results from a prospective-longitudinal study in the UK with implications for longitudinal research on neighbourhood effects on health. *PLoS ONE*, *15*(4). https://doi.org/10.1371/journal.pone.0231779

Yukhnovskyi, V., & Zibtseva, O. (2019). Normalization of green space as a component of ecological stability of a town. *Journal of Forest Science*, *65*(11). https://doi.org/10.17221/85/2019-JFS

Zaragoza, J., Generelo, E., Julián, J. A., & Abarca-Sos, A. (2011). Barriers to adolescent girls' participation in physical activity defined by physical activity levels. *Journal of Sports Medicine and Physical Fitness*.

Zare Sakhvidi, M. J., Mehrparvar, A. H., Zare Sakhvidi, F., & Dadvand, P. (2023). Greenspace and health, wellbeing, physical activity, and development in children and adolescents: An overview of the systematic reviews. In *Current Opinion in Environmental Science and Health* (Vol. 32). https://doi.org/10.1016/j.coesh.2023.100445

Zhang, L., Zhou, S., & Kwan, M. P. (2019). A comparative analysis of the impacts of objective versus subjective neighborhood environment on physical, mental, and social health. *Health and Place*, *59*. https://doi.org/10.1016/j.healthplace.2019.102170

Zhang, N., Beauregard, J. L., Kramer, M. R., & Bécares, L. (2017). Neighbourhood Ethnic Density Effects on Behavioural and Cognitive Problems Among Young Racial/Ethnic Minority Children in the US and England: A Cross-National Comparison. *Population Research and Policy Review*. https://doi.org/10.1007/s11113-017-9445-1

Zhang, R., Wulff, H., Duan, Y., & Wagner, P. (2019). Associations between the physical environment and park-based physical activity: A systematic review. In *Journal of Sport and Health Science* (Vol. 8, Issue 5). https://doi.org/10.1016/j.jshs.2018.11.002

Appendices

Appendix 1

Appendix 1 corresponds to Chapter Three.

1.1 Accelerometer season of wear

Table A1.1 – Accelerometer season of wear distribution			
Month	**Frequency (both days)**	**Weekend**	**Weekday**
January	237	106	131
February	918	426	492
March	856	435	421
April	1,086	517	569
May	865	424	441
June	823	410	413
July	860	400	460
August	1,067	528	539
September	729	361	368
October	582	268	314
November	641	326	315
December	314	164	150
Total	8,978	4,365	4,613

1.2 Correlations

Table A1.2: Correlation matrix of subjective and objective crime and physical activity variables

	IMD crime	**Data.Police.UK**	**Perceived safety**
IMD crime	1.00		
Data.Police.UK	0.10	1.00	
Perceived safety	-0.13	0.04	1.00
	MVPA	**Self-reported PA**	
MVPA	1.00		
Self-reported PA	0.22	1.00	

a. Raw (unadjusted) results

Table A1.3: Associations between objective and subjective crime (age 11) and self-reported physical activity (age 14) Coefficients (95% CI).
Self-reported physical activity age 14
Perceived safety age 11

	All (n = 10,580)	Male (n = 5,223)	Female (n = 4,576)
Very Safe (ref)			
Safe	-0.07 (-0.19, 0.05) p = 0.269	0.06 (-0.11, 0.24) p = 0.478	-0.16 (-0.32, 0.00) p = 0.052
Not safe	-0.32 (-0.52, -0.11) p = 0.002	-0.26 (-0.54, 0.02) p = 0.065	-0.29 (-0.58, 0.01) p = 0.057
IMD 2004 crime			
	All (n = 9,746)	Male (n= 4,855)	Female (n = 4,891)
1 (least crime)			
2	-0.22 (-0.37, -0.08) p = 0.003	-0.15 (-0.35, 0.05) p = 0.139	-0.28 (-0.47, -0.09) p = 0.005
3 (highest crime)	-0.33 (-0.48, -0.19) p = 0.000	-0.18 (-0.38, 0.03) p = 0.090	-0.48 (-0.66, -0.29) p = 0.000
Reported crime incidence (Data.Police.UK 2012-13)			
	All (n = 8,683)	Male (n= 4,337)	Female (n = 4,346)
1 (least crime)			
2	0.11 (-0.04, 0.26) p = 0.152	0.08 (-0.12, 0.28) p = 0.428	0.81 (-0.13, 0.29) p = 0.442
3 (highest crime)	-0.11 (-0.24, 0.01) p = 0.067	-0.09 (-0.27, 0.10) p = 0.351	-0.16 (-0.32, -0.01) p = 0.035
Note: separate linear regression models were fitted to examine relationships between objective and subjective indicators of crime and self-reported physical activity. IMD 2004 crime domain and Data.Police.UK 2012-2013 linked to MCS age 11 at the LSOA level.			

Table A1.4: Zero-Inflated Poisson Model and Margins for objective and subjective crime (age 11) and accelerometer-measured MVPA (age 14) Coefficients (95% CI).

IMD 2004 crime (n = 3,975)				
	Incidence Rate Ratio (IRR)	Inflate coefficient	Adjusted predictions (mins)	Marginal Effects at the Mean (MEMs)
1 (ref)			68.37 (63.87, 72.88)	
2	0.91 (0.84, 0.98) p = 0.018	0.88 (-0.08, 1.8) p = 0.073	61.86 (58.71, 65.01)	-6.51 (-11.64, -1.39)
3 (highest crime)	0.83 (0.77, 0.90) p = 0.000	1.03 (-0.03, 2.08) p = 0.058	56.57 (54.08, 59.06)	-11.80 (-17.00, -6.61)
Reported Crime Incidence (n = 3.435)				
1 (ref)			62.13 (59.66, 64.96)	
2	1.05 (0.96, 1.16) p = 0.229	-0.67 (-.1.94, 0.60) p = 0.300	65.88 (59.69, 72.06)	3.57 (-2.80, 9.93)
3 (highest crime)	0.96 (0.90, 1.02) p = 0.185	0.18 (-0.81, 1.18) p = 0.715	59.61 (56.41, 62.81)	-2.70 (-6.54, 1.14)
Perceived safety age 11 (n = 3,085)				
Very Safe (ref)			62.13 (58.42, 65.83)	
Safe	1.00 (0.94, 1.07) p = 0.923	0.09 (-0.65, 0.82) p = 0.815	62.27 (60.38, 64.16)	0.14 (-3.68, 3.97)
Not safe	0.93 (0.82, 1.06) p = 0.282	-0.34 (-1.65, 0.96) p = 0.604	57.92 (50.93, 64.92)	-4.20 (-12.02, 3.61)
Note: inflate coefficient predicts whether individuals are likely to achieve zero minutes of MVPA. Adjusted predictions analysis shows predicted minutes of MVPA with all other covariates held at the mean.				

1.4 Sensitivity analysis

Sensitivity analysis was conducted between the full sample, accelerometer sub-sample, the sample without Scottish participants (due to the lack of IMD crime domain in the Scottish IMD variable) and without those that moved house between the sweeps.

Table A1.6: Associations between objective crime and perceived safety (age 11) and self-reported physical activity (age 14) Adjusted for ethnicity, family income and parental education

Self-reported physical activity age 14			
Perceived safety age 11			
	All (n = 7,882)	Male (n = 3,913)	Female (n = 3,909)
Very Safe (ref)			
Safe	-0.11 (-0.24, 0.01)	-0.01 (-0.19, 0.17)	-0.16 (-0.32, 0.01)

	p = 0.079	p = 0.895	p = 0.068
Not safe	-0.21 (-0.43, 0.00) p = 0.050	-0.15 (-0.44, 0.13) p = 0.293	-0.18 (-0.48, 0.12) p = 0.232
IMD 2004 crime			
	All (n = 7,122)	Male (n= 3,585)	Female (n = 3,537)
1 (least crime)			
2	-0.25 (-0.40, -0.10) p = 0.001	-0.32 (-0.52, -0.14) p = 0.001	-0.13 (-0.34, 0.08) p = 0.224
3 (highest crime)	-0.34 (-0.50, -0.18) p = 0.000	-0.37 (-0.60, -0.14) p = 0.001	-0.25 (-0.47, -0.03) p = 0.027
Reported crime incidence (Data.Police.UK 2012-13)			
	All (n = 6,327)	Male (n= 3,197)	Female (n = 3,130)
1 (least crime)			
2	0.01 (-0.15, 0.17) p = 0.896	-0.02 (-0.24, 0.20) p = 0.873	0.00 (-0.22, 0.22) p = 0.981
3 (highest crime)	-0.04 (-0.18, 0.10) p = 0.600	0.01 (-0.20, 0.22) p = 0.922	-0.10 (-0.28, 0.08) p = 0.273
Note: Only non-movers. separate linear regression models were fitted to examine relationships between objective and subjective indicators of crime and self-reported physical activity *IMD 2004 crime domain and Data.Police.UK 2012-2013 linked to MCS age 11 at the LSOA level.*			

