Neighbourhood Greenspace and Mental Health and Well-Being: Associations in Children and Adolescents in the United Kingdom

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A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy at University College London.

University College London

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I, Marie Antonia Elisabeth Müller, confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

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Abstract

The evidence to date suggests that there is an association between greenspace and health, but the specifics of this association remain unclear. In this thesis, I investigated the association between neighbourhood greenspace and mental health and well-being in children and adolescents living in the United Kingdom (UK).

I completed four studies. In my first two studies, I used data from the UK Millennium Cohort Study (MCS). I investigated the associations of neighbourhood greenspace quantity at ward level with self-regulation in 3- to 7-year-old children (*n* = 13,774), and well-being in urban 11-year-old adolescents (*n* = 4,534). In the second study, I also tested for interactions with contextual factors. In my last two studies, I used data from Understanding Society, the UK Household Longitudinal Study (UKHLS). I investigated the associations of different types of green spaces (i.e., parks & gardens, natural & semi-natural urban greenspaces, and outdoor sports facilities) and access to ‘high-quality’ green spaces with mental health and well-being in children (5 and 8 years; *n* = 740) and adolescents (10 to 15 years; *n* = 1,879) living in London. In the fourth study, I also tested for interactions with perceived neighbourhood quality.

I did not find a significant association between neighbourhood greenspace and self-regulation in children or well-being in young urban adolescents. I also did not find consistent associations of certain types of green spaces, or access to ‘high-quality’ green spaces, with mental health or well-being in children or adolescents living in London. Nevertheless, I found interesting interactions (e.g., related to access to private gardens) and patterns (e.g., related to age) that are worth further discussion and investigation.

In summary, I did not find a robust association between neighbourhood greenspace and children’s and adolescents’ mental health and well-being. There are several possible explanations for this, one of which is that the association may be context-specific and therefore difficult to capture.

Impact Statement

I investigated the relationship between neighbourhood greenspace and mental health and well-being among children and adolescents in the United Kingdom (UK). I focused on the role of different types of green spaces, context, and age, uncovering complex interactions between them. A better understanding of these interactions could inform the development of neighbourhoods that can protect and promote the mental health and well-being of children and adolescents in the UK (and potentially beyond), a desirable outcome not only for the individual but also for society (e.g., due to a potential economic impact).

My thesis builds on a substantial body of literature that, to date, provides mixed and inconclusive evidence, probably because of the great complexity underlying the association between greenspace and health. I contributed to the literature by investigating the association between neighbourhood greenspace and a range of mental health and well-being outcomes in both children and adolescents. Importantly, I investigated exposures beyond ‘generic’ quantity, exploring the potential roles of (a) availability of different types of green spaces and (b) access to ‘high-quality’ green spaces. Moreover, I investigated modification and moderation by contextual factors, such as access to private gardens and perceived neighbourhood quality, shedding light on context-specific associations. My thesis not only addresses substantial gaps in the literature, it also raises questions for future research, especially regarding the complexity of interactions between different types of green spaces, context, and age, which should be further explored by several scientific disciplines (e.g., psychology, epidemiology, and geography).

My thesis also has an impact on society. Indeed, the main motivation for this thesis was to add to a body of evidence that could have implications for the ‘real world’, and my findings add to the evidence base that could inform evidence-based decision-making (e.g., policymaking, and urban planning and design). Although I found limited evidence for a potential positive association between neighbourhood greenspace and children’s and adolescents’ mental health and well-being, as mentioned above, my findings raise questions regarding the role of context, which could have an important impact on real-world interventions. For example, rather than developing ‘one-size-fits-all’ solutions, policymakers should consider contextual factors in their decisions. This would allow for more effective real-world interventions that have the potential to protect and promote individual, community, and population health and well-being.

In summary, by addressing important gaps in the literature and raising questions for future research and real-world interventions, my thesis has a potential impact both inside and outside academia. I have made this impact, primarily inside academia, by publishing my findings in peer-reviewed journals and presenting my work at national and international conferences.

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Abbreviations

ADHD	Attention Deficit Hyperactivity Disorder
AIC	Akaike Information Criterion
AoD	Area of Deficiency
ART	Attention Restoration Theory
BAS	British Ability Scales
BASC-2	Behavior Assessment System for Children
CAS	Census Area Statistics
CBCL	Child Behavior Checklist
CIC	Community Interest Company
CO	Carbon monoxide
CORINE	Coordination of Information on the Environment
CPI	Child Poverty Index
CRS	Coordinate Reference System
CRT	Collective Restoration Theory
CSBQ	Child Social Behaviour Questionnaire
ECEC	Early Childhood Education and Care
EDI	Early Development Instrument
EEA	European Environment Agency
GHQ	General Health Questionnaire
GIGL/GiGL	Greenspace Information for Greater London
GIS	Geographic Information System
GLA	Greater London Authority
GLUD	Generalised Land Use Database

GPS	Global Positioning System
IQ	Intelligence quotient
LAQT	London Air Quality Toolkit
LiDAR	Light Detection and Ranging
LSOA	Lower Layer Super Output Area
MAR	Missing at random
MAUP	Modifiable Areal Unit Problem
MCS	Millennium Cohort Study
MEDIx	Multiple Environmental Deprivation Index
MENE	Monitor of Engagement with the Natural Environment
MHI-5	Mental Health Inventory
MICE	Multiple Imputation by Chained Equations
NDVI	Normalized Difference Vegetation Index
NHS	National Health Service
NISRA	Northern Ireland Statistics and Research Agency
NO_2	Nitrogen dioxide
ONS	Office for National Statistics
PCA	Principal Components Analysis
PEARL	Person-Environment-Activity Research Laboratory
PHAC	Public Health Agency of Canada
PM	Particulate matter
PPG17	Planning Policy Guidance 17
PRCS-C	Perceived Restorative Components Scale for Children
PSS	Perceived Stress Scale
PSU	Primary Sampling Unit
RADS-SF	Reynolds Adolescent Depression Scale Short Form

RRT	Relational Restoration Theory
SDQ	Strengths and Difficulties Questionnaire
SEB	Socio-emotional and behavioral
SES	Socio-economic status
SINC	Site of Importance for Nature Conservation
SO_2	Sulphur dioxide
SRT	Stress Recovery Theory
UK	United Kingdom
UKDS	UK Data Service
UKHLS	UK Household Longitudinal Study
US	United States
WHO-5	World Health Organisation-Five Well-Being Index

1. Introduction

How do the places where we live, work, learn, and play affect our health and well-being? This question about the relationship between place and health concerns scholars from a wide range of scientific disciplines, including epidemiology, geography, and psychology. It also concerns policymakers, and professionals working in ‘placemaking’ (e.g., architects, designers, and planners). A better understanding of the complex relationship between ‘place’ and ‘health’ would allow for the design of places that protect and promote people’s health and well-being.

A place is more than a position in space. It is characterised by many physical and social factors which can be positive, protective, or risk factors for health and well-being. The focus of this thesis is on one factor of the physical environment that may influence health and well-being positively: greenspace. Anecdotal evidence from people's accounts of their experiences with greenspace suggests that greenspace does, indeed, have a positive influence on health and well-being: greenspace seems to make people calm, restored, and happy. Such anecdotal evidence is supported by a growing body of scientific evidence. However, this scientific evidence is inconclusive, and much is yet to be learned about the link between greenspace and health. In fact, there are many open questions. For example, we do not know how exactly greenspace influences health and well-being, or whether different types of green spaces may have different effects on different dimensions of health and well-being. It is also not clear whether other individual or environmental factors may play a role in the association. Further, we do not know what form of exposure is most beneficial, and for whom. Such open questions highlight that the seemingly obvious link between greenspace and health and well-being is not as obvious after all.

In this thesis, I will investigate the link between greenspace and health, focusing on the association of neighbourhood greenspace with mental health and well-being in children and adolescents living in the United Kingdom (UK). Therefore, the scope of this thesis is limited to one area of exposure (i.e., the residential neighbourhood), one dimension of health and well-being (i.e., mental health and well-being), one segment of the population (i.e., children and adolescents), and one country (i.e., the UK). I will show throughout this thesis that, despite this smaller scope, the subject remains complex. Before I will review the literature in Chapter 2, highlighting this complexity, I will use the following sections to set the scene for this thesis. I will briefly describe why it is important to focus on children's and adolescents' mental health and well-being, why the residential neighbourhood is an important area of exposure, and why greenspace is a promising factor for mental health and well-being. At the end of this chapter, I will provide a brief overview of the structure of my thesis.

1.1. Mental Health and Well-Being in Childhood and Adolescence

Good mental health and well-being in childhood and adolescence is one of the foundations for a healthy life. Early mental health problems have been linked to various adverse outcomes, both in the short and in the long term (Collishaw, 2015; Davies, 2013; Ford & Parker, 2016). For example, early mental health problems are linked to higher levels of distress, lower cognitive and academic outcomes, and poorer social relationships during childhood and adolescence (Davies, 2013; Ford & Parker, 2016; Fuhrmann et al., 2022); and to mental health disorders, poorer educational attainment, and poorer employment and economic prospects in adulthood (Fergusson et al., 2007; A. Goodman et al., 2011; Kim-Cohen et al., 2003; McLeod et al., 2016; Thompson et al., 2021; Wickersham et al., 2021). Further, in addition to the wide-ranging effects on the individual, one should also point out the effects on society, such as the economic burden of early mental health problems on societal systems and services (M. K. Christensen et al., 2020). In the UK, the average annual costs associated with one child or adolescent with a mental illness have been estimated to lie between £10,000 and £60,000, depending on the type of illness, which are distributed across a range of systems, such as health and social services, the education system, and the criminal justice system (Davies, 2013; Suhrcke et al., 2007).

In 2017, one in eight of 5- to 19-year-olds in England had at least one mental health disorder (NHS Digital, 2018). Emotional, behavioural, hyperactivity, and other mental health disorders occur throughout childhood, but the prevalence of mental disorders is highest in adolescence. In 2017, one in eighteen 2- to 4-year-olds, one in ten 5- to 10-year-olds, one in seven 11- to 16-year-olds, and one in six 17- to 19-year-olds in England had at least one mental health disorder (NHS Digital, 2018). Although these numbers should be alarming enough, it is important to note that they include only those children and adolescents who meet the criteria for a clinical diagnosis. As there is a whole spectrum of mental health and psychological functioning, where mental health disorders cover only one end, considerably more children and adolescents may experience mental health problems (Collishaw, 2015; Ford & Parker, 2016).

The great impact of mental health problems on individual and society, and the great prevalence of mental health problems among children and adolescents, together, highlight the importance of developing strategies for prevention and intervention. To this end, it is essential to identify both the factors that put children and adolescents at risk of developing mental health problems, and the factors that protect and promote their mental health and well-being. Several relevant factors have already been identified, many of which are ‘proximal’ factors at the individual or family level, including sex and ethnicity; parental education, employment, and mental health; family structure; social relationships; and social support (Davies, 2013; NHS Digital, 2018). However, more ‘distal’ factors, such as factors of the residential neighbourhood, may also play a role and provide opportunities for prevention and intervention.

1.2. The Residential Neighbourhood

The residential neighbourhood provides a proximal and immediate opportunity for children and adolescents to step outside to play, be active, and socialise. Although children and adolescents spend much of their time in childcare or school, the residential neighbourhood remains an important setting where they can spend some of their spare time. In the UK, children and young adolescents are typically not allowed far from home, at least not unsupervised (Shaw et al., 2015). Due to this generally restricted independent mobility, the residential neighbourhood remains an important setting for children and adolescents to spend time outdoors, either accompanied or unaccompanied. Parents may take their young children to a nearby park, and adolescents may meet their friends, unsupervised, at an outdoor sports area to ‘hang out’ or to play sports. For example, a study on 5- to 11-year-old British children’s outdoor play showed that, although children spend most of their play time at home indoors or at home outdoors, they also spend a significant amount of their spare time playing in the street, in playgrounds, and in public green spaces (Dodd et al., 2021).

Basic psychological and epidemiological theories suggest that the residential neighbourhood, as part of the wider (distal) environment, can influence human development and health. In psychology, a major theory describing the influence of the environment on human development is the Ecological Systems Theory. In *The Ecology of Human Development* (Bronfenbrenner, 1979), the theory, originally, described four systems that influence human development, microsystem, mesosystem, exosystem, and macrosystem, where the microsystem captures more proximal environments (e.g., the family), and the macrosystem captures more distal environments (e.g., culture). An additional system, the chronosystem, describes environmental changes over time that influence human development, such as starting school (Bronfenbrenner, 1986, 1994; Crawford, 2020). In 1994, the Ecological Systems Theory was developed to the so-called Bioecological Model to stress that both the environment and the individual play an important role in human development (Bronfenbrenner & Ceci, 1994). Both models (original and extended) suggest that the residential neighbourhood affects human development. It has been criticised, however, that these ecological models did not focus much on *physical* factors of the environment (Evans, 2006).

In epidemiology, several models have been developed to describe the factors that influence human health. One of the most widely used is the

Model of Health Determinants, also known as the ‘rainbow’ model, proposed by Dahlgren and Whitehead (1991). It organises influences into layers from proximal to distal: personal factors (e.g., age), individual lifestyle factors (e.g., smoking), social and community networks, living and working conditions (e.g., housing), and general socio-economic, cultural, and environmental conditions. The model can be used to identify levels for policy interventions that aim to improve population health. One should note that, although Dahlgren and Whitehead (1991) did acknowledge personal factors in their model, they emphasised that these were fixed factors over which one had only little control. Factors of the other layers, on the other hand, could be controlled. Aspects of the residential neighbourhood, for example, belong to these modifiable factors and, therefore, allow for (policy) interventions.

The Ecological Systems Theory and the Model of Health Determinants were developed for different purposes, one to describe influences on human development, the other to describe influences on human health. Both models highlight that we must consider factors of the wider environment as influences on the individual. There is now a large body of evidence that suggests that social and physical factors of the residential neighbourhood, which is part of the wider environment, are associated with human development and health (Leventhal & Brooks-Gunn, 2000; Minh et al., 2017; Sellström & Bremberg, 2006). One of these factors, a physical environment factor, is of primary interest for the present thesis: greenspace.

1.3. Greenspace as a Promising Factor for Health and Well-Being

Several factors contribute to the quality of a neighbourhood and to the health and well-being of its inhabitants. Some factors are risk factors and other factors are protective or promotive factors for health and well-being. Greenspace is thought to be one of these ‘positive’ factors, influencing health and well-being in several ways. Markevych et al. (2017) proposed three general functions of greenspace: reducing harm (i.e., mitigation), restoring capacities (i.e., restoration), and building capacities (i.e., instoration). Although I will not test these functions directly in this thesis, to illustrate the promising role that greenspace can play in human health and well-being, I will now briefly describe each of these three functions, or pathways, in turn.

Reducing Harm (Mitigation)

Greenspace can reduce exposure to environmental stressors that are harmful for human health and well-being. These include physical environment factors, such as air, noise, heat, and light pollution. I would like to describe how greenspace may be able to mitigate harmful effects of such stressors, using the examples of air pollution and noise.

Air pollution is made up of gases (e.g., nitrogen dioxide) and particulate matter (PM; e.g., dust). PM can be categorised into different sizes: coarse particles (with a diameter ranging from 10 µm to 2.5 µm), fine particles (with a diameter smaller than 2.5 µm), and ultra-fine particles (with a diameter smaller than 0.1 µm). Pollutants enter the lung, the bloodstream, and, basically, every cell in the human body (Schraufnagel et al., 2019). Consequently, air pollution is not only linked to respiratory and cardiovascular diseases but has been shown to also affect the central nervous system, including the brain, via neuroinflammation, oxidative stress, or changes in the blood-brain barrier. Exposure to air pollution has been linked to neurodevelopmental disorders, neurodegenerative diseases, and mental health problems (Borroni et al., 2022; Brockmeyer & D'Angiulli, 2016; Costa et al., 2020; Genc et al., 2012). Noise is another stressor that affects both auditory and non-auditory health. Exposure to noise has been linked to poor sleep, poor cognitive outcomes, poor mental health, and noise annoyance (Basner et al., 2014; A. Dzhambov et al., 2017; A. M. Dzhambov, Markevych, Tilov, Arabadzhiev, et al., 2018b; Grelat et al., 2016; Haines & Stansfeld, 2003; Klatte et al., 2013). Both air pollution and noise have a range of sources, including car, rail, and air traffic, industry, and construction (among many more).

Greenspace can reduce children's and adolescents' exposure to air pollution and noise. A large proportion of greenspace in an area is associated with lower levels of traffic and traffic-related air pollution and noise. In addition, certain types of greenery, particularly trees and shrubs, can reduce existing levels of air pollution and noise by uptaking pollutants from the air and by serving as a sound barrier (M. Li et al., 2020; Y. Li et al., 2019; Vieira et al., 2018). Moreover, greenspace may moderate the effects of air pollution and noise on mental health and well-being by helping children and adolescents to cope with these stressors. This means that the same level of air pollution or noise may have a less negative effect on children living in greener areas than children living in less green areas (A. M. Dzhambov, Markevych, Tilov, Arabadzhiev, et al., 2018a; A. M. Dzhambov, Markevych, Tilov, & Dimitrova, 2018; A. M. Dzhambov & Dimitrova, 2014).

Restoring Capacities (Restoration)

Greenspace can support the restoration of resources that one needs for managing cognitively demanding tasks, and for coping with stress. Humans need resources to manage life, and, at some point, these resources are exhausted. Exposure to greenspace may help humans replenish these exhausted resources, so they have capacity to tackle new tasks and to cope with new stressors. Two theories aim to explain the restorative function of natural environments more generally: Attention Restoration Theory (ART) and Stress Recovery Theory (SRT).

ART (R. Kaplan & Kaplan, 1989; S. Kaplan, 1995) proposes that exposure to natural environments positively affects attention. Concentrating on a cognitive task requires directed (or voluntary) attention, a limited resource that can become depleted (or fatigued). Natural environments encourage undirected (or involuntary) attention, which allows for the restoration of directed attention resources. Reviews of the scientific evidence suggest that exposure to natural environments may, indeed, be associated with better attention (Ohly et al., 2016; Stevenson et al., 2018).

SRT (Ulrich, 1981; Ulrich et al., 1991) proposes that humans show innate, adaptive responses to features of the natural environment, which, in turn, reduces physiological and psychological stress. There is scientific evidence that exposure to natural environments may, indeed, be associated with a decrease in stress and negative affect, and an increase in well-being and positive affect, although the evidence for physiological effects is limited

(Berto, 2014; Bratman et al., 2012, 2021; Corazon et al., 2019; R. Jones et al., 2021). Barger et al. (2021) reviewed the scientific evidence for the effects of greenspace on attention and stress in children and adolescents specifically. They concluded that the evidence was mixed, partly due to the great heterogeneity of studies regarding measures of greenspace, attention, and stress. I will also highlight this heterogeneity (regarding measures of exposures and outcomes) in my literature review in Chapter 2.

Noteworthy, researchers have started to extend traditional ART and SRT. Hartig (2021) proposes the extension of the 'conventional narrative' of restoration in nature with two new theories: relational restoration theory (RRT) and collective restoration theory (CRT). These theories add a social dimension to restoration theory, where social support is the depleted resource that can be restored in nature. The development of new, and the extension of existing, theories once again highlights that we are far from a thorough understanding of the association between greenspace and health.

Building Capacities (Instoration)

Greenspace can support the building of new capacities. This means that, even if a person does not need to be protected from environmental stressors or replenish exhausted resources, they can use green spaces to build new capacities. For example, greenspace can encourage physical and social activities, both of which are beneficial for human mental health and well-being (Biddle et al., 2019; McPherson et al., 2014).

Childhood and adolescence are characterised by rapid developments. Due to different needs and interests, children and adolescents likely use green spaces for different activities. For example, one important part of child development is play, and green spaces offer children the opportunity to engage in outdoor play (Freeman et al., 2021; Lambert et al., 2019; Veitch et al., 2007). Outdoor play involves both physical and social activities, and scientists have highlighted for a long time that outdoor play is a crucial part of childhood that is related to many positive outcomes, such as self-esteem, self-regulation, and academic achievements (Brussoni et al., 2015; Tremblay et al., 2015). Adolescents, depending on age, may not be interested in outdoor play per se (Kemp et al., 2022), but they use green spaces to exercise and to spend time with their friends (Bloemsma et al., 2018; Rivera et al., 2021). Therefore, although children and adolescents may be engaged in different activities in green spaces (accompanied by their parents, on their own, or with their friends), both are likely to engage in physical and social activities. There now is evidence that the relationship between greenspace and children's and adolescents' mental health and well-being may, indeed, be mediated, partially, by physical and social activities (Dadvand et al., 2019; Dimitrova et al., 2017; A. Dzhambov et al., 2018; Putra et al., 2021b).

Complexity of Associations

In the previous sections, I have highlighted the promising role that greenspace plays in children's and adolescents' mental health and well-being: clean air, quiet, the opportunity to recover and restore, and a place to play, be active, and socialise. I would like to conclude this section with a few remarks, highlighting the complexity of associations. First, the three functions described above are intertwined (A. M. Dzhambov et al., 2019), and, most of the time, children and adolescents will benefit from more than one of the three functions. In other words, the three functions do not work in isolation. Second, the three functions are not exhaustive, and there are other plausible ways in which greenspace could affect health and well-being. For example, exposure to greenspace may affect health and well-being via changes in the human microbiome and immune system (Mills et al., 2017). Further, there may be more indirect pathways. For example, exposure to greenspace may affect the mental health and well-being of parents, which, in turn, may affect the mental health and well-being of children (Schepman et al., 2011). Specifically, neighbourhood greenspace may have positive effects on the mental health and well-being of parents, which, in turn, may have positive effects on the mental health and well-being of children. Third, the association of neighbourhood greenspace with health and well-being is not 'generic' but context-specific; it likely depends on characteristics of greenspace (e.g., type), neighbourhood (e.g., safety), and individual (e.g., nature connectedness). It also likely depends on how exactly children and adolescents are exposed to greenspace (e.g., active versus passive exposure), and on whether children and adolescents are exposed at all. For example, even if children and adolescents (objectively) had access to green spaces in their neighbourhoods, there may be individual, physical, social, or cultural barriers to exposure (Public Health England, 2020). Therefore, objective measures of exposure may not capture children's and adolescents' true (subjective) exposure. In a nutshell, not all green spaces fulfil all functions for all people, and there are many factors to consider in the association. It is therefore important to understand better the nuances of the association between greenspace and health.

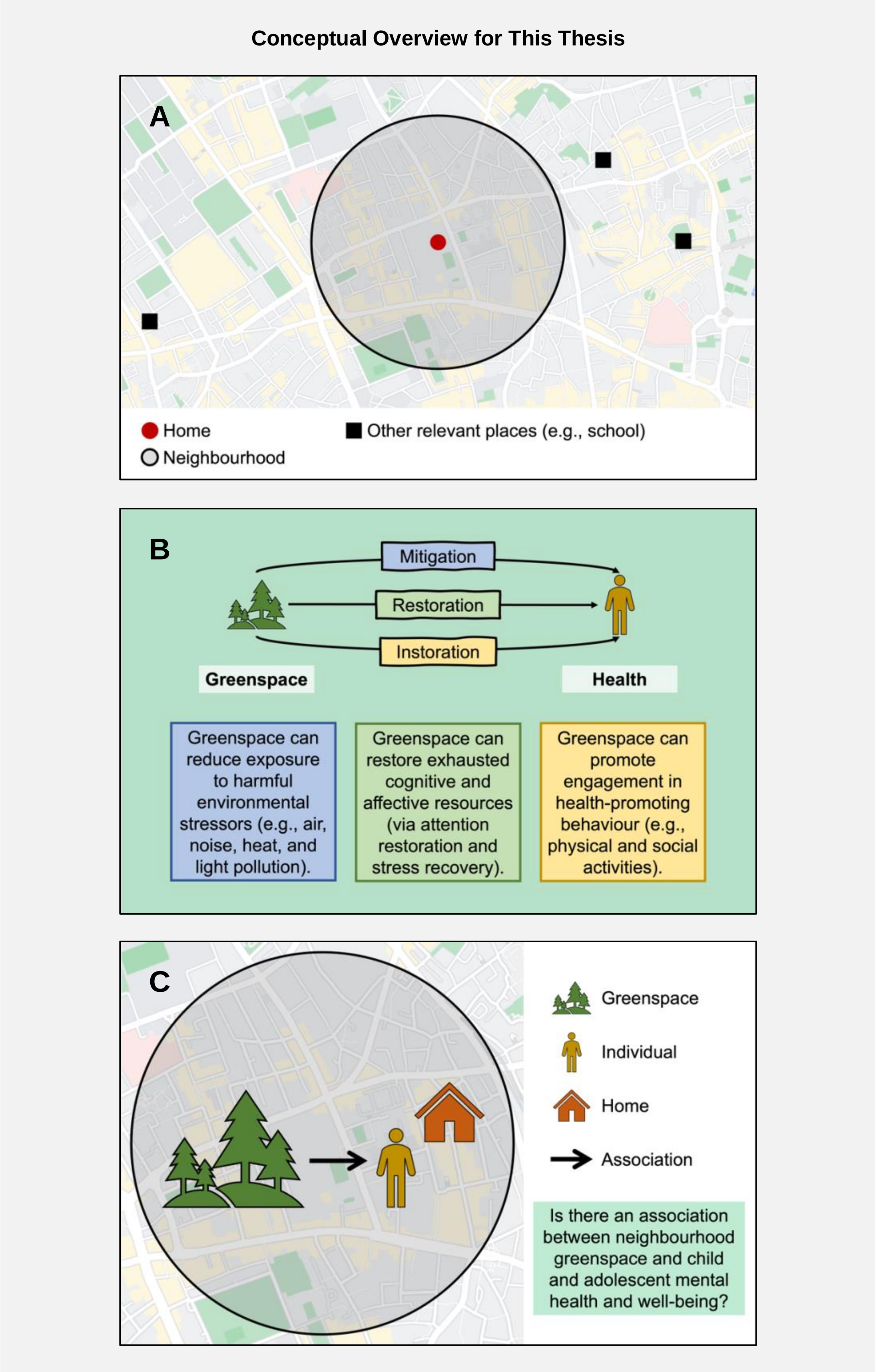

Figure 1.1 Conceptual overview for this thesis. A: Focus on the residential neighbourhood. **B:** Pathways that could explain an association between neighbourhood greenspace and child and adolescent mental health and well-being. **C:** Question: Is there an association between neighbourhood greenspace and child and adolescent mental health and well-being? Map data © 2022 Google. Google Maps™ mapping service is a trademark of Google LLC.

1.4. Summary and Outlook

In this brief introduction, I have highlighted the importance of mental health and well-being in childhood and adolescence, described the neighbourhood as part of the wider environment that influences health and development, and pointed out greenspace as a promising factor for mental health and well-being. Figure 1.1 provides a conceptual overview for this thesis. Despite a growing body of evidence, our understanding of the association between neighbourhood greenspace and mental health and well-being in children and adolescents is limited. In the next chapter, I will review the existing literature, describing its main findings and limitations (Chapter 2). Based on this review, I will outline the contributions of my thesis, including my research questions. I will then provide an overview of my methodology (Chapter 3) and present my four empirical studies, including Introduction, Methods, Results, and Discussion sections for each study (Chapters 4 to 7). Finally, I will provide a general discussion of my findings, considering the existing literature, pointing out my studies' limitations, making suggestions for future research, and discussing potential implications for policy and planning (Chapter 8).

2. Literature Review

To this point, I have highlighted the importance of this area of research, and described why a link between neighbourhood greenspace and children's and adolescents' mental health and well-being is, theoretically, plausible. I will now review the literature and provide an overview of the empirical evidence. The review will focus on neighbourhood greenspace (exposure), mental health and well-being (outcome), and children and adolescents (population). Reviews on similar topics, sometimes broader in scope, have been published (Davis et al., 2021; Evans, 2006; Fleckney & Bentley, 2021; Minh et al., 2017; Tillmann et al., 2018; Vanaken & Danckaerts, 2018; Weeland, Moens, et al., 2019; Zhang et al., 2020). The aim of this review is to provide an overview of the main streams in the literature, the main findings, and the main gaps, for the scope outlined above. The review is intended to be representative of the literature, not exhaustive, and to serve as a basis for this thesis. I will show that the evidence is mixed and inconclusive, which is partly due to the great heterogeneity of studies regarding exposures, outcomes, demographics, and geographies.

In the next sections, I will review studies that investigated associations related to greenspace quantity, proximity, and quality. Throughout, I will provide short summaries of key take-away messages. An illustration of the main findings of studies included in my review is provided in Table 2.1. At the end of this chapter, I will give a longer summary of the main findings and gaps, highlight the three main contributions of my thesis to the literature, and provide an overview of my research questions in Table 2.2.

2.1. Quantity

Most studies investigating the link between neighbourhood greenspace and child and adolescent mental health and well-being have used a measure of greenspace quantity as the primary exposure of interest. These studies ask whether higher levels of greenness or greenspace in a neighbourhood are associated with better mental health and well-being. It makes sense to distinguish studies investigating *greenness* and *availability of greenspace* because they typically use different types of data and, therefore, allow for different conclusions about the role of quantity. Most consistent positive associations with children's and adolescents' mental health and well-being have been found for neighbourhood greenness. However, this may also be explained by the fact that neighbourhood greenness is the most used exposure in the literature.

Greenness

The greenness of an area (e.g., a census area or a circular buffer around a geocoded address) is often measured with the so-called Normalized Difference Vegetation Index (NDVI). There are other measures of greenness, but almost all studies that I will review in this section used the NDVI. The NDVI is calculated from satellite data and is based on the fact that healthy vegetation reflects and absorbs light of different wavelengths than unhealthy vegetation or non-vegetated areas. Specifically, healthy vegetation absorbs red light and reflects near-infrared and green light. NDVI values range between -1 and +1, and higher positive values indicate higher density of vegetation (Gascon et al., 2016; C. E. Reid et al., 2018). To calculate the greenness of an area, one could calculate the average NDVI of all satellite image pixels (e.g., 30 m x 30 m) that intersect with the area of interest (e.g., a census area). Negative NDVI values (representing water, ice, and non-vegetated soil) are often set to zero (C. E. Reid et al., 2018) or removed (Gascon et al., 2016), so they do not offset positive values and bias the assessment of the greenness of an area. However, depending on the proportion of negative values (i.e., non-vegetated land), this could also introduce error in the assessment of individual exposure. One advantage of the NDVI compared to other measures of quantity is that it considers the density of vegetation. One disadvantage is that the NDVI does not provide information on the types of vegetation (e.g., trees or grass) or green spaces (e.g., parks or agricultural land) available in an area (Rhew et al., 2011).

Most studies that used the NDVI found positive associations between neighbourhood greenness and child and adolescent mental health and well-being. However, these associations are often limited to specific levels of aggregation (e.g., buffer sizes) or outcomes, and these more specific findings are not consistent across studies. To illustrate this, I will now describe and discuss a few studies in turn. I will provide short summaries of important take-away messages throughout the section.

Amoly et al. (2014) investigated the associations of ‘home’ and ‘school’ greenness with mental health in 7- to 10-year-old children in Barcelona, Spain (*n* = 2,111). Mental health was assessed with the Strengths and Difficulties Questionnaire (SDQ; parent-reported), and with attention deficit hyperactivity disorder (ADHD) symptoms (teacher-reported). Home and school greenness were assessed with the NDVI in 100 m, 250 m, and 500 m around the home, and 100 m around the school. Note that the researchers also used a measure of proximity, which I will discuss in a later section. In statistical models, adjusted for individual and neighbourhood confounders, they found that higher levels of ‘home’ greenness were associated with lower levels of total difficulties (100 m, 250 m, and 500 m), conduct problems (100 m and 250 m), emotional symptoms (500 m), peer relationship problems (250 m), hyperactivity and inattention (100 m, 250 m, and 500 m), and ADHD symptoms (100 m). Noteworthy, they did not find significant associations for ‘school’ greenness. The findings suggest that neighbourhood greenness may play a role in a range of mental health outcomes in children (although not equally consistently).

Madzia et al. (2019) investigated the associations of neighbourhood greenness with externalising and internalising problems in 7- and 12-year-old children in Cincinnati, US (*n* = 562 and *n* = 313). Externalising problems (i.e., aggression, conduct problems, and hyperactivity) and internalising problems (i.e., anxiety, depression, and somatisation) were measured with the Behavioral Assessment System for Children (BASC-2; parent-reported), as continuous and binary (‘at risk’ versus ‘not at risk’) scores. Neighbourhood greenness was measured with the NDVI in 200 m, 400 m, and 800 m around the home. In adjusted statistical models, the researchers found that, in 7-year-old children, higher levels of greenness were associated with lower levels of conduct problems (200 m) and a decreased risk of conduct problems (200 m and 800 m). In 12-year-old children, higher levels of greenness were associated with lower levels of anxiety (800 m), depression (200 m and 800 m), and somatisation (200 m and 400 m), and with a decreased risk of anxiety (200 m, 400 m, and 800 m). This suggests that neighbourhood greenness may play different roles in different age groups: in younger children, higher levels of greenness seemed to be associated with lower levels of externalising problems, whereas in older children (or young adolescents), higher levels of greenness seemed to be associated with lower levels of internalising problems. Considering the relatively large number of 72 tests (6 outcomes x 2 types of scales x 3 buffer sizes x 2 ages), the 11 significant associations provide only limited evidence, especially for externalising problems in 7-year-old children. Nevertheless, the pattern of findings is interesting and important for this thesis (in which I will look at a wide range of ages, spanning childhood and adolescence).

Mavoa et al. (2019) investigated the associations of neighbourhood greenspace with self-reported depressive symptoms and emotional well-being in 12- to 19-year-olds in urban New Zealand (n = 4,575). Depressive symptoms were measured with the short form of the Reynolds Adolescent Depression Scale (RADS-SF), and emotional well-being was measured with the WHO Well-Being Index (WHO-5). The researchers tested several exposures, including average greenness of the neighbourhood, measured with the NDVI in 400 m, 800 m, and 1,600 m around a meshblock, a unit of New Zealand census geography. In adjusted statistical models, higher levels of neighbourhood greenness were associated with lower levels of depressive symptoms (400 m and 800 m). Noteworthy, the researchers did not find an association of neighbourhood greenness with emotional well-being. If causal, these results suggest that the amount of green in a neighbourhood does not equally affect mental health and mental well-being, two related but distinct constructs. This is important to note in the context of this thesis, as I will use measures of both mental health and mental well-being.

All three studies (Amoly et al., 2014; Madzia et al., 2019; Mavoa et al., 2019) found positive associations of neighbourhood greenness with indicators of child and adolescent mental health. They have three main similarities. First, they used a cross-sectional design (which limits the ability to make causal inferences). Second, they used an ego-centric definition of the neighbourhood (using circular buffers around homes and meshblocks). Third, their findings are neither consistent across levels of aggregation (i.e., buffer sizes) nor across outcomes, but rather limited to specific buffer-outcome combinations. The three studies also have important differences. First, they investigated associations in different countries (i.e., Spain, US, and New Zealand). Second, they investigated associations in different age groups (i.e., 7- to 10-year-olds, 7- and 12-year-olds, and 12- to 19-year-olds). Third, they used different instruments to measure mental health and well-being (i.e., SDQ, BASC-2, and RADS-SF and WHO-5). Finally, they used different buffer sizes to delineate the residential neighbourhood (i.e., 100 m, 250 m, and 500 m; 200 m, 400 m, and 800 m; and 400 m, 800 m, and 1,600 m). In other words, although all three studies used the NDVI, there still is great heterogeneity, illustrating the complexity of this area of research (despite the already reduced scope). The heterogeneity of studies makes it challenging to draw clear and useful conclusions from the literature. We shall see later that this heterogeneity is not limited to studies using the NDVI but will also be evident in the following sections.

I would like to highlight three additional studies that found positive associations in adolescents but used outcomes different from the studies above. Wang et al. (2019) investigated the association of neighbourhood greenness with self-reported serious psychological distress in 12- to 17-year-old adolescents in California, US (n = 4,538). Serious psychological distress was measured with the six-item Kessler Psychological Distress Scale (Kessler-6). Neighbourhood greenness was measured with the NDVI in eight buffers around the home (250 m to 950 m). In adjusted models, higher levels of greenness were associated with lower odds of serious psychological distress, but only in the analysis using the 350 m buffer. Finding an association for only one buffer may mean that the association is not robust (or, more unlikely, that neighbourhood greenness only plays a role in this specific radius around the home).

Bloemsma et al. (2022) investigated the association of neighbourhood greenspace with self-reported mental health in a longitudinal study of 3,059 adolescents in the Netherlands. Mental health was measured with the Mental Health Inventory (MHI-5) at ages 11, 14, 17, and/or 20 years. Greenness was measured with the NDVI in 300 m, 1,000 m, and 3,000 m around the home. Note that the researchers also used land use variables as exposures, but these will be discussed in the next section. In statistical models, adjusting for some (but probably not enough) confounders, the researchers found that higher levels of greenness were associated with lower odds of poor mental health, in all three buffers. However, after additional adjustment for urbanisation, they found this association only for the 3,000 m buffer analysis. This suggests a confounding role of urbanisation in the association found for smaller buffer sizes (i.e., 300 m and 1,000 m).

Younan et al. (2016) investigated the association of neighbourhood greenness with aggression in a longitudinal analysis of 1,287 adolescents at the age of 9 to 18 years in urban Southern California, US. Adolescents were followed from 2000 to 2012 and had up to four assessments of aggression. Aggression was measured with one scale from the Child Behavior Checklist (CBCL/6–18; parent-reported). Neighbourhood greenness was measured with the NDVI in 250 m, 350 m, 500 m, and 1,000 m around the home. The researchers distinguished short-term exposure (1, 3, and 6 months) and long-term exposure (1, 2, and 3 years) prior to the assessment of aggression. In statistical models, adjusted for individual and neighbourhood confounders, they found that both short-term (months) and long-term (years) exposure to higher levels of greenness were associated with lower levels of aggressive behaviour, but only in the 1,000 m analysis.

The main take-away messages from these studies (Bloemsma et al., 2022; P. Wang et al., 2019; Younan et al., 2016) are the same as above. Even though all three studies used the NDVI and investigated associations in adolescents, there is great heterogeneity. Again, all three studies found associations only for specific (but different) buffer sizes (i.e., 350 m, 3,000 m, and 1,000 m, respectively). Therefore, it is not possible to draw conclusions about what radius around the home may be most relevant for adolescents (at least not regarding the association between greenspace and mental health).

I would like to point to studies that investigated associations of neighbourhood greenness with clinical outcomes (without describing these studies in detail). For example, both Thygesen et al. (2020) and Yuchi et al. (2022) investigated the association between neighbourhood greenness and ADHD diagnosis. In longitudinal studies in Denmark and Canada, respectively, they found that growing up with higher levels of neighbourhood greenness was associated with a lower risk of being diagnosed with ADHD later in life. In a longitudinal study in Denmark, Engemann et al. (2019) found that growing up with higher levels of greenness in the neighbourhood was associated with a lower risk of being diagnosed with a psychiatric disorder later in life. In a prospective, longitudinal study, Bezold et al. (2018) found that growing up in greener neighbourhoods in the US was associated with a lower risk of high depressive symptoms later in life (however, note, that, unlike the other three studies, their outcome was not a clinical diagnosis). These studies suggest that the greenness of the neighbourhood that an individual is growing up in may not only be associated with their short-term (immediate) mental health but also with their long-term mental health.