House movers

Table A1.5: Address change between sweeps 5 & 6	*Frequency*	*Percentage*
Same address	9,316	85.37 %
Different address	1,528	14.00 %
Missing/Not Applicable	69	0.63 %
Total	10,913	

Table A1.7: Zero-Inflated Poisson Model and Margins for objective and subjective crime (age 11) and accelerometer-measured MVPA (age 14) Coefficients (95% CI). Adjusted for ethnicity, family income and parental education

IMD 2004 crime (n = 3,975)				
	Incidence Rate Ratio (IRR)	Inflate coefficient	Adjusted predictions (mins)	Marginal Effects at the Mean (MEMs)
1 (ref)			67.22 (61.65, 72.79)	
2	0.94 (0.86, 1.03) p = 0.180	1.33 (-0.92, 3.59) p = 0.246	63.12 (59.52, 66.72)	-4.10 (-10.19, 1.98)
3 (highest crime)	0.90 (0.82, 1.00) p = 0.047	0.65 (-1.70, 3.00) p = 0.585	60.81 (57.46, 64.16)	-6.41 (-12.88, 0.06)
Reported Crime Incidence (n = 2,265)				
1 (ref)			63.61 (60.77, 66.46)	
2	1.06 (0.93, 1.20) p = 0.393	-16.36 (-17.38, -15.34) p = 0.000	67.23 (58.70, 75.75)	3.61 (-4.88, 12.10)
3 (highest crime)	0.97 (0.90, 1.05) p = 0.478	-0.33 (-1.96, 1.30) p = 0.691	61.82 (57.68, 65.97)	-1.79 (-6.73, 3.15)
Perceived safety age 11 (n = 3,034)				
Very Safe (ref)			62.16 (57.73, 66.59)	

Safe	1.04 (0.97, 1.12) p = 0.262	0.09 (-2.57, 0.89) p = 0.815	64.83 (62.71, 66.96)	2.68 (-1.92, 7.28)
Not safe	0.98 (0.80, 1.19) p = 0.817	-0.56 (-3.09, 1.97) p = 0.663	60.74 (49.16, 72.31)	-1.42 (-13.42, 10.58)
Note: only non-movers, inflate coefficient predicts whether individuals are likely to achieve zero minutes of MVPA. Adjusted predictions analysis shows predicted minutes of MVPA with all other covariates held at the mean.				

Sample without participants from Scotland

Table A1.8: Associations between objective crime, perceived safety (age 11) and self-reported physical activity (age 14) Adjusted for ethnicity, family income and parental education

	Self-reported physical activity age 14		
Perceived safety age 11			
	All (n= 8,077)	Male (n = 4,037)	Female (n = 4,040)
Very Safe (ref)			
Safe	-0.10 (-0.22, 0.02) p = 0.117	-0.00 (-0.18, 0.17) p = 0.974	-0.13 (-0.30, 0.04) p = 0.130
Not safe	-0.27 (-.47, -0.06) p = 0.012	-0.25 (-0.53, 0.02) p = 0.072	-0.19 (-0.49, 0.11) p = 0.216
Reported crime incidence (Data.Police.UK 2012-13)			
	All (n = 7,421)	Male (n= 3,740)	Female (n = 3,681)
1 (least crime)			
2	0.02 (-0.13, 0.18) p = 0.759	-0.03 (-0.24, 0.19) p = 0.801	0.03 (-0.18, 0.24) p = 0.769
3 (highest crime)	-0.08 (-0.22, 0.05) p = 0.221	-0.05 (-0.27, 0.15) p = 0.607	-0.11 (-0.29, -0.06) p = 0.199
Note: Sample without Scottish participants. Separate linear regression models were fitted to examine relationships between objective and subjective indicators of crime and self-reported physical activity. IMD 2004 crime domain and Data.Police.UK 2012-2013 linked to MCS age 11 at the LSOA level.			

Table A1.9: Zero-Inflated Poisson Model and Margins for objective and subjective crime (age 11) and accelerometer-measured MVPA (age 14) Coefficients (95% CI).

Perceived safety age 11 (n = 2,938)				
	Incidence Rate Ratio (IRR)	Inflate coefficient	Adjusted predictions (mins)	Marginal Effects at the Mean (MEMs)
Very Safe (ref)			61.25 (56.62, 65.88)	
Safe	1.01 (0.98, 1.14) p = 0.160	-0.66 (-2.52, 1.19) p = 0.482	64.73 (62.50, 66.97)	3.48 (-1.27, 8.24) p = 0.151
Not Safe	5.4 (0.81, 1.17) p = 0.800	-0.51 (-3.20, 2.19) p = 0.712	59.82 (49.55, 70.09)	-1.43 (-12.46, 9.59) p = 0.798
Reported Crime Incidence (n = 2,613)				
1 (ref)			63.25 (60.54, 65.96)	
2	1.05 (0.94, 1.17) p = 0.405	-16.13 (-17.16, -15.10) p = 0.000	66.34 (59.04, 73.64)	3.09 (-4.33, 10.51) p = 0.413
3 (highest crime)	0.96 (0.90, 1.04) p = 0.326	-0.37 (-0.81, 1.18) p = 0.654	61.02 (57.34, 64.69)	-2.23 (-6.67, 2.21) p = 0.323

Note: sample without Scottish participants. inflate coefficient predicts whether individuals are likely to achieve zero minutes of MVPA. Adjusted predictions analysis shows predicted minutes of MVPA with all other covariates held at the mean.

Weekday vs weekend

Table A1.10: Zero-Inflated Poisson Model and Margins for objective and subjective crime (age 11) and weekday accelerometer-measured MVPA (age 14) Coefficients (95% CI).

Perceived safety age 11 (n = 3,463)				
	Incidence Rate Ratio (IRR)	**Inflate coefficient**	**Adjusted predictions (mins)**	**Marginal Effects at the Mean (MEMs)**
Very Safe (ref)			61.90 (57.52, 66.27)	
Safe	1.06 (0.98, 1.14) p = 0.142	-0.19 (-0.84, 0.45) p = 0.558	65.75 (62.91, 68.59)	3.85 (-1.14, 8.85) p = 0.130
Not Safe	0.98(0.93,1.17) p = 0.8	0.433 (-0.48, 1.35) p = 0.352	59.81 (49.28, 70.35)	-2.08 (-13.16, 8.99) p = 0.712
IMD 2004 crime (n = 3,008)				
Very Safe (ref)			69.34 (63.93, 74.82)	
Safe	0.94 (0.86, 1.02) p = 0.150	0.21 (-0.64, 1.07) P = 0.621	64.96 (60.24, 69.68)	-4.41 (-10.31, 1.47) p = 0.141
Not Safe	0.85 (0.77. 0.94) p = 0.001	-0.27 (-1.25, 0.71) p = 0.583	58.97 (55.35. 62.58)	-10.41 (-17.15, -3.67) p = 0.003
Reported Crime Incidence (n = 2,617)				
1 (ref)			64.01 (60.42, 67.59)	
2	1.05 (0.93, 1.18) p = 0.425	-1.10 (-2.42, 0.22) p = 0.102	67.87 (60.51, 73.22)	3.86 (-3.98, 11.70) p = 0.333
3 (highest crime)	0.99 (0.90, 1.09) p = 0.796	0.233 (-0.63, 1.10) p = 0.597	62.90 (57.77, 68.04)	-1.10 (-7.36, 5.15) p = 0.729
Note: accelerometer weekday. Inflate coefficient predicts whether individuals are likely to achieve zero minutes of MVPA. Adjusted predictions analysis shows predicted minutes of MVPA with all other covariates held at the mean.				

Table A1.11: Zero-Inflated Poisson Model and Margins for objective and subjective crime (age 11) and weekend accelerometer-measured MVPA (age 14) Coefficients (95% CI).