The studies described and discussed so far suggest that there may be an association between neighbourhood greenness and children's and adolescents' mental health, both in the short and in the long term. However, findings tend to be specific and not consistent across (or even within) studies. Furthermore, some studies did not find an association of neighbourhood greenness with children's or adolescents' mental health, and others find an association but in the unexpected direction. For example, Ezpeleta et al. (2022) investigated the association of neighbourhood greenness with obsessive-compulsive behaviours (OCBs) in 9- and 10-year-old children in Barcelona (n = 378). OCBs were assessed with the parent-reported Spence Children's Anxiety Scale. Neighbourhood greenness was assessed with the

NDVI and with a measure of tree cover in 100 m, 300 m, and 500 m around homes and schools. They found associations only for greenness around schools, not homes, which contradicts the study by Amoly et al. (2014) that found associations only for greenness around homes, not schools. Similarly, Markevych et al. (2014) did not find an association between the NDVI (measured in 500 m around the home) and mental health problems (measured with the SDQ) in 10-year-old children in Munich, Germany (n = 1,932). Noteworthy, Balseviciene et al. (2014) even found a negative association of neighbourhood greenness with mental health in 4- to 6-year-old children from advantaged families in Kaunas, Lithuania. The researchers investigated the association of the NDVI in 300 m around the home with parent-reported SDQ scales. In children with mothers with higher education (i.e., advantaged children), higher levels of greenness were associated with higher levels of conduct problems and lower levels of prosocial behaviour. This was not found for children with mothers with lower education levels. It is important to note, however, that this study did not control for neighbourhood socio-economic status (SES), so the association may be confounded.

In summary, most studies using the NDVI as a measure of neighbourhood greenness found positive associations with mental health in children and adolescents, but these associations were typically linked to specific buffer-outcome combinations which were not the same across studies. Heterogeneity regarding buffer sizes, outcomes, age groups, and geographies make comparisons between studies, and drawing general conclusions, difficult. Furthermore, because studies used observational data (and often had a cross-sectional design), inferences about causality must be made with caution. However, even if we assumed causality, studies using the NDVI have one major limitation: they do not provide information on types of vegetation or types of green spaces, so what exactly may be ‘beneficial’ for children’s and adolescents’ mental health and well-being remains unknown. In the next section, I will review studies investigating the role of the availability of greenspace in the neighbourhood, typically using land cover or land use data. Some of these studies distinguished between different types of vegetation or types of land use, shedding light on the important question about ‘what works for whom’. However, we shall see that these studies are scarce, and findings are, again, mixed and inconclusive.

Availability of Greenspace

The availability of greenspace in a neighbourhood typically refers to the proportion of the area that is covered with green land cover or green land use. Land cover data capture the physical materials that land is covered with (e.g., grass, trees, or paved surfaces), whereas land use data capture the function of a land (e.g., agricultural, commercial, or residential). How exactly land cover and land use are categorised depends on the data at hand. Unlike the NDVI, there is no universal, standardised system or approach how to measure and categorise land cover and land use (C. E. Reid et al., 2018). For this review, the important point to keep in mind is that when I refer to the availability of greenspace, I do not mean the greenness of an area, as measured with the NDVI, but I mean the percentage or proportion of greenspace (i.e., green land cover or green land use) of an area. Again, I will describe and discuss a few studies in detail, summarising key insights throughout the section.

Feda et al. (2015) investigated the association of neighbourhood park land with perceived stress in 12- to 15-year-old adolescents in Buffalo, US (n = 68). Perceived stress was measured with the Perceived Stress Scale (PSS; self-reported). The proportion of park land was measured in an 800 m network buffer around the home. Park land included not only parks but also nature trails, bike paths, playgrounds, and athletic fields. In adjusted models, more park land was associated with lower levels of perceived stress. However, noteworthy, models were not adjusted for neighbourhood SES, so this association may be confounded.

Feng and Astell-Burt (2017) investigated the association of neighbourhood park land with 4,968 children’s mental health in a longitudinal study in Australia. Mental health was measured with the parent-reported SDQ, over a period of five waves (age 4–5 years to age 12–13 years). Park land (limited to parks) was measured for each Statistical Area 2 (SA2), a unit of Australian non-census geography. The researchers found that higher levels of park land were associated with lower levels of internalising, externalising, and total difficulties across childhood. They also report that largest associations were found for 21% to 40% park land (compared to smaller and larger percentages). It is important to note, however, that models were not adjusted for individual (family) SES, so the associations may be confounded.

Mygind et al. (2022) investigated the associations of green land cover at home and in early childhood education and care (ECEC) centres with the mental health of 2- to 5- year-old children in Perth, Australia (*n* = 1,196). Mental health was assessed with the parent-reported SDQ. Greenspace was measured as green land cover (i.e., trees, grass, and shrubs) in the home yard, the neighbourhood (in 500 m around the home), the ECEC centre outdoor area, and the ECEC centre neighbourhood (in 500 m around the ECEC centre). The researchers also summed the four values to calculate the average vegetation cover across the four exposure areas. In adjusted statistical models, they found that higher average vegetation cover, vegetation cover at home, and vegetation in the residential neighbourhood were associated with a lower risk of emotional difficulties (but not other SDQ dimensions). They did not find associations for vegetation cover in the ECEC centre outdoor area or neighbourhood. These findings are in line with the study by Amoly et al. (2014) that found significant associations for greenness around homes, but not schools.

These three studies (Feda et al., 2015; Feng & Astell-Burt, 2017c; Mygind et al., 2022) suggest that higher proportions of greenspace at home and in the residential neighbourhood are associated with better mental health, both in young children and in adolescents. By assessing a different aspect of quantity, they complement studies investigating neighbourhood greenness. As studies using the NDVI, studies assessing the availability of greenspace differ in terms of important factors (e.g., outcomes, age groups, and geographies). Moreover, these studies also differ in their definitions of greenspace. Feda et al. (2015) and Feng and Astell-Burt (2017) both used land use data to assess the role of park land. However, while Feng and

Astell-Burt (2017) only included park land, Feda et al. (2015) also included other types of open spaces (e.g., playgrounds). Mygind et al. (2022), on the other hand, used land cover data and assessed the role of vegetation cover. This is important to note because park land is open space that is typically public and free to access (i.e., usable), whereas vegetation cover includes any vegetation (e.g., street trees or private woodlands). It is plausible that these different aspects of greenspace are associated with different pathways to health and well-being. For example, vegetation cover may be particularly relevant for mitigation and restoration pathways, whereas the availability of (usable) green spaces in the neighbourhood may be especially important for the instoration pathway.

As studies using the NDVI, the three studies described above share one main limitation: they do not distinguish between different types of green spaces or vegetation. This is important, however, to be able to better understand the nuances of the association between greenspace and child and adolescent mental health and well-being. I will now review three studies that did distinguish different types of green spaces or vegetation.

Maes et al. (2021) investigated the association of natural space with mental health and well-being in 9- to 15-year-old adolescents in London, UK (n = 3,568). Mental health was measured with the SDQ total difficulties score, and well-being (i.e., health-related quality of life) was measured with the KIDSCREEN-10. Both outcomes were self-reported. The researchers also assessed cognitive ability. Natural space was measured with NDVI and Light Detection and Ranging (LiDAR) data. The researchers used these data together to calculate proportions of total natural space, green space and blue space, and grassland (vegetation lower than 1 m) and woodland (vegetation higher than 1 m) in 50 m, 100 m, 250 m, and 500 m around homes and schools. Exposure was daytime-weighted according to hours spent at home and at school. In statistical models, adjusted for individual and neighbourhood confounders, the researchers found that higher levels of natural space and green space were associated with better cognition. They also found that higher levels of woodland were associated with better mental health, whereas higher levels of grassland were associated with better well-being. Noteworthy, they found stronger associations for larger buffers (250 m and 500 m) than smaller buffers (50 m and 100 m). If causal, these findings suggest that different types of vegetation have different effects on mental health and well-being.

Bloemsma et al. (2022) investigated the association of neighbourhood greenspace with mental health in adolescents in the Netherlands (*n* = 3,059). Mental health was measured with the MHI-5 across ages 11, 14, 17, and/or 20 years. Greenspace was measured with the NDVI (as discussed in the previous section) and with land use data. They calculated the percentages of urban, agricultural, natural, and total greenspace in 300 m, 1,000 m, and 3,000 m around the home. They found associations for total, natural, and agricultural (but not urban) greenspace with mental health, but only in the 1,000 m and 3,000 m analysis. After additional adjustment for urbanisation, however, most associations disappeared. Only the association of total greenspace in 3,000 m remained (as did the association of the NDVI in 3,000 m, as discussed earlier). Again, this suggests a confounding role of urbanisation in the association (highlighting the importance of controlling for urbanisation/urbanicity when investigating the link between greenspace and health).

Jarvis et al. (2022) investigated the association of greenspace around the home with the development of young children (mean age 5.6 years) in Vancouver, Canada (*n* = 27,539). Development was measured with the Early Development Instrument (EDI) and reported by kindergarten teachers. The EDI assesses development more generally and is not limited to mental health and well-being. It includes five dimensions: physical health and well-being, social competence, emotional maturity, language and cognitive development, and communication skills and general knowledge. Neighbourhood greenspace was measured with land cover data, distinguishing tree cover, grass cover, and paved surfaces. The researchers measured ‘life-time’ exposure (from birth to assessment) and found that higher levels of total vegetation, tree cover, and grass cover were associated with better development, whereas higher levels of paved surfaces were associated with worse development. They reported stronger associations for tree cover than grass cover.

The three studies (Bloemsma et al., 2022; Jarvis et al., 2022; Maes et al., 2021) add to the studies described above, finding a positive association between availability of greenspace and mental health and well-being, both in young children and adolescents. Furthermore, the studies add detail by distinguishing different types of vegetation or land use. Maes et al. (2021) and Jarvis et al. (2022) used data on grassland/grass cover and woodland/tree cover, and both found associations with mental health, well-being, and development. Findings suggest that trees may be more 'beneficial' than grass, especially for mental health, but both studies report positive associations for grassland/grass cover too. Looking at the wider literature, Donovan et al. (2020), for example, found that higher levels of tree cover around the home and the school were associated with higher math scores and higher reading scores, respectively, in a large sample of students in Portland, US. Noteworthy, they did not find the same for grass-and-shrubs cover. Although it is not possible to draw general conclusions from these studies about whether tree cover or grass cover is more 'beneficial', it is plausible that both are linked to different pathways to health and well-being and, therefore, may benefit different outcomes or outcome domains. For example, trees/tree cover may be linked more to mitigation and restoration, whereas grass/grass cover may be linked more to instoration.

Bloemsma et al. (2022) used land use (rather than land cover) data and did not find robust evidence for differences between urban, agricultural, and natural greenspace. Again, looking at the wider literature, Markevych et al. (2019) investigated the relationship between greenspace and academic performance in adolescents in Munich and Wesel, Germany, using measures of NDVI, tree cover, and different types of land use (agricultural, forest, and urban) in 500 m and 1,000 m around homes and schools. They did not find an association of any exposure with academic performance. Although findings of these studies suggest that the type of greenspace may not make a difference, it is unclear whether this is a generalisable finding, or whether this also has to do with the study characteristics. For example, the two studies used similar greenspace categories (i.e., agricultural, forest/natural, and urban), which may not be specific enough, and each category may capture a range of types of spaces. If only some types in a certain category are relevant for adolescent mental health, an association of these types with mental health (or cognition) could be offset by other non-relevant types of spaces in the same category. This, in turn, would explain the null findings.

As for studies using the NDVI, some studies did not find a link between neighbourhood greenspace availability and mental health in children. Flouri et al. (2014) investigated the association of greenspace with 3- to 7-year-old children's mental health, measured with the parent-reported SDQ, in urban England (*n* = 6,348). Neighbourhood greenspace quantity was measured as the percentage of greenspace (excluding domestic gardens) for each Lower Layer Super Output Area (LSOA), a unit of census geography in England and Wales. In adjusted statistical models, they did not find an association of availability of greenspace with mental health (except for one negative association with emotional symptoms in disadvantaged children). In a similar study in urban Scotland, Richardson et al. (2017) did not find an association between natural space or public park space in 500 m around the postcode with 4- to 6-year-old children's mental health (except for one positive association with prosocial behaviour), measured with the parent-reported SDQ (*n* = 2,909). In analyses stratified by sex and household education, however, they did find associations. Higher levels of public park space were associated with lower levels of peer relationship problems and total difficulties in boys, whereas higher levels of total natural space were associated with lower levels of hyperactivity and inattention, peer relationship problems, and total difficulties, and higher levels of prosocial behaviour in girls. Further, higher levels of total natural space were associated with lower levels of peer relationship problems in children from 'low-education' households, and with higher levels of prosocial behaviour in children from 'high-education' households.

Noteworthy, both studies found that access to a private garden (i.e., proximal greenspace) was associated with children's mental health. If causal, this suggests that the immediate opportunity for exposure to greenspace could be more 'beneficial' for young UK children's mental health than the availability of public greenspace in the neighbourhood. I will discuss the role of proximity more generally in the next section.

Studies on children and adolescents outside the UK also report null findings or even negative associations. In a study on American children, Reuben et al. (2020) did not find an association between availability of parks in the neighbourhood and risk of anxiety or depression (although they did find an association with ADHD diagnosis). Similarly, in a study on adolescents in the Netherlands, Weeland et al. (2019) did not find an association between the availability of neighbourhood greenspace and externalising behaviour. Noteworthy, they did find a positive association between the experience of stressful life events and externalising behaviour, and this association was stronger in adolescents living in neighbourhoods with *higher* levels of greenspace. These findings suggest that neighbourhood greenspace may neither be a promotive nor a protective factor for adolescent mental health, and (if associations were causal) could even exacerbate negative effects of stressful life events on mental health. Of course, findings of individual studies need to be taken with caution, but, together, studies reporting null findings underline that the association between neighbourhood greenspace and children's and adolescents' mental health and well-being is not as obvious as one might assume based on the anecdotal evidence.

In summary, studies investigating neighbourhood greenspace quantity, either as the greenness of an area or the availability of greenspace in an area, generally find positive associations with mental health in younger children and adolescents. However, typically, findings are limited to a specific combination of level of aggregation (e.g., a buffer size) and outcome (e.g., a dimension of the SDQ). Moreover, some studies did not find significant associations. In general, due to the great heterogeneity of studies regarding exposures, outcomes, demographics, and geographies, drawing general conclusions is challenging, if not impossible. Nevertheless, it is probably safe to conclude that there is some relationship between neighbourhood greenspace quantity and child and adolescent mental health. However, what types of green spaces or vegetation are associated with what outcomes, what area around the home captures individual exposure best, and how all this may differ by age cannot be concluded. An additional question is whether greenspace quantity is the best way (as varied as it is) to assess children's and adolescents' exposure to greenspace in the neighbourhood. We shall see in the next two sections that there are other dimensions to consider. I will start with reviewing the literature on proximity.

2.2. Proximity

The proximity of, or distance to, greenspace is another way to assess exposure to greenspace. A measure of proximity does not capture how much greenspace is available but approximates how easy it is to access (or reach) a greenspace. Studies investigating the role of proximity typically calculate the distance to the nearest greenspace, and shorter distances indicate better 'accessibility'. Although this sounds straightforward, there are many ways to measure proximity, so studies, again, tend to use different measures of exposure. First, one must decide what green spaces to include: any greenspace or only green spaces that fulfil certain criteria (e.g., regarding type or size). Second, one must decide how to measure distance: one could use the Euclidean (straight-line) distance or the network distance (along a road network); further, one could calculate the distance to the boundary, the centroid, or the closest access point of a greenspace. How to best assess proximity is unclear, and each of the approaches above has their own advantages and disadvantages. For this review, however, the most important point to keep in mind is that proximity captures a different aspect of exposure than quantity, and may be associated with other (primary) pathways to health and well-being. For example, the quantity of greenspace may be more important for the reduction of air pollution and noise, whereas the proximity of green spaces may be more important for people's use of these spaces.

Significantly fewer studies have investigated the association between proximity of neighbourhood greenspace and child and adolescent mental health and well-being. Markevych et al. (2014) investigated the association between the shortest distance to urban green spaces (i.e., cemeteries, gardens, parks, and plant nurseries), and, in a sensitivity analysis, forests, and 10-year-old children's mental health (assessed with the parent-reported SDQ) in Munich, Germany (n = 1,932). In adjusted statistical models, they found that larger distances to urban green spaces (but not forests) were linked to higher levels of hyperactivity and inattention, and peer relationship problems. These findings are plausible considering that nearby urban green spaces are likely to facilitate physical activity (likely associated with lower levels of hyperactivity and inattention) and social activities (likely associated with lower levels of peer relationship problems).

Alderton et al. (2022) investigated the associations of distances to public open spaces with internalising and externalising difficulties, and competence in young Australian children living in a capital city (n = 199,200; school-entrant population). Distances to any public open space and child-friendly public open space were calculated along street networks, and binary variables for living within 400 m and 800 m of any open space and a child-friendly open space were created. In adjusted models, the researchers found that living in proximity of public open space was associated with lower odds of externalising difficulties and higher odds of competence (in the 800 m buffer analysis). Child-friendly public open spaces (defined as having a playground and a public toilet) seemed to bring an additional 'benefit' only for the competence scale.

In their study on 4- to 6-year-old children in Lithuania (already described above), Balseviciene et al. (2014) investigated the association of proximity to city parks with mental health (assessed with the parent-reported SDQ). Only parks larger than 1 ha with over 65% tree cover were included, and distances were square-root-transformed (due to a skewed distribution). The researchers found associations only for children with mothers with lower education levels: closer proximity to city parks was associated with lower levels of peer relationship problems, conduct problems, hyperactivity and inattention, and total difficulties, and with higher levels of prosocial behaviour. Noteworthy, as mentioned earlier, statistical models were not adjusted for neighbourhood SES, so findings may be confounded. However, under the assumption that the association is real and causal, results suggest that disadvantaged children may benefit more from nearby parks than advantaged children. One explanation would be that disadvantaged children depend more on nearby green spaces because they may not have the time and financial resources to visit green spaces further away or to engage in formal activities outside their own neighbourhoods (Olsen et al., 2022).

The three studies (Alderton et al., 2022; Balseviciene et al., 2014; Markevych et al., 2014) suggest that living in close proximity to public open spaces, city parks, or urban green spaces may be associated with better mental health in children. All three investigated associations in urban children (not adolescents). It is plausible that children, who typically move in a limited radius around their home, depend on nearby green spaces, especially in urban areas where much of the space is expected to be 'grey' (e.g., paved). Balseviciene et al. (2014) found this 'benefit' only in children with mothers with lower education level (i.e., disadvantaged children). These children may depend even more on proximal green spaces than children from advantaged families because they may not have the time and financial resources to visit green spaces outside their neighbourhoods. It is interesting that, in the same study, Balseviciene et al. (2014) did not find the same 'benefit' of greenness (assessed with the NDVI) for disadvantaged children (as described in the previous section). This could be explained by the quality of the greenness. It is likely that children from disadvantaged families live in disadvantaged areas where the vegetation may be of lower quality and, therefore, not as 'beneficial'. Although one could argue that the same logic applies to nearby city parks, it is important to note that the researchers only included parks larger than 1 ha with over 65% tree cover, so these parks may be of relatively high quality.

As for quantity, some studies did not find associations for proximity. In their study on 7- to 10-year-old children in Barcelona (already described in the previous section), Amoly et al. (2014) tested whether living within 300 m of a major greenspace (i.e., a greenspace of at least 0.05 km^2) was associated with children's mental health (i.e., parent-reported SDQ scores and teacher-reported ADHD symptoms). They did not find an association between the proximity of major green spaces and mental health. Similarly, in their study on obsessive-compulsive behaviours (already described in the previous section), Ezpeleta et al. (2022) did not find an association between the Euclidean distance to the nearest greenspace and obsessive-compulsive behaviours in 9- and 10-year-old children in Barcelona (neither from home nor from school). These two studies investigated similar age groups as the studies above but did not find significant associations. It is unclear whether this is due to characteristics of study samples, assessment of proximity, or even more nuanced differences, such as the choice of statistical model or adjustment for confounders. Nonetheless, the null findings indicate that an association of proximity of greenspace with children's mental health may not be robust (or may at least be highly context-specific).

In summary, a smaller number of studies has investigated the role of proximity of greenspace in children's mental health, and some found positive associations. However, again, the great heterogeneity of studies makes comparisons, and drawing general conclusions, challenging (or impossible). As with quantity, it is unclear how to best assess proximity, and it is likely that the way of assessment influences results substantially. Both measures of quantity and proximity have one major limitation: they do not capture important nuances of exposure, such as the quality of green spaces, or individual use (and usage) of green spaces. This is problematic because it is likely that nuances like these influence the association of neighbourhood greenspace with mental health and well-being. For example, 'high-quality' green spaces likely 'benefit' children and adolescents more than 'low-quality' green spaces. Further, individuals who use green spaces in their neighbourhoods more often probably 'benefit' more from these spaces than individuals who use them less often. There are possible interactions too. For example, ‘high-quality’ green spaces may be used more often than ‘low-quality’ green spaces. In the course of this review, it has become clear that we are looking at complex relationships, where merely more or closer greenspace may not always be sufficient for the protection and/or promotion of mental health and well-being. I will now review the literature on the role of greenspace quality in child and adolescent mental health and well-being. We shall see that this is even more limited than the literature on quantity and proximity.

2.3. Quality

The quality of greenspace plays a role in the association of greenspace with mental health and well-being because it likely influences each of the three main pathways to health (described in the previous chapter): mitigation, restoration, and instoration (Markevych et al., 2017). What exactly makes a greenspace ‘high-quality’ probably depends on pathway and demographic group of interest. Different people have different needs, and demographic characteristics, such as age, are important factors influencing what may be perceived as ‘high-quality’ greenspace. The construct of quality is multidimensional (Knobel et al., 2019), and which dimension matters most, or how much, depends on many factors. There may not be a single combination of dimensions that works best for everyone, and what is perceived as ‘high-quality’ is highly subjective. However, it is plausible that some dimensions, such as access and safety, are generally important.

As for quantity and proximity, there are many ways to measure quality, for example, by asking people about their subjective perceptions of a greenspace, by evaluating a greenspace on certain objective criteria/dimensions (e.g., accessibility), or by using objective site designations (e.g., ‘Site of Special Scientific Interest’). Note that, in Chapter 7, my fourth empirical chapter, I will discuss the multidimensional construct of quality in more depth. For now, it is important to remember that quality adds another layer of complexity to the association between greenspace and health and well-being. For example, a person may have a lot of greenspace in their neighbourhood or live close to a greenspace, but if that greenspace is of 'low quality', it will probably not benefit their mental health and well-being.

The role of quality in the association between greenspace and child and adolescent mental health and well-being has been understudied. Some of the studies described earlier investigated different types of land cover or land use which capture qualities (i.e., characteristics) but not the overall quality of a space. A few studies have investigated the 'broader' construct of quality, using subjective measures of *perceived* quality.

In their longitudinal study on Australian children (already described above), Feng and Astell-Burt (2017) investigated the associations of greenspace quantity and quality with mental health (assessed with the parent-reported SDQ) across childhood (from 4–5 years to 12–13 years). Greenspace quality was measured with a single item that asked parents whether there were 'good' parks, playgrounds, and/or play spaces in their neighbourhood. Children whose parents strongly agreed to this question showed fewer internalising, externalising, and total difficulties than their counterparts. For internalising and total difficulties, this association appeared to become stronger with age.

In a more recent study, using data from the same cohort study and using the same measure of quality, Feng et al. (2022) found an association with mental health also in older adolescents at the age of 16 to 17 years: availability of 'high-quality' greenspace was associated with lower levels of internalising, externalising, and total difficulties. Interestingly, there seemed to be moderation by personality: in females with the highest levels of introversion and neuroticism, the availability of 'high-quality' greenspace was associated with lower levels of internalising (but not externalising) problems.

Putra et al. (2021a), also using data from the same study, found an association with prosocial behaviour: the availability of 'high-quality' greenspace in the neighbourhood was associated with higher levels of prosocial behaviour.

The findings of the three studies above suggest that the quality of neighbourhood greenspace plays a role in mental health across childhood and adolescence. The availability of 'high-quality' greenspace in the neighbourhood was associated with fewer difficulties and higher prosocial behaviour in childhood and adolescence. However, the studies share an important limitation, i.e., that the assessment of quality was based on a single item answered by the parent. Indeed, this comes with several problems. First, parent perceptions may not reflect child perceptions, especially as children grow older and are less dependent on their parents. For example, adolescents may not have the same needs or preferences as their parents, so green spaces that their parents perceive as 'high-quality' may not actually be 'high-quality' green spaces for them. Second, the question did not ask about greenspace more generally, but about parks, playgrounds, and play spaces. Third, parents did not give any information about why they thought these spaces were 'good', which limits the implications of findings for real-world applications, such as policymaking or planning. Using more objective measures of quality, such as assessing certain dimensions or using site designations, may have greater implications for real-world solutions (especially when we look at the whole population). Again, every individual has their own subjective perception, but these individual, subjective perceptions are not well suited to inform policy or planning. Identifying objective factors and linking these to mental health and well-being, therefore, is important. We shall see in Chapter 7, my fourth empirical chapter, that assessing greenspace quality and linking it to mental health and well-being is, indeed, not at all straightforward.

Table 2.1 Summary of findings of studies included in my literature review

	Age (years)	SDQ Conduct problems	SDQ Emotional symptoms	SDQ Hyperactivity and inattention	SDQ Peer relationship problems	SDQ Total difficulties	SDQ Prosocial behaviour	Internalising problems [1]	Externalising problems [2]	Depression/psychological distress [3]	Perceived stress [4]	(Mental) well-being [5]	Other [6]
Quantity – Greenness													
Amoly et al. (2014)	7–10												
Balseviciene et al. (2014)	4–6												
Bezold et al. (2018)	-												
Bloemsma et al. (2022)	11–20												
Ezpeleta et al. (2022)	9–10												
Engemann et al. (2019)	-												
Madzia et al. (2019)	7–12												
Markevych et al. (2014)	10												
Mavoa et al. (2019)	12–19												
Thygesen et al. (2020)	-												
Wang et al. (2019)	12–17												
Younan et al. (2016)	9–18												
Yuchi et al. (2022)	-												

	Age (years)	SDQ Conduct problems	SDQ Emotional symptoms	SDQ Hyperactivity and inattention	SDQ Peer relationship problems	SDQ Total difficulties	SDQ Prosocial behaviour	Internalising problems [1]	Externalising problems [2]	Depression/psychological distress [3]	Perceived stress [4]	(Mental) well-being [5]	Other [6]
Quantity – Availability of greenspace													
Feda et al. (2015)	12–15												
Bloemsma et al. (2022)	11–20												
Feng & Astell-Burt (2017)	4–13												
Flouri et al. (2014)	3–7												
Jarvis et al. (2022)	5.6 (mean)												
Maes et al. (2021)	9–15												
Mygind et al. (2022)	2–5												
Reuben et al. (2020)	0–17												
Richardson et al. (2017)	4–6												
Weeland et al. (2019)	11–22												
Proximity													
Alderton et al. (2022)	-												
Amoly et al. (2014)	7–10												
Balseviciene et al. (2014)	4–6												
Ezpeleta et al. (2022)	9–10												

	Age (years)	SDQ Conduct problems	SDQ Emotional symptoms	SDQ Hyperactivity and inattention	SDQ Peer relationship problems	SDQ Total difficulties	SDQ Prosocial behaviour	Internalising problems [1]	Externalising problems [2]	Depression/psychological distress [3]	Perceived stress [4]	(Mental) well-being [5]	Other [6]
Markevych et al. (2014)	10												
Quality													
Feng et al. (2022)	16–17												
Feng & Astell-Burt (2017)	4–13												
Putra et al. (2021a)	4–15												

Note. This table summarises findings of studies included in my literature review. This table does not include interactions or findings from stratified analyses (except for Balseviciene et al.'s [2014] and Madzia et al.'s [2019] studies which only included analyses stratified by maternal education and age, respectively, but no analyses of whole samples). SDQ: Strengths and Difficulties Questionnaire. [1] Measured with SDQ or Behavioral Assessment System for Children (BASC-2). [2] Measured with SDQ, BASC-2, or Child Behavior Checklist (CBCL). [3] Measured with Mental Health Inventory (MHI-5), Reynolds Adolescent Depression Scale (short form; RADS-SF), Kessler psychological distress scale (Kessler-6), or anxiety/depression diagnosis. [4] Measured with the Perceived Stress Scale (PSS). [5] Measured with KIDSCREEN-10 or WHO Well-Being Index (WHO-5). [6] Includes ADHD symptoms/diagnosis, diagnosis of other psychiatric disorders, and measures of competence, early development, and obsessive-compulsive behaviours.

X Significant association suggesting a positive association between greenspace and health.

X No significant association.

X Significant association suggesting a negative association between greenspace and health.

2.4. Summary and Outlook

In the sections above, I have reviewed the literature on the associations of neighbourhood greenspace with children's and adolescents' mental health and well-being, focusing on quantity, proximity, and quality of greenspace. I showed that most studies to date have used a measure of quantity, measuring either the greenness of an area or the availability (i.e., proportion) of greenspace in the neighbourhood. Fewer studies have investigated the role of proximity, and even fewer the role of quality. Although most studies that investigated quantity and proximity found positive associations with mental health and well-being, the findings seemed to be context-specific and depended on exposures, outcomes, demographics, and geographies (also highlighted in Table 2.1). Despite some studies not finding associations, it is probably safe to conclude that there is some association between greenspace quantity and proximity and children's and adolescents' mental health and well-being. Due to the great heterogeneity of studies, however, it is impossible to draw conclusions about what types of exposures are associated with what outcomes, where, and in whom.

In addition to inconsistent findings and, therefore, inconclusive evidence, the studies reviewed above share a main limitation regarding the possibility for causal inferences. All studies used observational data, and most used a cross-sectional design, which makes inferences about causality challenging because reverse causality and confounding cannot be ruled out. All studies accounted for some confounders, but some studies did not include important confounders (e.g., proxy variables for individual or neighbourhood SES). Probably all studies needed to accept residual confounding to some extent. In addition, some studies were prone to selection bias (because they did not account for selective attrition over time) and may, therefore, not be representative of the general population. Moreover, all studies will have encountered some level of information bias, especially due to exposure misclassification bias, a common problem in place and health studies (as I will discuss in more depth in later chapters).

In consideration of the inconsistencies across studies, and the risk for confounding, selection, and information bias, the evidence must be interpreted with caution. Further, it should have become clear that there are substantial gaps in the literature and that many open questions remain. I will now describe the three main ways in which I will address some of these gaps. An overview of my specific research questions is provided in Table 2.2 at the end of this chapter. These will be repeated in my empirical chapters.

First, I will investigate the association in both children and adolescents. This is important because, needs, interests, and behaviours change with age (or development), so the association between neighbourhood greenspace and mental health and well-being will probably differ. Similarly, I will investigate associations with several outcomes. This is important because mental health and well-being are related but distinct, complex, multidimensional constructs, and associations with neighbourhood greenspace are probably not the same across dimensions. Moreover, most studies investigated mental health, but only few investigated well-being as a separate construct. In my review, I have already shown that associations may differ by age and outcome, so investigating a range of both is important to understand better the nuances of the association.

Second, I will investigate exposures beyond mere quantity or proximity. I will use data on different types of green spaces and investigate their roles in children's and adolescents' mental health and well-being. Further, I will use an objective measure of quality to assess whether living near green spaces with 'high ecological quality' is associated with better mental health and well-being in adolescents. In my literature review, I have highlighted that we have a limited understanding of the nuances of associations, so assessing the roles of more detailed exposures is crucial.

Third, I will investigate the roles of other factors in the association of neighbourhood greenspace with children's and adolescents' mental health and well-being. This is important because it is likely that the association is not 'generic', or universal, but context-specific. I will investigate factors that could influence children's and adolescents' use of neighbourhood greenspace and therefore moderate its association with mental health and well-being. Studies on place and health tend to focus on the spatial dimension of exposure. However, the temporal dimension (e.g., the frequency and length of visits) is important too. As this dimension tends to be more difficult to measure, assessing factors that may affect use of green spaces is an important step forward.

In the next chapter (Chapter 3), I will provide an overview of my methodology, including conceptualisations of ‘neighbourhood greenspace’ and ‘mental health and well-being’, descriptions of primary datasets, and an outline of my analytic strategy. I will also provide an overview of the main characteristics of my four studies. Thereafter, the empirical part of my thesis will start with a study on the association between neighbourhood greenspace quantity and self-regulation in early childhood (Chapter 4). Then, I will investigate the association between neighbourhood greenspace quantity and well-being in young adolescents, exploring modification and moderation by other factors, i.e., private garden access, perceived area safety, and physical activity (Chapter 5). In my third study, I will look at the associations of different types of green spaces with mental health and well-being in children and adolescents living in London (Chapter 6). Finally, I will investigate the associations between perceived neighbourhood quality and access to ‘high-quality’ green spaces, and adolescent mental health and well-being in London (Chapter 7). After the empirical part of my thesis, I will provide a general discussion of my studies, in light of the existing literature and my studies’ limitations. I will also make suggestions for future research and discuss potential implications for policy and planning (Chapter 8).

Table 2.2 Overview of research questions

Study 1 (Chapter 4) 1. Is there an association of neighbourhood greenspace quantity with young children's self-regulation?
Study 2 (Chapter 5) 1. Is there an association of neighbourhood greenspace quantity with young, urban adolescents' mental well-being? 2. Is this association modified or moderated by other factors that may affect young, urban adolescents' use of green spaces?
Study 3 (Chapter 6) 1. Is there an association between neighbourhood greenspace quantity and children's and adolescents' mental health and well-being? 2. Is this association different for different measures of greenspace (i.e., proportions of green land cover, green land use, parks & gardens, natural & semi-natural urban greenspaces, and outdoor sports facilities)?
Study 4 (Chapter 7) 1. Does perceived neighbourhood quality moderate the association between neighbourhood greenspace and adolescents' mental health and well-being? 2. Is there an association between access to 'high-quality' green spaces (i.e., living within or beyond 1,000 m from 'high-quality' green spaces) and adolescents' mental health and well-being?

Note. Research questions will be repeated in each of the four empirical chapters.

3. Methodology

In the previous two chapters, I have highlighted the importance of this area of research and provided a review of the literature. These two chapters are the basis for my thesis. Before I will present my four empirical chapters, I will provide an overview of my methodology, including conceptualisations of ‘neighbourhood greenspace’ and ‘mental health and well-being’, an overview of the primary datasets I will use in my thesis, and a description of my analytic strategy. Note that more detailed information on primary (and additional) datasets and more specific methodological decisions for each study will be provided in my four empirical chapters (Chapters 4 to 7). Discussions of the impact and limitations of certain decisions will also be provided in the empirical chapters and in my general discussion in Chapter 8. This chapter is intended to provide a broader overview of important concepts, primary datasets, and analytic strategy for my thesis.

3.1. Conceptualisations

In the study of the association between neighbourhood greenspace and children’s and adolescents’ mental health and well-being, it is important to conceptualise ‘neighbourhood greenspace’ and ‘mental health and well-being’, both of which are complex concepts that are used in the literature in many ways (as illustrated in my literature review in Chapter 2). Due to this complexity, it is probably impossible to develop (accurate) universal definitions of these concepts that apply across contexts. Therefore, I will now describe how I conceptualise ‘neighbourhood greenspace’ and ‘mental health and well-being’ in the context of my thesis.

Neighbourhood Greenspace

For the conceptualisation of my primary exposure of interest, neighbourhood greenspace, I will conceptualise both ‘neighbourhood’ and ‘greenspace’, starting with the latter. In the literature, there exist many definitions and conceptualisations of greenspace (L. Taylor & Hochuli, 2017). What is considered ‘greenspace’ varies between studies, and alternative terms are used, such as ‘greenness’, ‘greenery’, or ‘vegetation’. Sometimes, also more specific measures are used that capture only a certain type of greenspace or greenery, such as parks or trees. In a review of the different uses of the term ‘greenspace’, Taylor and Hochuli (2017) found that most studies did not provide a definition of greenspace. However, across studies that did define greenspace, they identified two themes: ‘greenspace as nature’ and ‘greenspace as urban vegetation’. To illustrate the scope of the term ‘greenspace’, the following definition by Public Health England may be useful (Public Health England, 2020, p. 6):

> ‘[Greenspace is] any area of vegetated land, urban or rural. This includes both public and private spaces such as parks, gardens, playing fields, children’s play areas, woods and other natural areas, grassed areas, cemeteries and allotments, green corridors, disused railway lines, rivers and canals, [and] derelict, vacant and contaminated land which has the potential to be transformed.’

Here, greenspace is defined as any area of vegetated land. Taylor and Hochuli (2017), however, describe that the term ‘greenspace’, as used in the literature, can also refer to open space that is not vegetated. In studies where greenspace does refer to green (vegetated) space, the operationalisation of greenspace varies, as highlighted in my literature review in Chapter 2. Some studies use subjective data, such as perceived greenness; other studies use objective data, such as the proportion of a certain green land use or green land cover, or the greenness of an area; some studies may also use a combination of subjective and objective data. In other words, what exactly a measure of greenspace captures varies, and there is no universal definition of the concept of greenspace (L. Taylor & Hochuli, 2017).

In this thesis, I use the term ‘greenspace’ broadly to refer to vegetated land. However, I will use different operationalisations in my four studies that are based on different (combinations of) data. These operationalisations range from open space data (where the type of space or land use is known but the level of greenness is unknown) to data on green land cover (where the type of space or land use is unknown). For each of my four studies, I will describe the data used in detail in the Methods section (Chapters 4 to 7).

In addition to describing the type of data used to measure greenspace, it is also important to describe how exposure to this type of greenspace is measured. There are many ways to assess people's exposure to greenspace (Davis et al., 2021; Holland et al., 2021; Labib et al., 2020). Exposure to neighbourhood greenspace, for example, could be measured as the proportion of greenspace around the home, the proximity of the closest greenspace, or views of greenspace from the home. How exactly exposure is measured, however, varies between studies, as I have highlighted in my literature review in Chapter 2. For example, proximity could be measured as the Euclidean (straight-line) distance, or as the network distance to the boundary, centroid, or closest point of access of the nearest greenspace. It is important to note that any metric can only approximate children's and adolescents' true exposure. For example, a higher proportion of greenspace in an area would suggest more exposure to greenspace, but this is not necessarily true. A higher proportion of neighbourhood greenspace does not mean that children and adolescents visit and use these spaces. There may be individual, social, physical, or other barriers to exposure, so some may not be exposed to greenspace as much as others (Public Health England, 2020).

In the *Cambridge Dictionary*, exposure is defined as 'the fact of experiencing something or being affected by it because of being in a particular situation or place' (*Exposure*, 2023). In the context of my thesis, exposure, therefore, means 'experiencing' greenspace or 'being affected by' greenspace due to living in a certain neighbourhood. This conceptualisation is inclusive of the many different forms of exposure. For example, one could think of exposure as purposeful (intentional) visits to greenspace, or as incidental (unintentional) exposure (Mears et al., 2021). Further, one could think of exposure as direct contact with greenspace, or as indirect, passive exposure (e.g., by breathing cleaner air). In this thesis, I will use quantity and proximity of neighbourhood greenspace as proxies for children's and adolescents’ exposure to greenspace. I will discuss limitations of this approach throughout my four empirical chapters (Chapters 4 to 7) and in the general discussion of my thesis (Chapter 8).

In addition to deciding how to conceptualise greenspace and how to measure exposure, one must define the exposure area, i.e., where to measure exposure. Children and adolescents spend their days in different places where they are exposed to different levels and types of greenspace. Furthermore, they spend a different amount of time in each of these places, where they interact with different people and participate in different activities. Therefore, children’s and adolescents’ environments are dynamic, and this makes measuring true exposure to greenspace difficult (if not impossible). In fact, defining the geographic context and the spatial scale of exposure is a challenge widely recognised in the study of place and health (Kwan, 2012; Labib et al., 2020; Nuckols et al., 2004; Perchoux et al., 2016).

In this thesis, the exposure area of interest is the residential neighbourhood, one of the environments that children and adolescents are exposed to the most. Social and physical factors of the residential neighbourhood, therefore, have the potential to influence children’s and adolescents’ development and health. However, how is the ‘residential neighbourhood’ defined? This question is a long-standing one, and there is no universal answer to it (Chaix et al., 2009; Guest & Lee, 1984; Perchoux et al., 2016; Spielman & Yoo, 2009). Formally, we could distinguish three conceptions of neighbourhoods: spatial, social, and institutional (Guest & Lee, 1984). However, ultimately, every individual has their own definition of their own neighbourhood, and, because there is no universal definition, operationalisations of neighbourhoods in the literature tend to be arbitrary (Chaix et al., 2009; Perchoux et al., 2016). Researchers typically use territorial (allocentric) definitions (e.g., administrative areas) or ego-centric definitions (e.g., circular buffers around homes). Consequently, neighbourhoods, as defined and delineated in the existing literature, vary in form and function.