Perceived safety age 11 (n = 3,463)				
	Incidence Rate Ratio (IRR)	Inflate coefficient	Adjusted predictions (mins)	Marginal Effects at the Mean (MEMs)
Very Safe (ref)			60.61 (55.88, 65.35)	
Safe	1.03 (0.94, 1.12) p = 0.496	-0.68 (-1.40, 0.36) p = 0.062	63.17 (60.54, 65.80)	2.56 (-2.70, 7.82) p = 0.340
Not Safe	0.96 (0.80,1.15) p = 0.670	-0.21 (-0.48, 1.11) p = 0.751	58.55 (48.61, 68.49)	-2.07 (-12.89, 8.76) p = 0.708
IMD 2004 crime (n = 3,008)				
1 (ref)			65.17 (59.88, 70.47)	
2	0.94 (0.85, 1.04) p = 0.227	1.45 (0.51, 2.39) p = 0.003	59.70 (55.73, 63.67)	-5.47 (-12.05, 1.12) p = 0.103

3 (highest crime)	0.93 (0.84, 1.03) p = 0.096	0.45 (-0.67, 1.56) p = 0.430	60.55 (56.70. 64.41)	-4.62 (-11.14, 1.91) p = 0.165
Reported Crime Incidence (n = 2,617)				
1 (ref)			62.25 (58.86, 65.65)	
2	1.04 (0.91, 1.19) p = 0.566	-1.15 (-1.13, 0.83) p = 0.764	64.94 (56.53, 73.36)	2.69 (-6.08, 11.47) p = 0.546
3 (highest crime)	0.96 (0.90, 1.03) p = 0.263	0.33 (-0.46, 1.13) p = 0.408	59.26 (55.78, 62.74)	-2.99 (-7.72, 1.74) p = 0.214
Note: accelerometer weekend. Inflate coefficient predicts whether individuals are likely to achieve zero minutes of MVPA. Adjusted predictions analysis shows predicted minutes of MVPA with all other covariates held at the mean.				

Accelerometer sub-sample

Table A1.12: Associations between objective crime and perceived safety (age 11) and self-reported physical activity (age 14) Adjusted for ethnicity, family income and parental education			
Self-reported physical activity age 14			
Perceived safety age 11			
	All (n = 3,942)	Male (n = 1,922)	Female (n = 1,762)
Very Safe (ref)			
Safe	-0.05 (-0.23, 0.12) p = 0.568	-0.03 (-0.29, 0.23) p = 0.811	-0.03 (-0.26, 0.19) p = 0.784
Not safe	-0.44 (-0.52, -0.11) p = 0.010	-0.28 (-0.75, 0.18) p = 0.231	-0.51 (-0.96, -0.05) p = 0.030
IMD 2004 crime			
	All (n = 3,440)	Male (n= 1,678)	Female (n = 4,891)
1 (least crime)			
2	-0.23 (-0.44, -0.03) p = 0.025	-0.23 (-0.53, 0.08) p = 0.140	-0.26 (-0.51, -0.01) p = 0.039
3 (highest crime)	-0.31 (-0.55, -0.06) p = 0.016	-0.26 (-0.58, 0.06) p = 0.112	-0.34 (-0.65, -0.03) p = 0.033
Reported crime incidence (Data.Police.UK 2012-13)			
	All (n = 2,987)	Male (n= 1,453)	Female (n = 1,534)
1 (least crime)			
2	-0.01 (-0.25, 0.23) p = 0.928	-0.14 (-0.46, 0.19) p = 0.403	0.04 (-0.28, 0.37) p = 0.783
3 (highest crime)	-0.15 (-0.37, 0.07) p = 0.173	-0.30 (-0.61, 0.01) p = 0.055	-0.05 (-0.35, 0.24) p = 0.720
Note: accelerometer sub-sample. separate linear regression models were fitted to examine relationships between objective and subjective indicators of crime and self-reported physical activity *IMD 2004 crime domain and Data.Police.UK 2012-2013 linked to MCS age 11 at the LSOA level.*			

Reported Crime Incidence subcategories

Table A1.13: Associations between Reported Crime Incidence subcategories and self-reported physical activity (age 14) adjusting for ethnicity, parental education and family income			
	Self-reported physical activity age 14		
Anti-Social Behaviour			
	All (n = 7,431)	Male (n= 3,743)	Female (n = 3,688)
Very Safe (ref)			

Safe	0.00 (-0.16, 0.16) p = 0.967	-0.07 (-0.30, 0.17) p = 0.585	-0.03 (-0.18, 0.24) p = 0.768
Not safe	-0.07 (-0.20, 0.16) p = 0.277	-0.30 (-0.22, 0.15) p = 0.705	-0.11 (-0.27, 0.06) p = 0.204
Criminal Damage and Arson			
1 (least crime)			
2	-0.00 (-0.15, -0.14) p = 0.972	-0.02 (-0.22, 0.18) p = 0.828	-0.03 (-0.22, 0.16) p = 0.738
3 (highest crime)	-0.07 (-0.20, 0.06) p = 0.306	-0.09 (-0.29, 0.12) p = 0.389	-0.07 (-0.26, 0.11) p = 0.444
Drugs			
1 (least crime)			
2	-0.01 (-0.16, 0.14) p = 0.930	-0.01 (-0.216, 0.21) p = 0.987	-0.03 (-0.24, 0.18) p = 0.805
3 (highest crime)	-0.12 (-0.25, 0.01) p = 0.081	-0.06 (-0.27, 0.16) p = 0.604	-0.16 (-0.34, 0.01) p = 0.067
Possession of weapons and public order			
1 (least crime)			
2	0.01 (-0.19, 0.20) p = 0.946	0.05 (-0.21, 0.32) p = 0.681	-0.13 (-0.35, 0.09) p = 0.251
3 (highest crime)	-0.08 (-0.21, 0.05) p = 0.222	-0.06 (-0.25, 0.13) p = 0.520	-0.09 (-0.27, 0.09) p = 0.342
Robbery			
1 (least crime)			-0.18
2	-0.22 (-0.59, 0.14) p = 0.236	-0.37 (-0.93, 0.19) p = 0.191	-0.41 (-1.13, 0.30) p = 0.255
3 (highest crime)	-0.45 (-1.92, 1.02) p = 0.547	-1.36 (-2.17, -0.55) p = 0.001	0.26 (-2.03, 2.54) p = 0.824
Note: separate linear regression models were fitted to examine relationships between objective indicators of crime and self-reported physical activity *Data.Police.UK 2012-2013 linked to MCS age 11 at the LSOA level.*			

Table A1.14: Zero-Inflated Poisson Model and Margins for Reported Crime Incidence subcategories (age 11) and accelerometer-measured MVPA (age 14) (n = 2,617)
Adjusted for family income, ethnicity, parental education, sex and season of wear. Coefficients (95% CI).

Anti-Social Behaviour				
	Incidence Rate Ratio (IRR)	Inflate coefficient	Adjusted predictions (mins)	Marginal Effects at the Mean (MEMs)
1 (ref)			63.28 (60.58, 66.00)	
2	1.06 (0.94, 1.19) p = 0.364	-16.12 (-17.16, -15.09) p = 0.000	66.85 (59.07, 74.63)	3.57 (-4.33, 11.47) p = 0.375
3 (highest crime)	0.96 (0.90, 1.03) p = 0.277	-0.37 (-1.98, 1.25) p = 0.655	60.88 (57.31, 64.44)	-2.40 (-6.72, -1.91) p = 0.274
Criminal Damage and Arson				
1 (ref)			63.67 (60.80, 66.54)	
2	0.99 (0.91, 1.09) p = 0.867	-16.12 (-17.16, -15.09)	63.17 (59.69, 68.65)	-0.49 (-6.26, 5.28) p = 0.866

		p = 0.000		
3 (highest crime)	0.99 (0.90, 1.08) p = 0.777	-0.37 (-1.98, 1.25) p = 0.655	62.84 (57.85, 67.83)	-0.83 (-6.53, 4.88) p = 0.776
Drugs				
1 (ref)			63.29 (60.75, 65.82)	
2	1.10 (0.96, 1.26) p = 0.186	-16.12 (-17.15, -15.09) p = 0.000	69.38 (59.98, 78.79)	6.10 (-3.33, 15.53) p = 0.204
3 (highest crime)	0.94 (0.88, 1.02) p = 0.134	-0.37 (-3.15, 1.97) p = -0.45	59.78 (56.00, 63.61)	-3.50 (-8.04, 1.03) p = 0.130
Possession of weapons and public order				
1 (ref)			65.35 (61.98, 68.72)	
2	0.96 (0.87,1.05) p = 0.340	-16.12 (-17.16, -15.09) p = 0.000	62.41 (56.54, 68.29)	-2.94 (-8.89, 3.02) p = 0.333
3 (highest crime)	0.90 (0.84, 0.97) p = 0.007	-0.37 (-1.98, 1.25) p = 0.655	59.06 (55.69, 62.43)	-6.29 (-10.82, -1.76) p = 0.007
Robbery				
1 (ref)			63.29 (60.72, 65.85)	
2	1.02 (0.63, 1.67) p = 0.925	-16.12 (-17.16, -15.09) p = 0.000	64.78 (33.23, 96.33)	1.49 (-30.25, 33.23) p = 0.926
3 (highest crime)	1.01 (0.63, 1.60) p = 0.975	-0.37 (-1.98, 1.25) p = 0.655	63.75 (34.13, 93.36)	0.46 (-29.14, 30.07) p = 0.976)

Note: inflate coefficient predicts whether individuals are likely to achieve zero minutes of MVPA. Adjusted predictions analysis shows predicted minutes of MVPA with all other covariates held at the mean.