In this thesis, I use the term 'neighbourhood' to refer to the area around the home that children and adolescents are likely to be exposed to. I use allocentric definitions (e.g., electoral wards) and egocentric definitions (e.g., circular buffers around postcodes). Again, I will discuss the limitations of this approach throughout my empirical chapters (Chapters 4 to 7) and in my general discussion in Chapter 8.

Mental Health and Well-Being

The World Health Organization (WHO) argues that 'mental health is more than the absence of mental illness' and defines mental health as 'a state of well-being in which the individual realizes his or her own abilities, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to his or her community' (World Health Organization, 2004, p. 12). While it is widely recognised that mental health is not simply the absence of mental illness but that there is a whole spectrum of psychological functioning, there still is no consensus about the definition of mental health, and, in fact, many scientists disagree with the WHO definition (Huber et al., 2011). Some criticise that positive feelings should not be identified as a key factor of mental health because negative feelings are 'part of a fully lived life' (Galderisi et al., 2015). In a survey on the core concepts of mental health that was completed by 50 international participants with expertise in mental health, only 20% were satisfied with the WHO definition (Manwell et al., 2015). Forty-six per cent preferred the following definition by the Public Health Agency of Canada (PHAC): 'Mental health is the capacity of each and all of us to feel, think, and act in ways that enhance our ability to enjoy life and deal with the challenges we face. It is a positive sense of emotional and spiritual well-being that respects the importance of culture, equity, social justice, interconnections and personal dignity.' (Public Health Agency of Canada, 2006, p. 2). Noteworthy, 30% of the experts were not satisfied with either of the above (or with two other definitions provided in the survey; Manwell et al., 2015).

For my thesis, I conceptualise mental health as a spectrum of psychological functioning that is indexed by emotional and behavioural outcomes. Poor emotional and/or behavioural outcomes are correlates of mental health problems and disorders. Although the experience of negative emotions and the engagement in problem behaviour are part of healthy child development, some children and adolescents have more difficulties than others, even if they do not meet criteria for a clinical diagnosis of a mental health disorder. Therefore, emotional and behavioural problems can be used as indicators of mental health problems, and this is the approach I will take in this thesis. To this end, I will use the Strengths and Difficulties Questionnaire (SDQ; Goodman, 1997; Goodman et al., 1998), a multi-dimensional, validated, and commonly used measure of children's mental health (Studies 3 and 4). I will also use a measure of self-regulation as a proxy for children's mental health (Study 1).

Before I move on to describing primary datasets and analytic strategy, I would like to make a remark about the definition of well-being. Health and well-being are related but distinct concepts (Patalay & Fitzsimons, 2016). The WHO and PHAC definitions of mental health above use well-being as an indicator of mental health. Although it is true that poor mental well-being can contribute to, and be a symptom of, poor mental health (Steptoe, 2019), an individual can be healthy and well-functioning but still feel unwell (Galderisi et al., 2015). Therefore, it makes sense to distinguish between health and well-being (even if the concepts are complex and definitions are not clear).

Terms used in the literature to describe dimensions of well-being include 'subjective well-being', 'psychological well-being', 'happiness', 'life satisfaction', and 'positive and negative affect'. Steptoe (2019) distinguishes between affective (or hedonic) well-being (i.e., positive moods and feelings), eudaimonic well-being (i.e., judgments about the realisation of personal potential and the fulfilment of life goals), and evaluative well-being (i.e., judgments about the quality and goodness of life or satisfaction with life). Probably the most common distinction in the literature, however, is made between hedonic and eudaimonic well-being. Dodge et al. (2012, p. 230) criticised that most attempts of capturing 'well-being' were descriptions (and not definitions) and attempted to define well-being: 'In essence, stable wellbeing is when individuals have the psychological, social and physical resources they need to meet a particular psychological, social and/or physical challenge.' However, despite the appeal of a simple definition, descriptive measures of more specific concepts (e.g., happiness, or positive and negative affect) may be useful and, indeed, necessary to be able to assess well-being in practice. In this thesis, I will use measures of happiness (Studies 2, 3, and 4), and positive and negative mood (Study 2) to measure different aspects of hedonic well-being. I will also use a measure of self-esteem as a proxy for well-being (Studies 2, 3, and 4).

Before I move on to describing primary datasets and analytic strategy, three points are important to remember. First, there is a spectrum (or continuum) of mental health and well-being. Second, mental health and well-being are not stable but dynamic. Risk factors can 'move' the individual towards ill-health and feeling unwell, whereas positive and protective factors can 'move' the individual towards better health and well-being. Finally, mental health and well-being are related but distinct concepts. In this thesis, measures of mental health (i.e., dimensions of self-regulation, and the SDQ) focus primarily on children's and adolescents' functioning, whereas measures of well-being (i.e., happiness, mood, and self-esteem) focus primarily on experiences of, or feelings about, one's life and oneself.

3.2. Overview of Datasets

Outcome Data

The association between neighbourhood greenspace and children's and adolescents' mental health and well-being can be investigated in different ways. For this thesis, I chose to use observational data to investigate the association. Specifically, I will use secondary data from large, longitudinal studies that follow children and households in the United Kingdom (UK) over time. Based on the experience of my research group with longitudinal studies in the UK, I chose to work with data from two studies. In Studies 1 and 2 (Chapters 4 and 5), I will use data from the UK Millennium Cohort Study (MCS; *Millennium Cohort Study*, n.d.). In Studies 3 and 4 (Chapters 6 and 7), I will use data from Understanding Society, the UK

Household Longitudinal Study (UKHLS; *Understanding Society – The UK Household Longitudinal Study*, n.d.). The MCS is a birth cohort study that started around the year 2000 and includes data on over 19,000 children (Sweep 1). The UKHLS is a household study that started around the year 2010 and includes data on the members of approximately 40,000 households (Wave 1). MCS and UKHLS are both ongoing.

MCS and UKHLS are suitable studies for my thesis for three main reasons. First, they include variables on children's and adolescents' mental health and well-being (my outcomes of interest). Second, they include, or allow the linkage of, neighbourhood greenspace variables (my exposure of interest). The MCS includes a variable on neighbourhood greenspace quantity. This is relatively rare because multi-purpose studies like the MCS often do not include data on the neighbourhood physical environment. For example, Understanding Society does not provide a measure of neighbourhood greenspace. However, it is possible to access sensitive data on the postcodes of households included in the UKHLS, in order to link external neighbourhood physical environment variables to the UKHLS main data. This is the approach that I will take in Studies 3 and 4. Finally, an additional reason for using MCS and UKHLS data is that the members of my research group have substantial experience with these studies. For example, the decision to change from using the MCS in Studies 1 and 2 to using the UKHLS in Studies 3 and 4 was motivated by the experience of members of our research group that getting access to sensitive MCS data takes much longer than getting access to sensitive UKHLS data. Considering the limited time frame of my PhD, it therefore made sense to change datasets.

Exposure Data

As mentioned in the previous paragraph, the MCS includes a variable on neighbourhood greenspace quantity. This variable was taken from the Multiple Environmental Deprivation Index (MEDIx; *MEDIx and MEDClass*, 2010). The MEDIx provides a measure of the quantity of greenspace in every UK ward, and this measure was linked to the MCS. A ward is a geographic unit in the UK that is based on electoral boundaries. I will use this measure of neighbourhood greenspace quantity as my exposure variable in Studies 1 and 2 (Chapters 4 and 5). I will describe it in more detail in my first empirical chapter (see section 4.2).

In Studies 3 and 4 (Chapters 6 and 7), I will create my own exposure variables that I will link to UKHLS data. The two key datasets I will use to create my own exposure variables are Greenspace Information for Greater London (GiGL) open space data (*Greenspace Information for Greater London CIC*, n.d.), and London Green and Blue Cover data (*London Green and Blue Cover - London Datastore*, n.d.). The GiGL open space dataset includes data on all open spaces in London, including information on type of open space and other non-spatial attributes, such as site access and site designations. I decided to use the GiGL open space data because it provides comprehensive information that will allow me to address my research questions in Studies 3 and 4. In addition, I will use London Green and Blue Cover data. The London Green and Blue Cover dataset has a high resolution and provides information on all natural areas in London, including even small areas of vegetation. Therefore, it is a good complement to GiGL data, and I will use it to measure the greenness of a neighbourhood. Note that, for Studies 3 and 4, I changed the level of geography from ward to Lower Layer Super Output Area (LSOA) and postcode. The LSOA is a unit of Census geography in the UK. On average, an LSOA is smaller in population and area than a ward and, therefore, allows for a more accurate exposure assessment. The postcode is an even smaller unit of geography.

This section provided a brief overview of the key datasets I will use in my thesis. I will provide more information on MCS, UKHLS, GiGL, and London Green and Blue Cover datasets, and how I use these to measure outcomes and exposures, in my empirical chapters (Chapters 4 to 7).

3.3. Analytic Strategy

In all my four studies, I will use observational data from large-scale, longitudinal studies to investigate the association between neighbourhood greenspace and children's and adolescents' mental health and well-being in the UK. MCS and UKHLS provide data on the mental health and well-being of children and adolescents in the UK. Combined with data on availability, accessibility, and quality of greenspace, these studies allow me to investigate my research questions which are summarised in Table 2.2 at the end of the previous chapter.

General Analytic Strategy

To test the hypotheses linked to my research questions, which I will provide in each of my four empirical chapters, I will run linear regression models. In Study 1, I will run a multilevel model with three levels (i.e., observations, individuals, and neighbourhoods). This is a suitable model because the sample in this study was followed over three time points, so multiple observations (level 1) were clustered in children (level 2), and children (level 2) were clustered in neighbourhoods (level 3). In Studies 2 to 4, I will use linear regression models with one level. In these studies, observations were not clustered in individuals because every individual contributed only one observation to each model. However, I will use a survey design variable, the primary sampling unit (PSU), to account for clustering of children and adolescents in PSUs. For this, I do not have to add a second level to my models but, instead, can declare the survey design (i.e., primary sampling unit, strata, and weight) before running statistical analyses.

To summarise, I will use linear regression models (multi-level or single-level) to investigate the association between neighbourhood greenspace and children's and adolescents' mental health and well-being. Noteworthy, using secondary, observational data to study this association comes with challenges. I will use the next sections to describe how I address these challenges in my thesis: confounding, selection bias and information bias, and limited data availability. Many of my decisions across my four studies had to do with these challenges, so it is worth describing them prior to my four empirical chapters. After describing the more general analytic strategy, I will describe and justify some of my study-specific decisions.

Confounding

One major challenge of observational studies is the ability to make causal inferences. One reason for this is confounding bias. Confounding bias refers to bias introduced by a variable that causes both exposure and outcome (Porta, 2014). One way to minimise confounding bias is the adjustment of statistical models for confounding variables. This is a strategy that I will use in all my four studies. I will adjust linear regression models for confounding variables at neighbourhood and individual (or family) levels that I have identified based on theoretical assumptions and the existing literature.

I will consider three neighbourhood-level confounders in this thesis: neighbourhood deprivation, air pollution, and urbanicity. All three are associated with both neighbourhood greenspace and mental health and well-being. For example, neighbourhood socio-economic position (SEP) is related to neighbourhood greenspace: high-SEP areas tend to have more greenspace than low-SEP areas (Schüle et al., 2017). At the same time, neighbourhood deprivation is related to health: people living in more deprived areas have poorer health than people living in less deprived areas (Jivraj et al., 2020). In other words, neighbourhood socio-economic status (or deprivation) is linked to both neighbourhood greenspace and health, and may explain the association between neighbourhood greenspace and mental health and well-being. Variables related to neighbourhood socio-economic status (or deprivation) should therefore be adjusted for in statistical models to minimise confounding bias. The same applies to air pollution and urbanicity.

I will also consider confounders at individual (or family) level: maternal mental health, maternal education, housing tenure, family structure, and ethnicity. These variables tend to influence where families live and, therefore, levels of greenspace. They are also associated with children's and adolescents' mental health and well-being. For example, individuals with poor health are more likely to move to high-poverty neighbourhoods than individuals with good health (Rolheiser et al., 2022). As described earlier, high-poverty (low-SEP) neighbourhoods are likely to have lower levels of greenspace. At the same time, children of mothers with poor mental health are more likely to experience mental health problems than children of mothers with good mental health (Meadows et al., 2007). Therefore, maternal mental health may be linked to neighbourhood selection and neighbourhood greenspace, and to children's and adolescents' mental health and well-being. Maternal mental health should therefore be adjusted for in statistical models to minimise confounding bias. The same applies to variables measuring socio-economic status, such as maternal education, housing tenure, or family structure. In all my four studies, I will control for confounders at neighbourhood, family, and individual levels. However, because residual confounding remains a problem, I will revisit limitations regarding observational data and causality in my general discussion in Chapter 8 (see section 8.3).

Selection Bias and Information Bias

I will now describe two additional biases that are, together with confounding bias, the most relevant in the context of my thesis: selection bias and information bias. Selection bias refers to bias that results from the selection of participants into a study and from factors that may influence participation in the study (Porta, 2014). The result of selection bias are systematic differences between participants in the study and the real-world population. In other words, selection bias means that participants in the study are not representative of the real-world population. A special type of selection bias is attrition bias due to selective loss to follow-up. In longitudinal studies, attrition occurs when participants leave a study. In turn, attrition bias refers to systematic differences between participants who continue a study and participants who leave a study (Catalogue of Bias Collaboration et al., 2017). Bias introduced by selection into a study or by selective attrition can be minimised, for example, by using study weights. Using study weights helps to keep the study sample representative of the real-world population. Both MCS and UKHLS provide study weights which I will use in all my four studies.

Information bias refers to bias due to measurement errors (Porta, 2014). Measurement errors can occur during collection, recall, or handling of data (Catalogue of Bias Collaboration et al., 2019). In this thesis, outcomes and exposures were prone to measurement error. All outcome variables were parent- or self-reported. Parent- and self-reports may be biased due to social desirability, or due to the inaccurate recall of events or situations. Another source of information bias are my exposure variables, where definitions of greenspace, exposure, and exposure area can lead to (exposure) misclassification (Catalogue of Bias Collaboration et al., 2018). In Studies 1 and 2, I will be limited to a pre-defined variable of greenspace quantity at ward level. This means that I do not have control over the type of greenspace included or the geographic unit used. In Studies 3 and 4, however, I will aim to minimise exposure misclassification bias by using smaller geographic units (i.e., LSOAs and postcodes) and by considering the radius in which children and adolescents might move around their neighbourhoods. Nevertheless, exposure misclassification bias remains an issue that needs to be considered in the interpretation of results. I will discuss the issue of measurement error generally, and exposure misclassification specifically, in my general discussion in Chapter 8 (see section 8.3).

Another source of information bias that I should note are missing data on exposures, outcomes, and covariates (Catalogue of Bias Collaboration et al., 2019). I will address the issue of missing data by using study weights and/or multiple imputation where appropriate. I will describe this strategy in more detail in the Methods sections of my four empirical chapters.

Limited Data Availability

An additional challenge is limited data availability. MCS and UKHLS are multi-purpose studies that cover a broad range of aspects of children's and adolescents' lives. This means that there are data on a wide range of variables. It also means that there may be limited data on the specific outcomes, exposures, and covariates of interest. For example, in longitudinal population studies, data on the physical environment are typically scarce. These studies have limited resources, and aspects other than the physical environment may be prioritised. Similarly, although mental health and well-being are typically of interest, large-scale, longitudinal population studies need to decide what aspects of mental health and well-being to focus on.

They often also need to limit the number of items included and sometimes do not measure a specific outcome at every time point in the study. In other words, using secondary data means that one must make compromises and accept associated limitations. In Studies 3 and 4, I could address this, to some extent, by linking my own exposure variables to UKHLS main data. However, as we shall see, throughout my thesis, I will make several compromises related to my outcomes (e.g., accepting a limited number of items) and exposures (e.g., accepting a geographic unit). I will acknowledge and discuss associated limitations throughout my empirical chapters and in my general discussion in Chapter 8.

Study-Specific Decisions

In the previous section, I have described my general analytic strategy that applies across my four studies. An overview of my four studies and their main characteristics is provided in Table 3.1 at the end of this chapter, illustrating a few important differences between them. I will now briefly describe and justify these more specific decisions related to each of my four studies. Please note that I will revisit study-specific decisions in the Methods sections of my four empirical chapters.

Study 1

In my first study, I will investigate the association between neighbourhood greenspace quantity and self-regulation in early childhood. The development of self-regulation is an integral part of child development and associated with several immediate and long-term outcomes. I will investigate whether neighbourhood greenspace, a modifiable physical environment factor, may be associated with self-regulation in young children in the UK. To this end, I will use data from the MCS. In the MCS, self-regulation was measured with two scales (independence and emotional dysregulation) at ages 3, 5, and 7 years. Neighbourhood greenspace quantity was measured with a variable provided by the MEDIx. The MEDIx variable includes information on the quantity of greenspace for each UK ward. For the MCS, raw data were transformed into deciles, a standard procedure to avoid the identification of MCS families. Because the greenspace variable is already linked to the MCS, I do not have control over the type of greenspace included or the definition of the residential neighbourhood (i.e., the level of geography at which greenspace was measured). I will discuss the limitations of a greenspace variable at ward level in the Discussion section of my first empirical chapter (see section 4.4). The great advantage of an already linked greenspace variable is that I do not have to apply for sensitive data, or create and link my own exposure variables. Therefore, I could start with investigating an interesting and relevant research question while applying for sensitive data for Studies 3 and 4.

Study 2

In my second study, I will investigate the association between neighbourhood greenspace quantity and well-being in early adolescence. As described earlier, most studies in children and adolescents investigated mental health, not well-being. Considering that mental health and well-being are related but distinct concepts, it is important to also investigate the association between greenspace and well-being. In my second study, I assess this in a sample of young adolescents in the UK. As in my first study, I will use data from the MCS. In the MCS, children completed their own questionnaire for the first time at the age of 7 years. However, this questionnaire includes a very limited number of items on well-being. The child self-completion questionnaire at age 11 years, on the other hand, includes relevant items on self-esteem, happiness, positive and negative mood, and antisocial behaviour, which I will use as outcomes in my second study. Neighbourhood greenspace quantity will be measured with the same variable as in my first study. Noteworthy, in addition to main ‘effects’ of neighbourhood greenspace on outcomes, I will also investigate interactions of neighbourhood greenspace with private garden access, perceived area safety, and physical activity, some of the contextual variables that may play a role in the association between greenspace and health. Therefore, compared to Study 1, the outcome and age group of interest will change, and I will add interactions. However, the exposure variable will be the same. One additional change should be noted: I will focus my analysis on adolescents who live in urban areas in the UK and who had never moved until the age of 11 years. In

Study 1, I find that neighbourhood greenspace may affect outcomes in urban and rural children differently. Therefore, to reduce noise, and considering that the vast majority of MCS children lives in urban areas (around 80%), I decided to focus on urban adolescents in Study 2. This also makes sense because, in Studies 3 and 4, I will investigate associations in children and adolescents in London, the largest urban area in the UK. Moreover, because I will investigate associations in 11-year-olds, I decided to only include adolescents who had never moved. This reduces potential noise introduced by changes in neighbourhood and neighbourhood greenspace due to household move. I will discuss limitations associated with this approach in the Discussion section of my second empirical chapter (see section 5.4).

Study 3

In my third study, I will investigate the associations of different types of green spaces with the mental health and well-being of children and adolescents living in London. Most studies to date have used a relatively crude measure of greenness or availability of greenspace. In this study, I will address this gap in the literature by investigating different types of green spaces. To this end, I will use data from the UKHLS. As mentioned earlier, I decided to switch to using the UKHLS because it is easier to access sensitive (postcode) data in the UKHLS than in the MCS. The UKHLS includes data on children (0 to 9 years) and adolescents (10 to 15 years). Data on children under the age of 10 years are reported by the parents. The outcome of interest, the SDQ, is only available for children at the age of 5 and 8 years. Adolescents in the UKHLS (10- to 15-year-olds) complete a youth questionnaire that includes items on SDQ, self-esteem, and happiness. This will allow me to investigate both mental health and well-being in adolescents. In this study, I will create and link my own exposure variables based on open space data provided by GiGL and London Green and Blue Cover data. GiGL provide rich information on open spaces in London, including information on site access and site designations. Because of this comprehensive data, I decided to use GiGL open space data and focus my third project on London (not the whole of the UK). An additional advantage of creating and linking my own exposure variables is that I have more control over the types of green spaces that I will include in my measures and, crucially, the unit or level of geography. The UKHLS offers access to LSOAs (under a special licence) and postcodes (under secure access), and this will allow me to create greenspace variables at smaller levels of geography (compared to the UK ward in Studies 1 and 2). I will describe my exposure variables in more detail in the Methods section of my third empirical chapter (see section 6.2). Limitations of my decisions will be discussed in the Discussion section (see section 6.4).

Study 4

In my fourth study, I will investigate the moderating role of perceived neighbourhood quality in the association between neighbourhood greenspace and adolescents' mental health and well-being (Part A). I will also investigate the association between access to 'high-quality' greenspace and adolescents' mental health and well-being (Part B). As in my third study, I will use data from the UKHLS (on the same outcomes), and I will focus on London. In Part A, I will use the same exposure variables as in Study 3, but I will add interactions with 'perceived neighbourhood quality', investigating another contextual variable that may play a role in the association between greenspace and health. In Part B, I will use a different exposure variable which assesses whether adolescents have good or poor access to green spaces with 'high ecological quality'. This variable is based on so-called Areas of Deficiency (AoDs) in Access to Sites of Importance for Nature Conservation (SINCs), provided by GiGL. SINCs are green spaces that are designated for their importance for the local habitat; they are an important part of London's biodiversity. AoDs are areas from which people have to walk more than 1,000 m to reach a SINC of Metropolitan or Borough importance. People who live in an AoD, therefore, may have poor access to green spaces with 'high ecological quality'. I will describe my exposure variable in more detail in the Methods section of my fourth empirical chapter (see section 7.2). Two more differences compared to Study 3 should be noted. First, I will focus on adolescents. This is because, for Part A, self-reported data on 'perceived neighbourhood quality' are not available for children. Note that, for Part B, I will run a supplementary analysis on children. Second, to create my exposure variables, I will use postcode data only and omit LSOA data. This is because postcodes are a smaller unit of geography and provide more accurate information on where adolescents live. Again, a discussion of limitations of my decisions will be provided in the Discussion section of my fourth empirical chapter (see section 7.4).

3.4. Summary and Outlook

In this chapter, I provided an overview of important conceptualisations, primary datasets, and my analytic strategy. In summary, across my four studies, I will run linear regression models to investigate the association between neighbourhood greenspace and children's and adolescents' mental health and well-being. I will adjust these models for important confounders, and consider and account for potential selection and information bias (e.g., using study weights). In addition to describing my general analytic strategy, I provided an overview of the main characteristics of each of my four studies, and justifications for changes across studies. Importantly, a comprehensive overview of study-specific methods, including information on samples, outcomes, exposures, covariates, and statistical analyses will be provided in the Methods sections of my four empirical chapters (where I will describe and justify decisions beyond the scope of this Methodology chapter). In the next chapter, I will present my first empirical study on the association between neighbourhood greenspace quantity and self-regulation in early childhood.

Table 3.1 Overview of main study characteristics

		Study	Age	Region	Geography	Exposure	Outcome	Moderator
Study 1 (Chapter 4)		MCS	3–7 years	UK	wards	MEDIx greenspace deciles	Self-regulation (independence, emotional dysregulation)	-
Study 2 (Chapter 5)		MCS	11 years	UK (urban)	wards	MEDIx greenspace deciles	Mental well-being (self-esteem, happiness, positive mood, negative mood, antisocial behaviour)	Private garden access, perceived area safety, physical activity
Study 3 (Chapter 6)		UKHLS	5–15 years	London	LSOAs, postcodes	% green land cover, green land use	Mental health (SDQ), mental well-being (self-esteem, happiness)	-
Study 4 (Chapter 7)	**Part A**	UKHLS	10–15 years	London	postcodes	% green land cover, green land use	Mental health (SDQ), mental well-being (self-esteem, happiness)	Perceived neighbourhood quality
	Part B					AoDs in access to SINCs		-

Note. UK = United Kingdom, LSOA = Lower Layer Super Output Area, MCS = Millennium Cohort Study, UKHLS = UK Household Longitudinal Study, MEDIx = Multiple Environmental Deprivation Index, AoD = Area of Deficiency, SINC = Site of Importance for Nature Conservation, SDQ = Strengths and Difficulties Questionnaire.

4. Neighbourhood Greenspace and Self-Regulation in Early Childhood

Abstract

I investigated the association between neighbourhood greenspace and self-regulation in early childhood. The development of self-regulation is an integral part of healthy child development and has been linked to immediate outcomes and to outcomes later in life. Self-regulation is related to several outcomes studied in the extant literature (e.g., conduct problems, hyperactivity and inattention, and mood), but few studies have investigated the association between neighbourhood greenspace and children's self-regulation directly.

In this study, I investigated the association of neighbourhood greenspace quantity with self-regulation in young children, using data from the UK Millennium Cohort Study (MCS), a large general-population birth cohort study. Self-regulation was measured with two scales, i.e., independence and emotional dysregulation. Neighbourhood greenspace quantity was defined as the proportion of greenspace at UK ward level. I modelled trajectories of independence and emotional dysregulation for 13,774 children across ages 3, 5, and 7 years, using growth curve models. In fully adjusted models, I included neighbourhood air pollution, deprivation, and urbanicity; factors of the home physical environment; and family- and child-level confounders.

Some factors of the home physical environment were linked to self-regulation. For example, higher levels of damp and condensation, and the presence of secondhand smoke were associated with higher levels of emotional dysregulation. I did not find an association of neighbourhood greenspace quantity with either dimension of self-regulation.

My findings suggest that proximal physical environment factors may play a greater role in children's self-regulation capacity than the availability of greenspace in the neighbourhood.

4.1. Introduction

Self-regulation is the capacity to plan and adapt cognitions, emotions, and behaviours in order to achieve personal goals (Heatherton & Baumeister, 1996; McClelland et al., 2010). It is a dynamic process (not a trait or an ability) that depends on constantly changing personal and environmental factors (McClelland et al., 2010; Zimmerman, 2000). McClelland et al. (2010) describe self-regulation as a multidimensional construct that includes emotion regulation and cognitive self-regulation (i.e., regulatory processes involved in planning, decision-making, and problem-solving). Furthermore, they describe the difficulty of defining self-regulation due to a large number of underlying theories (e.g., relational developmental systems theory, social cognitive theory, and life span theory), and the many disciplines involved (e.g., developmental, personality, and cognitive perspectives). Depending on the scientific discipline, other terms closely related to self-regulation may also be used, including effortful control (developmental perspective), ego control (personality perspective), and executive function (cognitive perspective; McClelland et al., 2010). For this chapter, I will define self-regulation as a dynamic and adaptive mechanism that involves cognitive, affective, and motivational processes and that is important for children to be able to conform to personal standards and to social expectations, to pursue short- and long-term goals, and to cope with adversity and stressors. This definition is in line with the view that self-regulation is important for ‘maintaining a positive trajectory […] [and] effectively managing and mastering changes in our lives’ (McClelland et al., 2010, p. 511).

Development of Self-Regulation

Self-regulation develops from infancy into adulthood, with great developments in early and middle childhood when child behaviour develops from mostly externally regulated and co-regulated behaviour to self-regulated behaviour (Erdmann & Hertel, 2019; Montroy et al., 2016; Zimmerman, 2000). With the development of self-regulation, social guidance or external control of behaviour is more and more reduced (McClelland et al., 2010; Zimmerman, 2000). The development of self-regulation is an integral part of healthy child development that is associated with multiple short- and long-term outcomes, including academic achievement (Graziano et al., 2007; Matthews et al., 2009; McClelland et al., 2007; Morrison et al., 2010), and physical and mental health (Brocki et al., 2019; Caspi et al., 2013; Howard & Williams, 2018; Kostyrka-Allchorne et al., 2020; Perry et al., 2018; Schmitt et al., 2019). Children vary in their levels of self-regulatory skills, and these variations depend on individual factors (e.g., temperament) and environmental factors (e.g., child-parent interactions). The existing literature suggests several factors that impact children's self-regulation, including parenting (Baron & Malmberg, 2019; Bridgett et al., 2018; Karreman et al., 2006; Perry et al., 2018), family socio-economic status, parental education, and parental mental health (Gunzenhauser & von Suchodoletz, 2015; Størksen et al., 2015; van Tetering et al., 2018). While the effect of the social environment on children's self-regulation has received much attention, the role of the physical environment has been relatively neglected. From a developmental psychology perspective, it is therefore interesting to investigate the role of neighbourhood greenspace, a physical environment factor, in children's self-regulation.

Greenspace and Children's Self-Regulation

In my literature review in Chapter 2, I have described associations of neighbourhood greenspace with several outcomes. Many of these outcomes, including attention, hyperactivity, conduct problems, aggression, emotional symptoms, mood, and stress, are closely linked to self-regulation (for a review and meta-analysis, see Weeland et al., 2019). Indeed, most of these outcomes likely feed into, or result from, 'successful' or 'unsuccessful' self-regulation. For example, attention has been described as a mechanism underlying 'successful' self-regulation (S. Kaplan & Berman, 2010), whereas behavioural problems, such as hyperactivity and aggressive behaviour, may result from 'unsuccessful' self-regulation (McClelland et al., 2010). The association between neighbourhood greenspace and these outcomes, even if not consistent, therefore, indicates that there may also be an association between neighbourhood greenspace and self-regulation.

In an early study two decades ago, Taylor et al. (2002) investigated the association between views of nature and children's self-regulation (referred to in the study as 'self-discipline'). The researchers asked mothers of 169 children from Chicago, US, to rate the amount of nature they could see from their home. Children completed tests on concentration, inhibition of initial impulses, and delay of gratification (described by the researchers as three measures of self-discipline). Higher levels of nature surrounding homes, as reported by the mothers, were associated with higher levels of self-discipline, but only in girls: the greener the view from the home, the better their performance in tests on concentration, inhibition of initial impulses, and delay of gratification. The researchers did not find the same in boys. These findings suggest that views of nature may be related to self-regulation in girls. However, it is unclear whether mere views of nature are sufficient, or whether views of nature are a proxy for visits to nature.

In a more recent study, Scott et al. (2018) investigated the association of nature surrounding children's preschools ('school nature') and homes ('home nature') with socio-emotional and behavioural (SEB) development. They used data on 1,551 children at the age of 4 to 5 years from 50 preschools in Charlotte, US. SEB development was measured with four scales completed by the teachers: initiative (the ability to think and act independently), self-regulation (the ability to appropriately experience and express a range of emotions), attachment (the development of mutual positive relations with other children and adults), and behavioural concerns (e.g., aggression). Levels of nature were measured with three indicators: park access, proportion of impervious surface, and proportion of tree canopy at home and school. The researchers found a positive association between home tree canopy cover and initiative in fall. In addition, they found that factors of the school environment were associated with children's improvement in SEB functioning from fall to spring: children improved in attachment with decreasing levels of impervious surface around schools, in initiative with decreasing levels of impervious surface and increasing levels of park access around schools, and in self-regulation and behavioural concerns with increasing tree canopy around both homes and schools. These findings suggest that good access to parks and, particularly, high levels of tree canopy could promote children’s development of self-regulation.

Bakir-Demir et al. (2019) investigated the role of nature connectedness in the association between neighbourhood greenery and children’s self-regulation. They measured emotional, behavioural, and cognitive self-regulation, as well as nature connectedness, in 299 children at the age of 8 to 11 years from the metropolitan capital city of Turkey. Neighbourhood greenery was measured using a composite score of the Normalized Difference Vegetation Index (NDVI) and mothers' and children's perceptions of the amount of nearby nature. The researchers did not find a direct association of greenery with self-regulation, but they did find an indirect association of neighbourhood greenery with emotional and cognitive (but not behavioural) self-regulation that was mediated by nature connectedness.

Finally, using an experimental study, Jenkin et al. (2018) investigated the effects of natural and urban environments on children’s self-regulation. The researchers tested selective attention, delay of gratification, and mood in 79 children at the age of 8 to 11 years before and after showing them videos of either natural or urban environments for 3 minutes. Children in the urban condition were less able to delay gratification post- than pre-exposure. There was no significant difference between pre- and post-exposure delay of gratification in children in the natural condition. In an additional study, in which the urban environment video was made more cognitively demanding, the researchers did not find an effect of either urban or natural videos on delay of gratification. These findings do not suggest an association between greenspace (or nature) and self-regulation.

The four studies provide inconclusive evidence for a potential association of (neighbourhood) greenspace with children’s self-regulation. The study by Jenkin et al. (2018) is the only one to report no significant association of exposure to nature with self-regulation (operationalised as children’s ability to delay gratification). However, this null finding could be explained by the relatively short and, importantly, virtual exposure to nature. The other three studies used more ecological measures of children’s exposure to greenspace around homes and schools. The three studies used measures of greenspace with different levels of objectivity: Taylor et al. (2002) used a subjective measure of greenspace (asking mothers to indicate how much nature they could see from their homes), Bakir-Demir et al. (2019) used a composite score of the objective NDVI and parents' and children's subjective perceptions of the amount of nearby nature, and Scott et al. (2018) used objective measures of park access and tree canopy. The three studies report at least some significant associations of greenspace with self-regulation, assessed with objective tests (A. F. Taylor et al., 2002), teacher-reports (Scott et al., 2018), or self- and parent-reports (Bakir-Demir et al., 2019). The variations in exposures and outcomes stress the heterogeneity of studies that I already highlighted in my literature review in Chapter 2, and, once again, it is not possible to draw general conclusions from these studies.

Despite the limited evidence, a relationship between neighbourhood greenspace and children's self-regulation is certainly plausible, especially considering Attention Restoration Theory and Stress Recovery Theory (i.e., ART and SRT, as described in Chapter 1). Self-regulation requires cognitive and affective resources (McClelland et al., 2010), both of which can become depleted and need to be restored. As proposed by ART and SRT, neighbourhood greenspace could help children to replenish resources important for 'successful' self-regulation. Higher levels of neighbourhood greenspace may therefore be associated with higher levels of self-regulation.

The Present Study

The evidence suggests a link between neighbourhood greenspace and children's self-regulation, but findings are mixed and obtained from few studies with relatively small samples. Further, due to the multidimensional nature of self-regulation, it is crucial to understand better the associations of greenspace with different dimensions of self-regulation. In my first study, I investigated the longitudinal associations of neighbourhood greenspace quantity with two dimensions of self-regulation, independence and emotional dysregulation, using data from the UK Millennium Cohort Study, a large general-population birth cohort study. In this study, I addressed the following research question:

1. Is there an association of neighbourhood greenspace quantity with young children's self-regulation?

I hypothesised that higher levels of neighbourhood greenspace quantity are associated with higher levels of self-regulation (i.e., higher independence and lower emotional dysregulation), even after full adjustment for confounders. This hypothesis was based on the restorative function of greenspace, which may help children replenish resources that are important for 'successful' self-regulation.

4.2. Methods

Study Sample

I used data on children from the UK Millennium Cohort Study (MCS; *Millennium Cohort Study*, n.d.), a longitudinal study following families in the UK with children born between 2000 and 2002 (i.e., between 1 September 2000 and 31 August 2001 in England and Wales, and between 24 November 2000 and 11 January 2002 in Scotland and Northern Ireland). The MCS provides data on the cohort members' development over time, behaviours, experiences, and lives. The MCS sample is disproportionately stratified to ensure adequate numbers for the four UK countries (i.e., England, Wales, Scotland, and Northern Ireland) and for electoral wards with disadvantaged or ethnic minority populations (Plewis, 2007). In total, there are nine strata: three for England ('Advantaged', 'Disadvantaged', and 'Ethnic Minority') and two for each of Wales, Scotland, and Northern Ireland ('Advantaged' and 'Disadvantaged'). Children have been followed from 9 months (at Sweep 1) to 17 years (at Sweep 7), with a total of 19,243 productive families across sweeps. In this study, I used data from Sweeps 2, 3, and 4 (when self-regulation was measured in the MCS) at ages 3, 5, and 7 years. In the case of multiple births (i.e., 253 sets of twins and 11 sets of triplets), I used data on first-born twins and triplets only. I excluded second- and third-born children to ensure independence of observations. Self-regulation was measured with two scales: independence and emotional dysregulation. My analytic sample included children who had at least one record of independence or emotional dysregulation across the three sweeps and who were available at Sweep 4 (n = 13,774). My non-analytic sample was the remaining MCS children (n = 5,469). Children in my analytic sample had to be present at Sweep 4 because I used the Sweep 4 study weight. Children who were not present at Sweep 4 did not have a Sweep 4 study weight and could, therefore, not be included in my analysis.

Study Variables

Self-Regulation

Self-regulation was measured with two scales, independence and emotional dysregulation, at child ages 3, 5, and 7 years, with items from the Child Social Behaviour Questionnaire (CSBQ). The CSBQ was based on the Adaptive Social Behavior Inventory (Hogan et al., 1992) and was developed and validated as part of the Effective Provision of Pre-School Education project for England (Sammons et al., 2004) and Northern Ireland (Melhuish et al., 2004). In the MCS, the number of CSBQ items was restricted to five for each scale. Items were completed by the parents, usually the mothers, on a three-point scale ranging from 1 (‘not true’) to 3 (‘certainly true’). The five items of the independence scale were ‘likes to work things out for self’, ‘does not need much help with tasks’, ‘chooses activities on their own’, ‘persists in the face of difficult tasks’, and ‘moves to new activity after finishing task’. The independence scale score was the mean of the five items. The items of the emotional dysregulation scale were ‘shows mood swings’, ‘gets over excited’, ‘easily frustrated’, ‘gets over being upset quickly’ (reversed), and ‘acts impulsively’. The emotional dysregulation scale score was the mean of the five items. Cronbach’s alphas were .58, .62, and .65 for independence, and .61, .66, and .68 for emotional dysregulation (for Sweeps 2, 3, and 4, respectively), suggesting acceptable internal consistencies.

Neighbourhood

Neighbourhood greenspace was measured (at Sweeps 2, 3, and 4) with greenspace data from the Multiple Environmental Deprivation Index (MEDIx; *MEDIx and MEDClass*, 2010). The greenspace variable in the MEDIx used data from the Coordination of Information on the Environment (CORINE; European Environment Agency, 2002) and the 2001 Generalised Land Use Database (GLUD; Office of the Deputy Prime Minister, 2001). CORINE is a land cover dataset from 2000 for the UK that was derived from remotely sensed satellite imagery. It is sensitive to larger green spaces and does not capture green spaces smaller than about 1 ha. GLUD classifies land use across England at high geographical resolution into nine categories: greenspace, domestic gardens, fresh water, domestic buildings, non-domestic buildings, roads, paths, railways, and other. Richardson and Mitchell (2010) combined data of CORINE and GLUD to create a neighbourhood greenspace measure that captures the percentage of greenspace in every 2001 Census Area Statistics (CAS) ward (*Census Geography - Office for National Statistics*, n.d.). A ward is a geographic unit in the UK, based on administrative boundaries, with an average population of 5,000. The greenspace measure included all vegetated areas larger than 5 m^2 (except for domestic gardens), regardless of their accessibility (i.e., public or private). In the MCS, greenspace data were converted into deciles ranging from 1 ('most deprived' or 'least green') to 10 ('least deprived' or 'most green'). Transforming raw spatial data into deciles is an approach taken by the MCS to avoid disclosure of sensitive information (i.e., disclosure of where exactly a family lived in the UK).

Neighbourhood air pollution was measured (at Sweeps 2, 3, and 4) using estimates of air pollution concentrations from the MEDIx. The MEDIx provides estimates of particulate matter smaller than 10 micrometres (PM_{10}), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), and carbon monoxide (CO) concentrations at ward level. I used PM_{10} as an indicator of neighbourhood air pollution. PM_{10} was highly correlated with NO_2 ($r = .88$, $p < .001$), CO ($r = .82$, $p < .001$), and SO_2 ($r = .54$, $p < .001$), and was accepted as an appropriate proxy for levels of neighbourhood air pollution. PM_{10} data were taken from 1-km grids modelled from National Atmospheric Emissions Inventory data. PM_{10} concentrations were measured as annual mean concentrations in micrograms per cubic meter air (μg/m^3) for each ward. Mean concentrations covered the years 1999 to 2003 and were population weighted (using output area units). In the MCS, air pollution data were converted into deciles ranging from 1 ('least polluted') to 10 ('most polluted'), again, to avoid disclosure of sensitive information.