Appendix 2

Appendix 2 corresponds to Chapter Five.

2.1 Descriptive characteristics

Table A2.1 shows the characteristics of the full sample of cohort members that completed the face-to-face interview at the age 17 sweep (n=9978) minus our analytic sample, compared to our analytic sample that additionally completed the online interview.

Table A2.1: Characteristics of age 17 sample minus analytic sample (n = 4336) compared to analytic sample (n = 5582)

	Face-to-face sample minus analytic sample		Analytic sample	
	Frequency	**Percent**	***Frequency***	***Percent***

Sex				
Female	2418	55.77	3123	55.95
Male	1918	44.24	2459	44.05
Total	**4336**	100.00	**5582**	100.00
Highest Parental Education				
NVQ level 1 (CSE below grade 1/GCSE or O Level below grade C, SCE Standard, Ordinary grades below grade 3 or Junior Certificate below grade C)	111	3.07	100	2.00
NVQ level 2 (O Level or GCSE grade A-C, SCE Standard, Ordinary grades 1-3 or Junior Certificate grade A-C)	546	15.10	722	14.46
NVQ level 3 (A/AS/S levels, SCE Higher, Scottish Certificate Sixth Year Studies, Leaving Certificate)	473	13.08	656	13.14
NVQ level 4 (first degree, diplomas in higher education, teaching qualifications for schools or further education)	1171	32.39	2107	42.20
NVQ level 5 (higher degree, postgraduate qualification, certificate or diploma)	589	16.29	1178	23.59
Other academic qualifications (incl. overseas)	190	5.26	230	4.61
Total	3615	100.00	4993	100.00
Missing			*589*	
Ethnicity				
White	3334	76.70	4472	80.13
Mixed	216	4.99	249	4.46
Indian	119	2.75	168	3.01
Pakistani and Bangladeshi	382	8.82	379	6.79
Black or Black British	189	4.36	170	3.05
Other ethnic group (inc Chinese, other)	95	2.19	143	2.56
Total	4332	100.00	5581	100.00
Missing			*1*	
Income Quintile				
First quintile	734	20.00	686	12.30
Second quintile	688	18.75	747	13.40
Third quintile	820	22.35	1037	18.60
Fourth quintile	803	21.89	1436	25.75
Highest quintile	624	17.01	1670	29.95
Total	3669	100.00	5576	100.00
Missing			*6*	
ONS Rural/Urban Classification				
Rural	1099	30.02	1399	25.09
Urban	2562	69.98	4177	74.91
Total	3661	100.00	5576	100.00
Missing			*6*	
Occupational status				
Not in work	969	29.70	1339	24.18
Semi-routine and routine	596	18.27	904	16.32
Lower supervisory and technical	70	21.45	142	2.56
Small employers/self-employed	199	6.10	373	6.74
Intermediate	482	14.77	971	17.53
Higher managerial	949	29.08	1809	32.67
Total	3263	100.00	5538	100.00
Missing			*44*	

2.2 Sensitivity Analyses

Non-linearity testing

The quadratic term was non-significant for proximity to high street and social contact (p = 0.152 and p = 0.959) and social support (p = 0.586). The non-linearity coefficient was statistically significant for the relationship between high street proximity and social activities (p = 0.007 and p = 0.018) (Table A2.2). However, the small coefficient (0.999) indicates minimal effect. Figure A2.1 depicts the adjusted model predictions with 95% CIs. I explored overall model fit further by fitting ROC curves; the AUC indicated minimal differences in model fit in adjusted models with or without the quadratic term (Figure A2.2).

In unadjusted models, the AIC suggested the model without the quadratic term best fit the data when comparing lowest and middle categories of social activities (Table A2.3). When comparing highest to lowest categories, the AIC suggest the model with the quadratic term was appropriate. However, the BIC reported conflicting results.

I additionally plot normal quantile plots to investigate the distribution of the residuals of adjusted models (Figure A2.3). These plots indicate no difference in the residual distribution in the models with or without the quadratic term included.

Table A2.2: Associations between distance (km) to closest high street and frequency of social activities OR

	All (n = 5577)	
Middle Category (compared to lowest)		
	Model 1	Model 2
Distance	1.06 (1.02, 1.10)	1.04 (1.00, 1.08)
Quadratic term	0.99 (0.99, 0.99) p = 0.008	0.99 (0.99, 0.99) p = 0.007
Highest Category (compared to lowest)		
Distance	1.04 (1.01, 1.08)	1.03 (1.00, 1.07)
Quadratic term	0.99 (0.99, 0.99) p = 0.002	0.99 (0.99, 0.99) p = 0.018

Note: Quadratic term coefficients, 95% CI, p value *Logistic multilevel regression with quadratic term. Model 2 adjusted for sex, ethnicity, parental education, income, occupational status and overall wealth (also depicted in Figure 1).*

Table A2.3: Information criteria for unadjusted models of associations between distance (km) to closest high street and frequency of social activities

	Model distance (km) without quadratic term		Model distance (km) with quadratic term	
	AIC	BIC	AIC	BIC
Middle Category (compared to lowest)	3550.597	3568.105	3566.686	3566.029
Highest Category (compared to lowest)	5196.748	5215.851	5191.281	5216.752

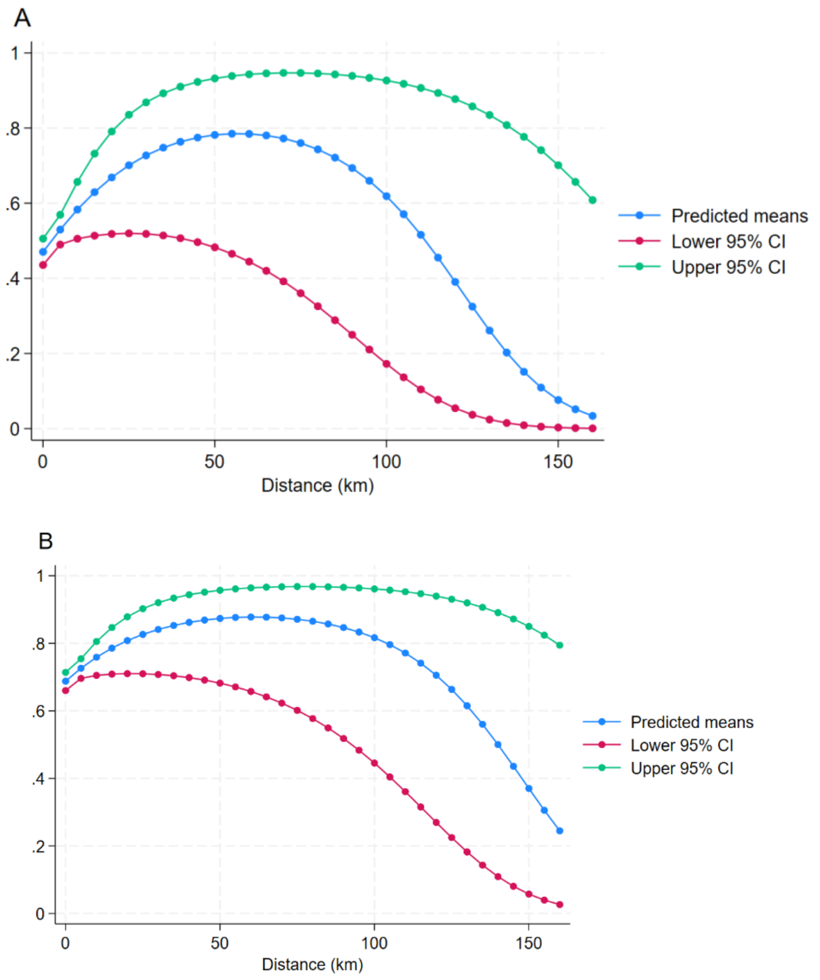

Figure A2.4 – Adjusted logistic multilevel models with quadratic term; association between distance (km) to closest high street and frequency of social activities. A – Middle category of social activities, compared to lowest. B – Highest category of social activities compared to lowest.