I included two additional neighbourhood variables: neighbourhood deprivation and urbanicity. Neighbourhood deprivation was measured with the nine MCS strata. The England-Ethnic Minority stratum included children living in wards that had an ethnic minority indicator of at least 30%, the England-Disadvantaged stratum included children living in wards that fell into the upper quartile of the Child Poverty Index (CPI), and the England-Advantaged stratum included children living in wards that did not fall into one of the other two strata. For the other three countries (Wales, Scotland, and Northern Ireland), the Disadvantaged stratum included children living in wards that fell into the top part of the CPI, and the Advantaged stratum included all remaining children. Note that there are only two strata for Wales, Scotland, and Northern Ireland because, for these countries, the number of ethnic minority wards was not sufficient. For more information, please see Plewis (2007). Urbanicity was measured with a binary variable (rural/urban) at each sweep, based on country-specific definitions of rural and urban areas (i.e., ONS Rural Urban Classifications [2005] for England and Wales, Scottish Executive Urban Rural Classifications [2005–2006], and NISRA Urban Rural Classifications [2005] for Northern Ireland). The following were categorised as 'rural': for England and Wales, 'Town and Fringe' and 'Village, Hamlet & Isolated Dwellings'; for Scotland, 'Accessible Small Towns', 'Remote Small Towns', 'Accessible Rural', and 'Remote Rural'; for Northern Ireland, 'Mixed Urban-Rural' and 'Rural'. The following were categorised as 'urban': for England and Wales, 'Urban > 10,000'; for Scotland, 'Large Urban Areas' and 'Other Urban Areas'; for Northern Ireland, 'Urban'.

Home Physical Environment

To control for the immediate (proximal) physical environment, I adjusted for the following home physical environment factors that were all time-varying for the three sweeps: access to a private garden (no/yes), presence of open fires (no/yes), level of damp/condensation (ranging from 1 'no damp' to 4 'great problem'), and presence of secondhand smoke (whether anyone smoked in the same room as the child; no/yes). Access to a private garden was an indicator of access to proximal greenspace. Presence of open fires, damp/condensation, and secondhand smoke in the home were indicators of poor indoor air quality.

Family- and Child-Level Variables

Family-level variables were maternal education (University education at Sweep 4; no/yes), and the following time-varying characteristics: poverty (family above or below the poverty line), maternal psychological distress (measured with the six-item Kessler Psychological Distress scale, ranging from 0 to 24, with higher scores indicating higher levels of distress), family structure (whether both natural [i.e., biological] parents resided in the home; no/yes), residential mobility (whether the family had moved since the last sweep; no/yes), and home ownership (whether the family owned its home; no/yes). Child-level variables were sex (male/female), ethnicity (White, Mixed, Indian, Pakistani and Bangladeshi, Black or Black British, or Other), and general cognitive ability (i.e., IQ). The most comprehensive assessment of children's IQ was at age 5 years (Sweep 3) with three subscales of the British Ability Scales (BAS): 'naming vocabulary', 'pattern construction', and 'picture similarities'. I conducted a principal components analysis (PCA) on these three scales and transformed the component score (derived from the PCA) into a standardised score with a mean of 100 and a standard deviation of 15. A higher score indicates higher cognitive ability.

Statistical Analysis

All analyses were conducted in Stata 15. To investigate children's trajectories of independence and emotional dysregulation from age 3 to 7 years, I fitted growth curve models (GCMs) for both outcomes. The GCMs had three levels: occasions (level one) were nested in children (level two) who were clustered in wards (level three). Including a third level for the clustering in wards was necessary to control for shared neighbourhoods. In my sample, children were clustered in 398 UK wards. Children's age was measured in months and was grand mean centred so that the intercept was set at around 64 months (or 5.33 years). In addition to a linear age term, I included a quadratic age term in the fixed part of my models to account for the curved shapes of the trajectories of children's independence and emotional dysregulation. Models were fitted with random intercepts for levels two (children) and three (wards), and with a random slope for age (at level two). The latter was added to allow for children to have individual slopes (i.e., slopes that varied from the average slope), as I expected that children would differ in their development of self-regulation over time.

I fitted two models for each outcome: a minimally adjusted model and a fully adjusted model. The minimally adjusted model included the linear age term, the quadratic age term, greenspace, deprivation, and urbanicity. The fully adjusted model added neighbourhood air pollution, factors of the home physical environment, and family- and child-level covariates. All variables are described in detail in the previous section. I used the Akaike Information Criterion (AIC) to compare the fully adjusted models to the minimally adjusted models. The fully adjusted models showed better fit than the minimally adjusted models, indicated by smaller AIC values. AIC values of the minimally adjusted models were 24237 and 38731 for independence and emotional dysregulation; AIC values of the fully adjusted models were 19376 and 31976, respectively. In all models, I included the MCS stratum (with nine levels, as described earlier) to account for the stratified design of the study (and as an indicator of neighbourhood SES). Attrition and non-response were taken into account by using study-specific weights (i.e., Sweep 4 study weights) that were provided by the MCS. Including a weight ensured that my analytic sample remained representative of the general population (despite selective attrition, i.e., non-random loss to follow-up).

4.3. Results

Bias Analysis

I tested whether children in the analytic sample (*n* = 13,774) were different from children in the non-analytic sample (*n* = 5,469) on the study variables (see Table 4.1). On average, children in the analytic sample lived in areas with higher levels of greenspace and lower levels of air pollution, were more likely to have access to a garden, were less likely to be poor, and had a higher IQ. This indicates that children in the analytic sample were of more advantaged families than children in the non-analytic sample. However, note that the descriptive statistics and bias analysis reported in Table 4.1 are unweighted, which is likely to explain at least some of the bias observed. The use of study weights in the GCMs below reduced selection bias introduced by selective attrition and ensured that my sample remained representative of the general UK child population.

Table 4.1 Bias analysis of study variables between analytic and non-analytic samples

	Analytic sample (*n* = 13,774)		Non-analytic sample (*n* = 5,469)		Test
Continuous variables					
	n	*M (SD)*	*n*	*M (SD)*	*F*
Independence 2 (1–3)	12,107	2.46 (0.35)	2,727	2.44 (0.36)	7.80 **
Independence 3 (1–3)	12,874	2.53 (0.35)	1,899	2.51 (0.37)	4.59 *
Independence 4 (1–3)	13,488	2.50 (0.37)	-	-	-
Emotional dysregulation 2 (1–3)	12,109	1.88 (0.45)	2,727	1.91 (0.46)	10.50 **
Emotional dysregulation 3 (1–3)	12,874	1.72 (0.46)	1,899	1.78 (0.47)	22.46 **
Emotional dysregulation 4 (1–3)	13,489	1.73 (0.47)	-	-	-
Greenspace 2 (1–10)	12,603	4.48 (2.70)	2,986	4.04 (2.61)	66.76 **
Greenspace 3 (1–10)	13,158	4.56 (2.72)	2,087	4.04 (2.63)	65.12 **
Greenspace 4 (1–10)	13,772	4.58 (2.72)	83	1.89 (1.37)	80.72 **
Air pollution (PM_{10}) 2 (1–10)	12,603	6.25 (3.04)	2,986	6.69 (3.08)	50.47 **
Air pollution (PM_{10}) 3 (1–10)	13,158	6.18 (3.04)	2,087	6.69 (3.11)	49.76 **
Air pollution (PM_{10}) 4 (1–10)	13,772	6.18 (3.04)	83	9.16 (1.63)	79.52 **
Damp and condensation 2 (1–4)	12,520	1.23 (0.62)	2,927	1.27 (0.69)	13.18 **
Damp and condensation 3 (1–4)	13,111	1.22 (0.62)	2,043	1.28 (0.72)	17.50 **
Damp and condensation 4 (1–4)	13,693	1.25 (0.66)	69	1.57 (0.93)	15.75 **
Maternal psychological distress 2 (0–36)	11,166	3.23 (3.69)	2,424	3.50 (4.09)	9.71 **
Maternal psychological distress 3 (0–36)	12,511	3.17 (3.82)	1,821	3.42 (4.18)	6.84 **
Maternal psychological distress 4 (0–36)	13,163	3.15 (3.87)	-	-	-
Child's age [months] 2	12,598	38.14 (2.42)	2,984	38.75 (2.96)	144.61 **
Child's age [months] 3	13,159	63.49 (2.99)	2,086	63.55 (3.16)	0.71
Child's age [months] 4	13,774	88.00 (3.00)	83	88.27 (2.88)	0.66
Child's IQ	12,902	100.64 (14.83)	1,961	95.78 (15.44)	180.54 **
Categorical variables					
	n	%	*n*	%	Chi^2
England-Advantaged	3,785	27.5	1,043	19.1	147.25 **
England-Disadvantaged	3,366	24.4	1,439	26.3	7.34 **
England-Ethnic Minority	1,611	11.7	980	17.9	130.12 **
Wales-Advantaged	621	4.5	211	3.9	4.00 *
Wales-Disadvantaged	1,393	10.1	535	9.8	0.48
Scotland-Advantaged	828	6.0	317	5.8	0.32
Scotland-Disadvantaged	799	5.8	392	7.2	12.60 **
Northern Ireland-Advantaged	534	3.9	189	3.5	1.92
Northern Ireland-Disadvantaged	837	6.1	363	6.6	2.11
Urban 2	9,800	77.8	2,427	81.3	17.68 **
Urban 3	10,098	76.8	1,716	82.2	30.88 **
Urban 4	10,546	76.6	81	97.6	20.39 **
Open fires 2	1,256	10.0	227	7.8	14.17 **
Open fires 3	1,031	7.9	102	5.0	21.03 **
Open fires 4	1,195	8.7	0	0.0	6.50 *
Secondhand smoke 2	2,162	17.3	632	21.6	29.93 **
Secondhand smoke 3	1,859	14.2	346	16.9	10.54 **
Secondhand smoke 4	1,775	13.0	4	5.6	3.37
Access to garden 2	11,723	93.2	2,636	88.8	64.58 **
Access to garden 3	12,274	93.5	1,837	88.5	67.85 **
Access to garden 4	12,848	93.5	61	77.2	33.53 **
Below poverty line 2	3,863	31.0	1,223	41.9	128.83 **
Below poverty line 3	4,165	31.8	976	47.9	202.96 **
Below poverty line 4	4,101	29.8	61	75.3	79.25 **
University education (mother)	4,117	29.9	936	17.3	320.11 **
Two natural parents 2	10,206	81.0	2,142	71.7	125.51 **
Two natural parents 3	10,075	76.6	1,383	66.3	102.40 **
Two natural parents 4	9,945	72.2	68	81.9	3.89 *
Changed address 2	3,527	29.6	901	33.3	14.67 **
Changed address 3	2,052	15.6	425	20.4	30.09 **
Changed address 4	1,356	9.9	6	7.2	0.64
Own home 2	8,318	66.4	1,542	52.7	194.44 **
Own home 3	8,713	66.5	1,012	49.6	219.12 **
Own home 4	9,053	66.1	32	47.1	10.93 **
Ethnicity White	11,584	84.1	4,159	76.4	170.64 **
Ethnicity Mixed	382	2.8	212	3.9	15.92 **
Ethnicity Indian	336	2.4	161	3.0	3.96 *
Ethnicity Pakistani and Bangladeshi	843	6.1	507	9.3	59.55 **
Ethnicity Black or Black British	451	3.3	279	5.1	35.81 **
Ethnicity Other	177	1.3	127	2.3	27.08 **
Female	6,794	49.3	2,555	46.7	10.65 **

*Note. N*s, *M*s, *SD*s, and %s are all unweighted. The numbers 2, 3, and 4 indicate the sweep. *$p < .05$, **$p < .01$.

Table 4.2 Correlations between outcomes, neighbourhood physical environment, and home physical environment (*n* = 13,774)

	IN 2	IN 3	IN 4	ED 2	ED 3	ED 4	GS 2	GS 3	GS 4	AP 2	AP 3	AP 4	OF 2	OF 3	OF 4	DC 2	DC 3	DC 4	SM 2	SM 3	SM 4	AG 2	AG 3
IN 3	.38																						
IN 4	.32	.50																					
ED 2	-.10	-.18	-.19																				
ED 3	-.13	-.26	-.27	.53																			
ED 4	-.13	-.24	-.32	.48	.65																		
GS 2	.02	.03	.04	-.06	-.08	-.08																	
GS 3	.02	.04	.04	-.07	-.09	-.09	.92																
GS 4	.03	.05	.04	-.07	-.09	-.09	.87	.94															
AP 2	-.03	-.04	-.05	.05	.07	.08	-.61	-.58	-.56														
AP 3	-.03	-.04	-.05	.06	.07	.08	-.59	-.60	-.58	.97													
AP 4	-.03	-.05	-.05	.06	.07	.08	-.58	-.59	-.60	.95	.98												
OF 2	.01 ^{n}	.02 ^{n}	.02	-.07	-.07	-.07	.28	.27	.27	-.20	-.20	-.20											
OF 3	.02	.02	.04	-.06	-.07	-.07	.22	.24	.23	-.15	-.16	-.16	.42										
OF 4	.02	.02	.02	-.07	-.08	-.07	.23	.24	.25	-.16	-.17	-.18	.38	.51									
DC 2	-.02	-.05	-.04	.09	.10	.10	-.06	-.05	-.06	.05	.05	.06	-.01 ^{n}	-.02	-.03								
DC 3	-.03	-.05	-.04	.06	.09	.08	-.04	-.05	-.05	.03	.04	.04	-.01 ^{n}	-.00 ^{n}	-.01 ^{n}	.33							
DC 4	-.01 ^{n}	-.04	-.02	.07	.09	.10	-.04	-.04	-.05	.03	.04	.04	-.00 ^{n}	.01 ^{n}	.01 ^{n}	.28	.39						
SM 2	-.03	-.04	-.05	.17	.16	.14	-.01 ^{n}	-.02	-.02	-.03	-.02	-.02	-.03	-.05	-.06	.10	.09	.11					
SM 3	-.01 ^{n}	-.04	-.05	.13	.15	.13	-.02 ^{n}	-.02	-.02	-.02	-.02	-.02	-.02	-.02 ^{n}	-.04	.08	.09	.10	.49				
SM 4	-.02	-.04	-.04	.14	.14	.15	-.01 ^{n}	-.02 ^{n}	-.02	-.02	-.02	-.02	-.04	-.02 ^{n}	-.04	.07	.08	.10	.45	.51			
AG 2	.01 ^{n}	.02 ^{n}	.02	-.04	-.06	-.06	.17	.16	.16	-.14	-.13	-.14	.08	.05	.06	-.13	-.09	-.11	-.06	-.05	-.04		
AG 3	.01 ^{n}	.02 ^{n}	.02	-.03	-.06	-.06	.17	.17	.17	-.13	-.14	-.14	.07	.06	.06	-.11	-.12	-.11	-.06	-.04	-.03	.83	
AG 4	.01 ^{n}	.02 ^{n}	.02 ^{n}	-.03	-.05	-.05	.16	.17	.17	-.13	-.14	-.14	.06	.06	.06	-.10	-.11	-.12	-.05	-.04	-.04	.79	.92

Note. IN = independence, ED = emotional dysregulation, GS = greenspace, AP = air pollution, OF = open fires, DC = damp/condensation, SM = secondhand smoke, AG = access to garden. The numbers 2, 3, and 4 indicate the sweep. For parsimony, binary variables are included in this table. All correlations are significant at $p < .05$ (except for correlations that are highlighted with ^{n}).

Descriptive Statistics

On average, independence and emotional dysregulation scores increased and decreased, respectively, from age 3 to 5 and then nearly plateaued from age 5 to 7 years (see Table 4.1). The average change over time appeared larger for emotional dysregulation than for independence. Children lived in comparatively less green and more polluted areas across the distribution of wards in the UK (i.e., on the fifth and seventh deciles, respectively). Using unweighted estimates, approximately 77% of the children lived in urban areas, over 90% had access to a garden, and about 10% had homes with open fires. Correlation coefficients suggest that neighbourhood greenspace was positively associated with independence and negatively associated with emotional dysregulation (see Table 4.2). Further, greenspace was negatively associated with neighbourhood air pollution and was correlated with the home physical environment, particularly with the presence of open fires and with access to a garden: children who lived in greener areas were more likely to live in homes with open fires and to have access to a garden. The home physical environment was also linked to self-regulation, with more consistent patterns for emotional dysregulation: open fires in the home and access to a private garden were negatively associated, whereas higher levels of damp and condensation, and the presence of secondhand smoke were positively associated with emotional dysregulation.

Model Results

Minimally Adjusted Models

The minimally adjusted models are summarised in Table 4.3 and Table 4.4. On average, children's independence and emotional dysregulation increased and decreased, respectively, but non-linearly over time. The random parts of the models indicate that children varied in their levels of self-regulation at age 5 years and in the development of self-regulation over time. The positive covariances of intercepts and slopes suggest that higher intercepts were associated with steeper slopes. Neighbourhood greenspace quantity was associated with emotional dysregulation but not with independence. On average, higher levels of greenspace were associated with lower levels of emotional dysregulation (b = -0.007, SE = 0.002, $p < .001$, 95% CI: -0.012, -0.003).

Fully Adjusted Models

The fully adjusted models are summarised in Table 4.5 and Table 4.6. Observed and predicted trajectories of independence and emotional dysregulation are shown in Figure 4.1 and Figure 4.2. The average linear slope appeared steeper for emotional dysregulation than for independence. However, again, quadratic age terms suggest that changes over time were not linear. As in the minimally adjusted model, neighbourhood greenspace did not predict children's levels of independence (see Table 4.5). Independence was, however, predicted by family- and child-level covariates. On average, children's independence was higher if they had not moved since the previous sweep and if their mothers had higher levels of education and lower levels of psychological distress. Also, independence was higher in girls and in children with a higher IQ. In addition, I found two significant associations that were unexpected: on average, children of families who owned their home and children who had access to a garden had lower levels of independence. A sensitivity analysis (not shown) revealed that these relationships were modified by urbanicity. In separate GCMs for urban and rural children, I found significant negative coefficients only for the urban children. Finally, the random part of the model indicates that children varied in their independence at age 5 and in their development of independence over time.

Neighbourhood greenspace did not remain a significant predictor of children's emotional dysregulation after full adjustment (see Table 4.6). Two of the home physical environment factors, however, yielded positive 'effects': on average, higher levels of damp and condensation, and the presence of secondhand smoke were associated with higher levels of emotional dysregulation. In addition, children's emotional dysregulation was lower if they lived with both their natural (i.e., biological) parents, if their mothers had higher education and lower psychological distress, and if their families had not moved since the previous sweep and owned their home. Finally, on average, emotional dysregulation decreased with increasing IQ, and girls had lower emotional dysregulation than boys. The random part of the model indicates that, as in the minimally adjusted model, children varied in their levels of emotional dysregulation at age 5 and in their development of emotional dysregulation over time.

Table 4.3 Minimally adjusted three-level growth curve model predicting independence (*n* = 13,771)

Fixed effects	*b* (*SE*)	95% *CI*
Age	0.001 (0.000) ***	[0.001, 0.001]
Age^2	-0.000 (0.000) ***	[-0.000, -0.000]
Greenspace	0.002 (0.001)	[-0.001, 0.005]
Stratum		
(ref. England-Advantaged)		
England-Disadvantaged	-0.013 (0.008)	[-0.029, 0.002]
England-Ethnic Minority	-0.053 (0.013) ***	[-0.078, -0.027]
Wales-Advantaged	0.011 (0.015)	[-0.017, 0.040]
Wales-Disadvantaged	-0.006 (0.010)	[-0.025, 0.014]
Scotland-Advantaged	0.038 (0.012) **	[0.015, 0.062]
Scotland-Disadvantaged	-0.005 (0.013)	[-0.030, 0.020]
Northern Ireland-Advantaged	0.056 (0.015) ***	[0.027, 0.086]
Northern Ireland-Disadvantaged	-0.004 (0.012)	[-0.028, 0.021]
Urban	0.007 (0.009)	[-0.010, 0.024]
Constant	2.506 (0.013) ***	[2.479, 2.532]

Random effects	Estimate (*SE*)	95% *CI*
Level 3 (ward-level)		
Intercept variance	0.001 (0.000)	[0.001, 0.001]
Level 2 (child-level)		
Intercept variance	0.055 (0.001)	[0.052, 0.058]
Slope (age) variance	0.000 (0.000)	[0.000, 0.000]
Intercept-slope covariance	0.000 (0.000)	[0.000, 0.000]

Note. Age was measured in months and grand mean centred at 64 months. For fixed effects: **p* < .05, ***p* < .01, ****p* < .001.