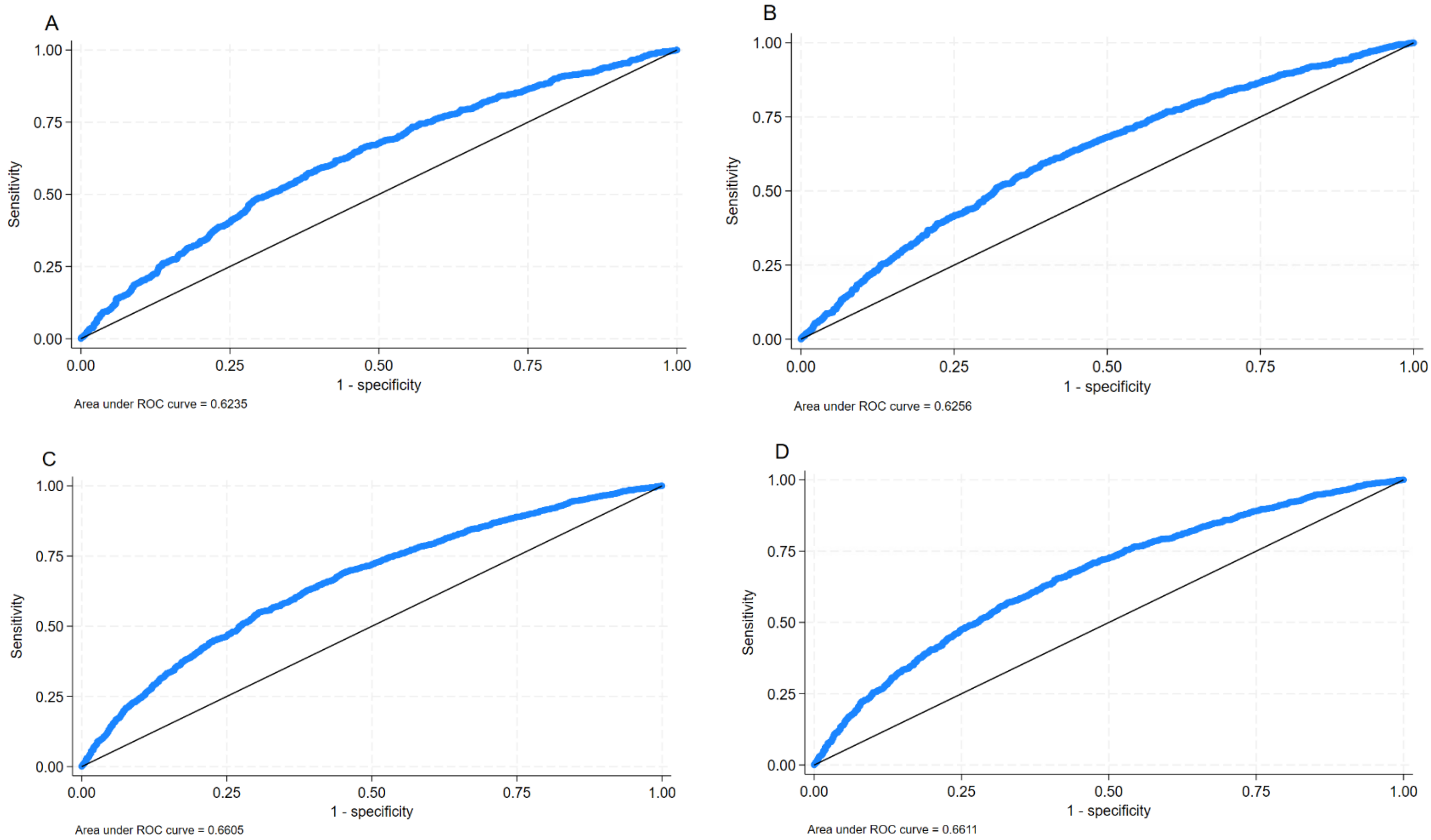

Figure A2.5 - ROC curves measuring AUC for adjusted models (adjusted for sex, ethnicity, parental education, income, occupational status and overall wealth). A – Social activities (middle category) without quadratic term. B - Social activities (middle category) with quadratic term. C - Social activities (highest category) without quadratic term D - Social activities (highest category) with quadratic term.

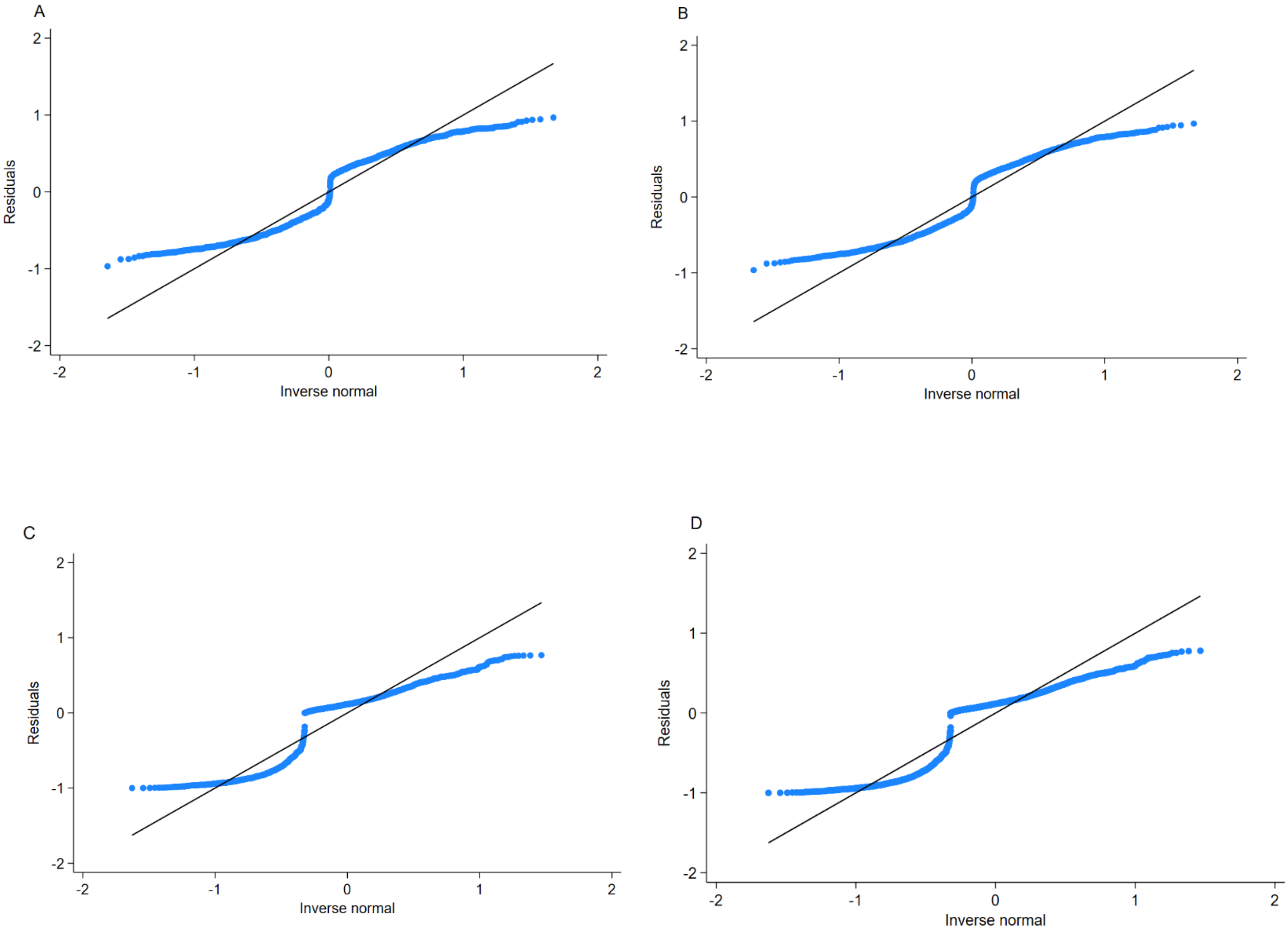

Figure A2.3 – Normal quantile plots of residuals. Logistic multilevel models of distance to closest high street and social activities; all models adjusted for sex, ethnicity, parental education, income, occupational status and overall wealth. A – Social activities (middle category) without quadratic term. B - Social activities (middle category) with quadratic term. C - Social activities (highest category) without quadratic term D - Social activities (highest category) with quadratic term.

Distance decay

Tables A2.4 – A2.6 display full modelling results. Tables A2.7 displays AIC/BIC model fit statistics.

Table A2.4: Associations between decayed distance (2000m) to closest high street and indicators of social isolation and social support

Frequency of social activities OR (95% CI)						
	All (n = 5577)		Male (n = 2455)		Female (n=3119)	
Middle Category (compared to lowest)						
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Fixed effects Intercept	0.88 (0.44, 1.77)	1.11 (0.53, 2.30)	1.52 (0.55, 4.19)	1.67 (0.57, 4.90)	0.50 (0.20, 1.30)	0.65 (0.26, 1.64)
VPC	10.1% (6.30, 15.81)	7.6% (4.46, 12.89)	12.7% (7.09, 21.65)	9.9% (4.88, 19.53)	12.9% (7.29, 21.85)	10.2% (5.20, 19.33)
Highest Category (compared to lowest)						
Fixed effects Intercept	0.98 (0.54, 1.78)	0.99 (0.55, 1.80)	1.68 (0.71, 3.95)	1.40 (0.57, 3.41)	0.73 (0.30, 1.82)	0.82 (0.34, 1.99)
VPC	9.4% (6.1, 14.37)	6.1% (3.87, 9.69)	13.2% (8.45, 20.13)	7.8% (3.96, 14.30)	11.1% (7.14, 16.88)	10.2% (6.0, 17.0)
Frequency of social contact OR (95% CI)						
Middle Category (compared to lowest)						
	All (n = 5577)		Male (n=2458)		Female (n=3119)	
Fixed effects Intercept	0.75 (0.32, 1.77)	0.90 (0.39, 2.12)	1.77 (0.51, 6.06)	1.83 (0.55, 6.06)	0.37 (0.10, 1.29)	0.53 (0.13, 2.14)
VPC	10.1% (6.30, 15.81)	10.3% (6.43, 16.15)	18.7% (9.92, 32.56)	18.7% (9,92, 32.56)	19.4% (11.90, 30.10)	0.20 (0.11, 0.34)
Highest Category (compared to lowest)						
Fixed effects Intercept	1.31 (0.69, 2.50)	1.98 (0.98, 4.02)	1.85 (0.70, 4.91)	2.50 (0.88, 7.12)	1.26 (0.51, 3.09)	2.16 (0.83, 5.61)
VPC	9.4% (6.09, 14.37)	9.0% (5.22, 15.08)	12.9% (7.51, 21.41)	12.9% (7.51, 21.41)	16.4% (10.50, 24.77)	0.16 (0.09, 0.27)
Social support coef (95% CI)						
	All (n = 5450)		Male (n = 2397)		Female (n = 3053)	
Fixed effects Intercept	-0.07 (-0.17, 0.03)	-0.04 (-0.14, 0.06)	-0.08 (-0.24, 0.07)	-0.06 (-0.22, 0.10)	-0.06 (-0.17, 0.06)	-0.02 (-0.13, 0.09)
VPC	1.3% (0.45, 3.47)	1.0% (0.27, 3.42)	2.9% (1.26, 6.37)	3.2% (1.44, 6.76)	2.3% (0.75, 6.95)	1.9% (0.51, 6.61)

Note: Logistic random intercept multilevel regression used to estimate relationships with frequency of social activities and social contact, OR (Odds ratio). Linear random intercept multilevel regression.
Model 2 adjusted for overall wealth, occupational status, income, parental education, sex and ethnicity. Social support variable was compromised of 3 items from the Social Provisions Scale; lower scores indicate lower social support.
VPC = Variance Partition Coefficient

Table A2.5: Associations between decayed distance (1400m) to closest high street and indicators of social isolation and social support						
Frequency of social activities OR (95% CI)						
	All (n = 5577)		Male (n = 2455)		Female (n=3119)	
Middle Category (compared to lowest)						
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Fixed effects Intercept	0.76 (0.34, 1.72)	0.94 (0.40, 2.21)	1.31 (0.39, 4.47)	1.36 (0.38, 4.90)	0.45 (0.15, 1.36)	0.57 (0.19, 1.66)
VPC	10.1% (6.59, 15.29)	7.6% (4.50, 12.89)	13.0% (7.36, 21.91)	10.1% (4.99, 19.71)	12.6% (7.04, 21.61)	10.2% (5.16, 19.30)
Highest Category (compared to lowest)						
Fixed effects Intercept	0.87 (0.42, 1.78)	0.90 (0.45, 1.81)	1.51 (0.53, 4.26)	1.23 (0.42, 3.60)	0.64 (0.21, 1.96)	0.76 (0.26, 2.21)
VPC	9.6% (7.00, 1.40)	6.2% (3.89, 9.75)	11.2% (7.21, 16.94)	7.8% (3.98, 14.36)	13.2% (8.45, 20.15)	10.2% (6.08, 17.23)
Frequency of social contact OR (95% CI)						
Middle Category (compared to lowest)						
	All (n = 5577)		Male (n=2458)		Female (n=3119)	
Fixed effects Intercept	0.81 (0.29, 1.29)	0.97 (0.34, 2.77)	2.61 (0.62, 11.07)	2.61 (0.64, 10.66)	0.28 (0.06, 1.34)	0.40 (0.07, 2.26)
VPC	10.1% (6.32, 15.80)	10.3% (6.43, 16.13)	18.78% (9.96, 33.60)	18.3% (9.55, 32.59)	19.47% (11.97, 30.08)	20.0% (11.44, 34.45)
Highest Category (compared to lowest)						
Fixed effects Intercept	1.53 (0.72, 3,27)	2.36 (1.02, 5.47)	2.22 (0.69, 7.12)	3.16 (0.94, 10.64)	1.51 (0.52, 4.37)	2.63 (0.84, 8.28)
VPC	9.4% (6.09, 14.37)	9.0% (5.24, 15.16)	13.0% (7.56, 21.43)	13.2% (0.08, 0.22)	16.5% (10.58, 24.73)	15.7% (8.78, 27.57)
Social support coefficient (95% CI)						
	All (n = 5450)		Male (n = 2397)		Female (n = 3053)	
Fixed effects Intercept	-0.08 (-0.20, 0.04)	-0.05 (-0.17, 0.08)	-0.10 (-0.31, 0.10)	-0.08 (-0.29, 0.12)	-0.05 (-0.19, 0.08)	-0.01 (-0.14, 0.11)
VPC	1.2% (0.44 3.45)	1.0% (0.27, 3.42)	2.8% (1.25, 6.33)	3.1% (1.43, 6.72)	2.3% (0.76, 6.91)	3.1% (1.43, 6.72)

Note: Logistic random intercept multilevel regression used to estimate relationships with frequency of social activities and social contact, OR (Odds ratio). Linear random intercept multilevel regression.
Model 2 adjusted for overall wealth, occupational status, income, parental education, sex and ethnicity. Social support variable was compromised of 3 items from the Social Provisions Scale; lower scores indicate lower social support.
VPC = Variance Partition Coefficient

Table A2.6: Associations between decayed distance (800m) to closest high street and indicators of social isolation and social support						
Frequency of social activities OR (95% CI)						
	All (n = 5577)		Male (n = 2455)		Female (n=3119)	
Middle Category (compared to lowest)						
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Fixed effects Intercept	0.59 (0.23, 1.53)	0.69 (0.26, 1.83)	0.93 (0.22, 3.95)	0.89 (0.20, 3.83)	0.39 (0.11, 1.40)	0.47 (0.14, 1.59)
VPC	10.1% (6.59, 15.27)	7.6% (4.52, 12.90)	13.05% (7.42, 21.95)	10.2% (5.06, 19.87)	12.6% (6.99, 21. 57)	10.2% (5.12, 19.27)
Highest Category (compared to lowest)						
Fixed effects Intercept	0.69 (0.29, 1.64)	0.74 (0.21, 1.71)	1.17 (0.34, 4.00)	0.93 (0.26, 3.32)	0.52 (0.13, 1.99)	0.66 (0.18, 2.40)
VPC	9.6% (6.68, 13.65)	6.2% (3.91, 9.81)	11.3% (7.29, 17.03)	7.8% (3.99, 14.42)	13.3% (8.45, 20.18)	10.2% (6.09, 17.27)
Frequency of social contact OR (95% CI)						
Middle Category (compared to lowest)						
	All (n = 5577)		Male (n=2458)		Female (n=3119)	
Fixed effects Intercept	0.99 (0.26, 3.72)	1.17 (0.30, 4.61)	4.99 (0.90, 27.68)	4.73 (0.88, 25.47)	0.20 (0.03, 1.51)	0.28 (0.03, 2.50)
VPC	10.14% (6.35, 15.81)	10.3% (6.43, 16.11)	18.8% (10.02, 32.67)	18.4% (9.63, 32.70)	19.6% (12.12, 30.08)	20.0% (11.47, 34.45)
Highest Category (compared to lowest)						
Fixed effects Intercept	1.98 (0.79	3.13 (1.10, 8.90)	3.02 (0.71, 12.78)	4.64 (1.08, 19.08)	1.99 (0.52, 7.61)	3.50 (0.79, 15.59)
VPC	9.43% (6.08, 14.36)	9.0% (5.27, 15.22)	0.13 (0.08, 0.21)	13.2% (7.63, 22.05)	16.5% (10.61, 24.68)	15.7% (8.77, 27.51)
Social support coefficient (95% CI)						
	All (n = 5450)		Male (n = 2397)		Female (n = 3053)	
Fixed effects Intercept	-0.09 (-0.24, 0.07)	-0.05 (-0.21, 0.10)	-0.14 (-0.41, 0.13)	-0.12 (-0.40, 0.15)	-0.04 (-0.19, 0.12)	0.00 (-0.14, 0.15)
VPC	1.2% (0.44, 3.44)	1.0% (0.27, 3.41)	2.8% (1.24, 6.30)	3.1% (1.43, 6.66)	2.3% (0.77, 6.85)	1.9% (0.51, 6.56)

Note: Logistic random intercept multilevel regression used to estimate relationships with frequency of social activities and social contact, OR (Odds ratio). Linear random intercept multilevel regression.
Model 2 adjusted for overall wealth, occupational status, income, parental education, sex and ethnicity. Social support variable was compromised of 3 items from the Social Provisions Scale; lower scores indicate lower social support.
VPC = Variance Partition Coefficient

Table A2.7: Information criteria for unadjusted models of associations between decayed distance to closest high street and social isolation and social support outcomes						
	2000m		1400m		800m	
	AIC	BIC	AIC	BIC	AIC	BIC
Frequency of social activities						
Middle category	3551.71	3569.218	3551.227	3568.735	3550.13	3567.638
Highest category	5197.458	5216.561	5197.179	5216.283	5196.131	5215.234
Frequency of social contact						
Middle category	2157.9	2174.224	2158.252	2174.252	2158.455	2174.779
Highest category	3524.02	3543.241	3523.524	3542.744	3522.793	3542.013
Social support						
	5108.561	5134.974	5109.161	5135.575	5109.993	5136.407
Note: unadjusted models						

Average diversity of high streets

Table A2.8: Associations between average diversity of all high streets within 2000m radii and indicators of social isolation and social support

	All (n = 5577)		Male (n = 2455)		Female (n=3119)	
Frequency of social activities OR (95% CI)						
Middle Category (compared to lowest)						
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Fixed effects Intercept	0.83 (0.64, 1.06)	0.92 (0.71, 1.17)	0.67 (0.46, 0.98)	0.73 (0.50, 1.08)	0.98 (0.69, 1.38)	1.10 (0.78, 1.54)
VPC	10.2% (6.62, 15.26)	7.5% (4.36, 12.90)	13.6% (7.93, 22.41)	10.7% (5.40, 20.32)	12.7% (7.09, 21.73)	10.1% (5.09, 19.43)
Highest Category (compared to lowest)						
Fixed effects Intercept	0.94 (0.74, 1.18)	0.97 (0.78, 1.21)	0.86 (0.63, 1.17)	0.87 (0.64, 1.19)	1.06 (0.78, 1.44)	1.08 (0.79, 1.47)
VPC	9.6% (6.60, 13.63)	6.0% (3.74, 9.48)	11.5% (7.40, 12.36)	7.9% (4.02, 14.59)	13.1% (8.29, 20.06)	10.1% (5.96, 17.21)
Frequency of social contact OR (95% CI)						
Middle Category (compared to lowest)						
	All (n = 5577)		Male (n=2458)		Female (n=3119)	
Fixed effects Intercept	0.93 (0.67, 1.30)	0.99 (0.71, 1.39)	0.99 (0.56, 1.69)	1.07 (0.61, 1.90)	0.83 (0.52, 1.31)	0.91 (0.57, 1.45)
VPC	10.1% (6.35, 15.78)	10.3% (6.41, 16.15)	18.7% (9.93, 32.61)	18.1% (9.30, 32.67)	19.9% (12.59, 30.19)	18.8% (10.83, 32.47)
Highest Category (compared to lowest)						
Fixed effects Intercept	0.99 (0.75, 1.29)	1.10 (0.83, 1.46)	1.16 (0.79, 1.69)	1.25 (0.84, 1.88)	0.86 (0.57, 1.29)	0.99 (0.66, 1.47)
VPC	9.5% (6.11, 14.38)	9.0% (5.28, 15.13)	12.7% (7.32, 21.20)	12.4% (7, 21.57)	16.4% (10.47, 24.74)	15.8% (8.86, 27.53)
Social support coef (95% CI)						
	All (n = 5450)		Male (n = 2397)		Female (n = 3053)	
Fixed effects Intercept	-0.02 (-0.05, 0.01)	-0.01 (-0.04, 0.02)	0.03 (-0.02, 0.07)	0.03 (-0.02, 0.08)	0.00 (0.00, 0.01)	-0.05 (-0.09, -0.01)
VPC	1.2% (0.4, 3.5)	1.0% (0.26, 3.47)	2.8% (1.2, 6.4)	3.1% (1.43, 6.65)	2.6% (0.1, 7.0)	2.2% (0.68, 6.78)

Note: Logistic random intercept multilevel regression used to estimate relationships with frequency of social activities and social contact, OR (Odds ratio). Linear random intercept multilevel regression.
Model 2 adjusted for overall wealth, occupational status, income, parental education, sex and ethnicity. Social support variable was compromised of 3 items from the Social Provisions Scale; higher scores indicate higher social support. VPC = Variance Partition Coefficient

Table A2.9: Associations between average diversity of all high streets within 1400m radii and indicators of social isolation and social support						
Frequency of social activities OR (95% CI)						
	All (n = 5577)		Male (n = 2455)		Female (n=3119)	
Category 2 (compared to lowest)						
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Fixed effects Intercept	0.87 (0.69, 1.10)	0.94 (0.75, 1.19)	0.88 (0.62, 1.24)	0.91 (0.65, 1.28)	0.84 (0.62, 1.16)	0.94 (0.67, 1.30)
VPC	10.1% (6.60, 15.23)	7.6% (4.50, 12.89)	13.2% (7.52, 22.12)	10.3% (5.09, 20.02)	12.7% (7.13, 21.66)	10.2% (5.15, 19.36)
Category 3 (compared to lowest)						
Fixed effects Intercept	0.90 (0.73, 1.11)	0.89 (0.72, 1.09)	0.88 (0.66, 1.18)	0.85 (0.62, 1.15)	0.95 (0.71, 1.26)	0.95 (0.72, 1.25)
VPC	9.6% (6.67, 13.71)	6.2% (3.89, 9.86)	11.4% (7.42, 17.27)	7.9% (4.01, 14.60)	13.1% (8.32, 20.09)	10.1% (6.00, 17.20)
Frequency of social contact OR (95% CI)						
Category 2 (compared to lowest)						
	All (n = 5577)		Male (n=2458)		Female (n=3119)	
Fixed effects Intercept	1.05 (0.77, 1.43)	1.20 (0.87, 1.65)	0.99 (0.60, 1.65)	0.98 (0.58, 1.65)	0.97 (0.64, 1.47)	1.29 (0.82, 2.04)
VPC	10.1% (6.33, 15.74)	9.9% (6.18, 15.70)	18.8% (9.87, 32.79)	18.8% (10.83, 32.47)	19.9% (12.62, 29.96)	18.8% (10.83, 32.47)
Category 3 (compared to lowest)						
Fixed effects Intercept	0.99 (0.76, 1.27)	1.14 (0.87, 1.48)	1.12 (0.79, 1.58)	1.16 (0.81, 1.65)	0.89 (0.61, 1.31)	1.15 (0.77, 1.73)
VPC	9.5% (6.13, 14.34)	9.0% (5.28, 14.95)	12.7% (7.36, 21.09)	12.8% (7.35, 21.57)	16.3% (10.37, 25.67)	15.4% (8.76, 26.89)
Social support coef (95% CI)						
	All (n = 5450)		Male (n = 2397)		Female (n = 3053)	
Fixed effects Intercept	-0.01 (-0.04, 0.02)	0.00 (-0.03, 0.03)	-0.02 (-0.06, 0.02)	-0.01 (-0.05, 0.03)	-0.01 (-0.04, 0.03)	0.01 (-0.03, 0.05)
VPC	1.3% (0.4, 3.5)	0.9% (0.25, 3.40)	2.9% (1.27, 6.52)	3.2% (1.44, 6.87)	2.4% (0.79, 6.81)	

Note: Logistic random intercept multilevel regression used to estimate relationships with frequency of social activities and social contact, OR (Odds ratio). Linear random intercept multilevel regression.
Model 2 adjusted for overall wealth, occupational status, income, parental education, sex and ethnicity. Social support variable was compromised of 3 items from the Social Provisions Scale; lower scores indicate lower social support. VPC = Variance Partition Coefficient

Table A2.10: Associations between average diversity of all high streets within 800m radii and indicators of social isolation and social support						
Frequency of social activities OR (95% CI)						
	All (n = 5577)		Male (n = 2455)		Female (n=3119)	
Category 2 (compared to lowest)						
	Model 1	Model 2	Model 1	Model 2	Model 1	Model 2
Fixed effects Intercept	1.13 (0.88, 1.44)	1.19 (0.93, 1.53)	1.38 (0.97, 1.96)	1.40 (0.98, 2.00)	0.92 (0.67, 1.26)	0.98 (0.70, 1.38)
VPC	10.1% (6.53, 15.35)	7.5% (4.36, 12.90)	12.7% (7.10, 21.74)	9.8% (4.75, 19.61)	12.7% (7.15, 12.73)	10.2% (5.17, 19.30)
Category 3 (compared to lowest)						
Fixed effects Intercept	1.21 (0.96, 1.52)	1.17 (0.93, 1.46)	1.46 (1.07, 1.99)	1.34 (0.96, 1.87)	1.10 (0.81, 1.48)	1.10 (0.82, 1.46)
VPC	9.3% (22.47, 50.39)	6.0% (3.74, 9.48)	10.9% (6.93, 16.74)	7.6% (3.87, 14.03)	13.1% (8.28, 19.99)	10.1% (5.96, 17.19)
Frequency of social contact OR (95% CI)						
Category 2 (compared to lowest)						
	All (n = 5577)		Male (n=2458)		Female (n=3119)	
Fixed effects Intercept	0.94 (0.67, 1.32)	1.02 (0.71, 1.46)	1.03 (0.62, 1.72)	1.03 (0.62, 1.71)	0.87 (0.54, 1.38)	1.08 (0.66, 1.77)
VPC	10.14% (6.33, 15.83)	10.3% (6.42, 16.11)	18.7% (9.89, 32.60)	18.0% (9.39, 32.37)	19.7% (12.29, 30.08)	19.8% (11.41, 33.99)
Category 3 (compared to lowest)						
Fixed effects Intercept	1.06 (0.80, 1.39)	1.26 (0.93, 1.68)	1.22 (0.83, 1.79)	1.33 (0.88, 2.03)	0.98 (0.65, 1.49)	1.27 (0.83, 1.94)
VPC	9.4% (6.07, 14.31)	8.8% (5.15, 14.89)	12.6% (7.22, 12.16)	12.7% (7.08, 21.63)	16.24% (10.26, 24.75)	15.6% (8.76, 27.31)
Social support coef (95% CI)						
	All (n = 5450)		Male (n = 2397)		Female (n = 3053)	
Fixed effects Intercept	-0.02 (-0.05, 0.01)	-0.01 (-0.04, 0.02)	-0.03 (-0.08, 0.17)	-0.03 (-0.08, 0.02)	-0.01 (-0.05, 0.03)	0.00 (-0.03, 0.04)
VPC	1.3% (0.46, 3.48)	1.0% (0.27, 3.45)	2.9% (1.28, 6.52)	3.2% (1.47, 6.91)	2.3% (0.79, 6.84)	1.8% (0.50, 6.59)
Note: Logistic random intercept multilevel regression used to estimate relationships with frequency of social activities and social contact, OR (Odds ratio). Linear random intercept multilevel regression, coef 95% CI *Model 2 adjusted for overall wealth, occupational status, income, parental education, sex and ethnicity. Social support variable was compromised of 3 items from the Social Provisions Scale; higher scores indicate higher social support. VPC = Variance Partition Coefficient*						

High Street size

Table A2.11: Associations between distance (km) to closest high street and indicators of social isolation and social support	
Frequency of social activities *OR (95% CI) (n = 5577)*	
Middle category (compared to lowest)	
Distance	1.01 (0.98, 1.04)
VPC	7.5% (4.38, 12.75)
Highest category (compared to lowest)	
Distance	1.01 (0.98, 1.04)
VPC	6.1% (3.79, 9.62)
Frequency of social contact *OR (95% CI) (n = 5577)*	
Middle category (compared to lowest)	
Distance	1.01 (0.99, 1.02)
VPC	10.2% (6.37, 16.08)
Highest category (compared to lowest)	
Distance	0.98 (0.96, 1.00)
VPC	9.1% (5.38, 15.16)
Social Support coef *(95% CI) (n = 5450)*	
Distance	0.00 (0.00, 0.00)
VPC	0.09% (0.24, 3.34)
Note: *Note: Logistic random intercept multilevel regression used to estimate relationships with frequency of social activities and social contact, OR (Odds ratio). Linear random intercept multilevel regression. Models adjusted for overall wealth, occupational status, income, parental education, sex, ethnicity and closest high street size. Social support variable was compromised of 3 items from the Social Provisions Scale; higher scores indicate higher social support. VPC = Variance Partition Coefficient*	

Table A2.12: Associations between decayed distance to closest high street at 2000m, 1400m and 800m radii and indicators of social isolation and social support, additionally adjusted for high street size			
	2000m	1400m	800m
Frequency of social activities *OR (95% CI)* (n = 5577)			
Middle category (compared to lowest)			
Distance	0.94 (0.44, 2.01)	0.85 (0.35, 1.05)	0.52 (0.19, 1.38)
VPC	7.4% (4.28, 12.83)	7.4% (4.26, 12.81)	7.3% (4.21, 12.71)
Highest category (compared to lowest)			
Distance	0.95 (0.50, 1.81)	0.81 (0.39, 1.71)	0.65 (0.28, 1.54)
VPC	6.1% (3.88, 9.64)	6.1% (3.89, 9.61)	6.1% (3.84, 9.60)
Frequency of social contact *OR (95% CI)* (n = 5577)			
Middle category (compared to lowest)			
Distance	1.01 (0.43, 2.40)	0.99 (0.34, 2.88)	1.54 (0.36, 6.57)
VPC	10.4% (6.66, 16.26)	10.4% (6.64, 16.29)	10.3% (6.55, 16.15)
Highest category (compared to lowest)			
Distance	1.94 (0.94, 3.99)	2.36 (1.01, 5.51)	2.97 (1.04, 8.48)
VPC	6.1% (3.85, 9.63)	9.1% (5.41, 15.24)	9.1% (5.41, 15.29)
Social Support *coef (95% CI)* (n = 5450)			
Distance	-0.02 (-0.12, 0.09)	-0.03 (0.16, 0.09)	-0.03 (-0.19, 0.13)
VPC	1.0% (0.00, 0.03)	1.0% (0.27, 3.38)	1.0% (0.27, 3.33)
Note: Logistic random intercept multilevel regression used to estimate relationships with frequency of social activities and social contact, OR (Odds ratio). Linear random intercept multilevel regression. Models adjusted for overall wealth, occupational status, income, parental education, sex, ethnicity and high street size. Social support variable was compromised of 3 items from the Social Provisions Scale; higher scores indicate higher social support. VPC = Variance Partition Coefficient			