Table 4.4 Minimally adjusted three-level growth curve model predicting emotional dysregulation (*n* = 13,772)

Fixed effects	*b* (*SE*)	95% *CI*
Age	-0.003 (0.000) ***	[-0.003, -0.003]
Age^2	0.000 (0.000) ***	[0.000, 0.000]
Greenspace	-0.007 (0.002) ***	[-0.012, -0.003]
Stratum		
(ref. England-Advantaged)		
England-Disadvantaged	0.136 (0.014) ***	[0.108, 0.164]
England-Ethnic Minority	0.101 (0.023) ***	[0.056, 0.147]
Wales-Advantaged	-0.023 (0.019)	[-0.061, 0.015]
Wales-Disadvantaged	0.116 (0.018) ***	[0.082, 0.151]
Scotland-Advantaged	-0.017 (0.022)	[-0.060, 0.025]
Scotland-Disadvantaged	0.114 (0.024) ***	[0.066, 0.161]
Northern Ireland-Advantaged	-0.067 (0.022) **	[-0.111, -0.023]
Northern Ireland-Disadvantaged	0.066 (0.017) ***	[0.033, 0.099]
Urban	-0.001 (0.012)	[-0.024, 0.021]
Constant	1.724 (0.020) ***	[1.684, 1.765]

Random effects	Estimate (*SE*)	95% *CI*
Level 3 (ward-level)		
Intercept variance	0.005 (0.001)	[0.003, 0.006]
Level 2 (child-level)		
Intercept variance	0.117 (0.002)	[0.113, 0.122]
Slope (age) variance	0.000 (0.000)	[0.000, 0.000]
Intercept-slope covariance	0.000 (0.000)	[0.000, 0.000]

Note. Age was measured in months and grand mean centred at 64 months. For fixed effects: **p* < .05, ***p* < .01, ****p* < .001.

Table 4.5 Fully adjusted three-level growth curve model predicting independence (*n* = 12,670)

Fixed effects	*b* (*SE*)	95% *CI*
Age	0.001 (0.000) ***	[0.000, 0.001]
Age^2	-0.000 (0.000) ***	[-0.000, -0.000]
Greenspace	0.000 (0.001)	[-0.003, 0.003]
Air pollution (PM_{10})	0.000 (0.002)	[-0.003, 0.003]
Stratum		
(ref. England-Advantaged)		
England-Disadvantaged	0.011 (0.008)	[-0.004, 0.027]
England-Ethnic Minority	-0.000 (0.015)	[-0.029, 0.029]
Wales-Advantaged	0.016 (0.014)	[-0.012, 0.043]
Wales-Disadvantaged	0.020 (0.010) *	[0.001, 0.040]
Scotland-Advantaged	0.038 (0.015) *	[0.009, 0.067]
Scotland-Disadvantaged	0.021 (0.013)	[-0.004, 0.047]
Northern Ireland-Advantaged	0.049 (0.012) ***	[0.024, 0.073]
Northern Ireland-Disadvantaged	0.002 (0.011)	[-0.020, 0.025]
Urban	0.008 (0.008)	[-0.008, 0.025]
Open fires	-0.001 (0.007)	[-0.015, 0.013]
Damp/condensation	-0.006 (0.003)	[-0.013, 0.001]
Secondhand smoke	-0.004 (0.007)	[-0.018, 0.009]
Access to garden	-0.026 (0.012) *	[-0.050, -0.001]
Below poverty line	0.001 (0.006)	[-0.011, 0.013]
University education (mother)	0.021 (0.006) ***	[0.009, 0.033]
Two natural parents	-0.003 (0.007)	[-0.016, 0.011]
Changed address	-0.012 (0.005) *	[-0.022, -0.002]
Maternal psychological distress	-0.008 (0.001) ***	[-0.009, -0.007]
Own home	-0.016 (0.006) *	[-0.028, -0.003]
Female	0.075 (0.006) ***	[0.064, 0.086]
Ethnicity		
(ref. White)		
Mixed	-0.023 (0.019)	[-0.060, 0.014]
Indian	-0.013 (0.021)	[-0.053, 0.028]
Pakistani and Bangladeshi	-0.052 (0.017) **	[-0.085, -0.018]
Black or Black British	-0.003 (0.021)	[-0.043, 0.038]
Other	-0.026 (0.032)	[-0.088, 0.036]
IQ	0.004 (0.000) ***	[0.004, 0.004]
Constant	2.134 (0.031) ***	[2.074, 2.195]

Random effects	Estimate (*SE*)	95% *CI*
Level 3 (ward-level)		
Intercept variance	0.001 (0.000)	[0.000, 0.001]
Level 2 (child-level)		
Intercept variance	0.046 (0.001)	[0.044, 0.049]
Slope (age) variance	0.000 (0.000)	[0.000, 0.000]
Intercept-slope covariance	0.000 (0.000)	[0.000, 0.000]

Note. Age was measured in months and grand mean centred at 64 months. For fixed effects: *$p < .05$, **$p < .01$, ***$p < .001$.

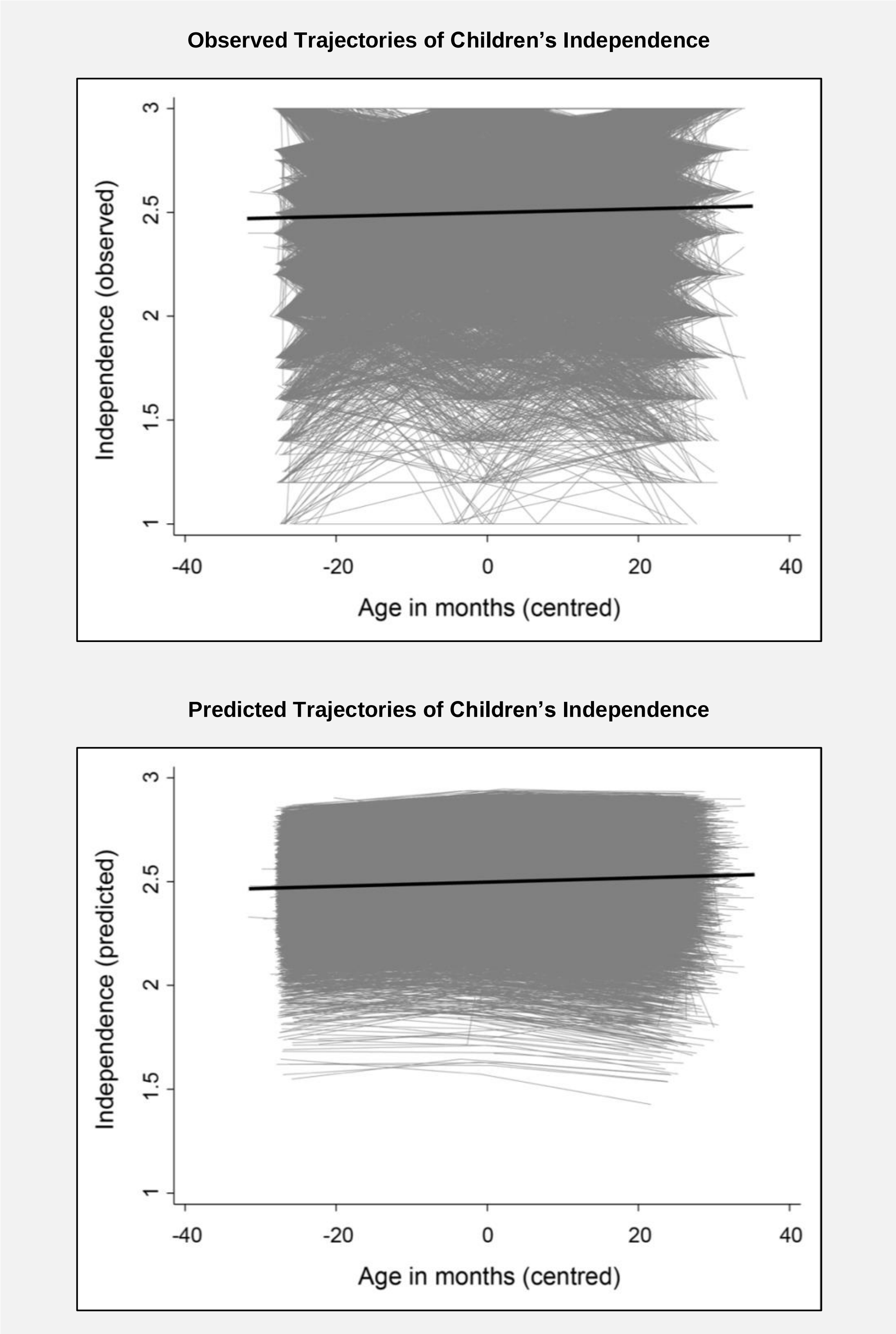

Figure 4.1 Children's observed (top) and predicted (bottom) trajectories of independence and the average linear slope (black lines). Children's age is grand mean centred at around 64 months. The graph shows (a) that children's average independence increased over time, (b) that children differed in their baseline independence and in their development of independence, and (c) that only few children had very low levels of independence.

Table 4.6 Fully adjusted three-level growth curve model predicting emotional dysregulation (n = 12,670)

Fixed effects	*b* (*SE*)	95% *CI*
Age	-0.003 (0.000) ***	[-0.003, -0.003]
Age^2	0.000 (0.000) ***	[0.000, 0.000]
Greenspace	-0.004 (0.002)	[-0.008, 0.000]
Air pollution (PM_{10})	0.001 (0.002)	[-0.002, 0.005]
Stratum		
(ref. England-Advantaged)		
England-Disadvantaged	0.057 (0.010) ***	[0.037, 0.078]
England-Ethnic Minority	0.039 (0.018) *	[0.003, 0.075]
Wales-Advantaged	-0.036 (0.016) *	[-0.066, -0.005]
Wales-Disadvantaged	0.037 (0.014) **	[0.010, 0.064]
Scotland-Advantaged	-0.012 (0.019)	[-0.050, 0.025]
Scotland-Disadvantaged	0.028 (0.020)	[-0.011, 0.066]
Northern Ireland-Advantaged	-0.039 (0.017) *	[-0.072, -0.007]
Northern Ireland-Disadvantaged	0.009 (0.016)	[-0.022, 0.040]
Urban	-0.006 (0.012)	[-0.029, 0.017]
Open fires	-0.007 (0.008)	[-0.023, 0.009]
Damp/condensation	0.021 (0.004) ***	[0.012, 0.030]
Secondhand smoke	0.057 (0.008) ***	[0.041, 0.072]
Access to garden	-0.008 (0.015)	[-0.038, 0.021]
Below poverty line	0.017 (0.008) *	[0.002, 0.032]
University education (mother)	-0.087 (0.008) ***	[-0.103, -0.071]
Two natural parents	-0.035 (0.009) ***	[-0.052, -0.018]
Changed address	0.017 (0.006) **	[0.004, 0.030]
Maternal psychological distress	0.019 (0.001) ***	[0.018, 0.021]
Own home	-0.069 (0.009) ***	[-0.086, -0.052]
Female	-0.062 (0.007) ***	[-0.075, -0.050]
Ethnicity		
(ref. White)		
Mixed	-0.017 (0.022)	[-0.059, 0.026]
Indian	0.007 (0.032)	[-0.056, 0.070]
Pakistani and Bangladeshi	0.012 (0.019)	[-0.026, 0.051]
Black or Black British	-0.106 (0.028) ***	[-0.161, -0.052]
Other	-0.058 (0.035)	[-0.127, 0.010]
IQ	-0.004 (0.000) ***	[-0.004, -0.003]
Constant	2.118 (0.045) ***	[2.029, 2.206]

Random effects	Estimate (*SE*)	95% *CI*
Level 3 (ward-level)		
Intercept variance	0.001 (0.000)	[0.001, 0.002]
Level 2 (child-level)		
Intercept variance	0.094 (0.002)	[0.090, 0.097]
Slope (age) variance	0.000 (0.000)	[0.000, 0.000]
Intercept-slope covariance	0.000 (0.000)	[0.000, 0.000]

Note. Age was measured in months and grand mean centred at 64 months. For fixed effects: *p < .05, **p < .01, ***p < .001.

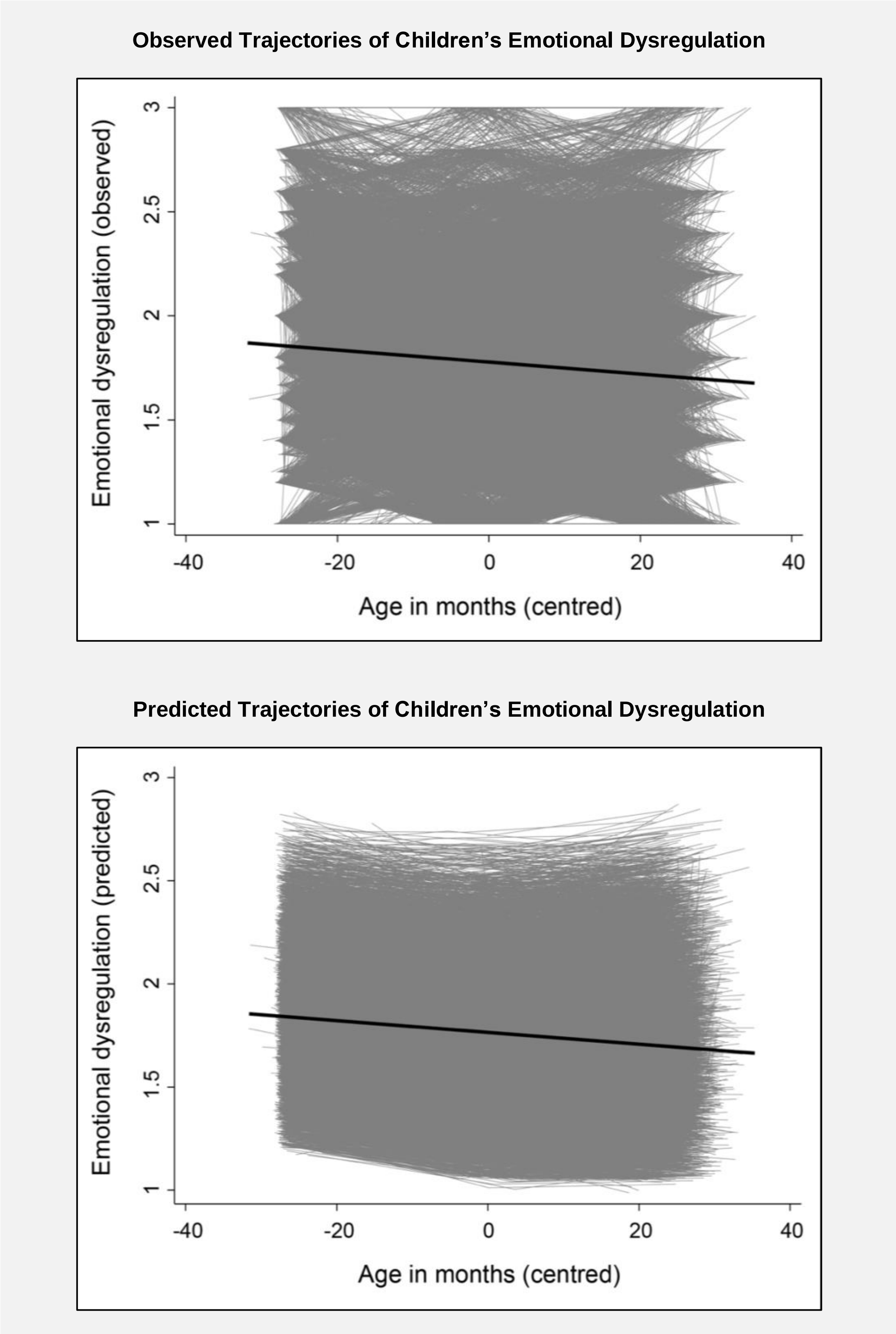

Figure 4.2 Children’s observed (top) and predicted (bottom) trajectories of emotional dysregulation and the average linear slope (black lines). Children’s age is grand mean centred at around 64 months. The graph shows (a) that children’s average emotional dysregulation decreased over time, (b) that children differed in their baseline emotional dysregulation and in their development of emotional dysregulation, and (c) that only few children had very high levels of emotional dysregulation.

Supplementary Analysis

In a sensitivity analysis, I transformed the continuous exposure variable into a binary variable (‘least green’ versus all other deciles) to test for potential non-linear associations. As for the continuous greenspace variable, in fully adjusted models, I did not find an association with independence (*b* = 0.002, *SE* = 0.009, *p* = .824, 95% *CI*: -0.016, 0.020) or emotional dysregulation (*b* = -0.009, *SE* = 0.011, *p* = .375, 95% *CI*: -0.030, 0.011).

In another sensitivity analysis, I stratified my analysis by urbanicity, i.e., I ran separate models for urban and rural children. This was to investigate whether the amount of greenspace in the neighbourhood plays a different role in the self-regulation of children from urban and rural areas in the UK. In urban children (*n* = 10,061), I did not find a significant association of greenspace with independence (*b* = 0.001, *SE* = 0.002, *p* = .767, 95% *CI*: -0.003, 0.004) or emotional dysregulation (*b* = -0.002, *SE* = 0.002, *p* = .366, 95% *CI*: -0.007, 0.002). In rural children (*n* = 3,359), I did not find a significant association with independence (*b* = -0.004, *SE* = 0.004, *p* = .299, 95% *CI*: -0.012, 0.004), but I did find a significant association with emotional dysregulation (*b* = -0.012, *SE* = 0.005, *p* = .013, 95% *CI*: -0.021, -0.003): in rural children in the UK, higher levels of neighbourhood greenspace quantity may be associated with lower levels of emotional dysregulation.

In a supplementary analysis, I added an interaction term (greenspace * age) to my models to test the role of greenspace in the slopes of children’s trajectories of independence and emotional dysregulation. The interaction term was not significant for either independence (*b* = 0.000, *SE* = 0.000, *p* = .720, 95% *CI*: -0.000, 0.000) or emotional dysregulation (*b* = -0.000, *SE* = 0.000, *p* = .580, 95% *CI*: -0.000, 0.000), suggesting that greenspace did not moderate the association between age and self-regulation.

4.4. Discussion

I investigated the association between neighbourhood greenspace quantity and self-regulation in early childhood, using longitudinal data from the UK Millennium Cohort Study (MCS). I modelled trajectories of independence and emotional dysregulation across the ages of 3, 5, and 7 years, using growth curve models. On average, independence and emotional dysregulation increased and decreased, respectively, from 3 to 7 years. This suggests an average improvement of self-regulation in early childhood. Family characteristics were more strongly associated with self-regulation than area characteristics, which is in line with findings from previous studies on the association of greenspace with related outcomes in children (Huynh et al., 2013; Reuben et al., 2019). Some aspects of the home physical environment were associated with children's self-regulation: access to a private garden was linked to lower levels of independence, whereas higher levels of damp and condensation, and the presence of secondhand smoke were associated with higher levels of emotional dysregulation. Most importantly, I did not find an association of my primary exposure of interest, neighbourhood greenspace quantity, with self-regulation.

As described in the introduction, self-regulation is an integral part of child development that is linked to several short- and long-term outcomes. Understanding what factors may support or impair children's development of self-regulation is crucial. This is especially true for modifiable factors that are subject to policymaking, such as the provision of greenspace in the neighbourhood. Unlike some of the studies described earlier, I did not find evidence for an association of neighbourhood greenspace quantity with children's development of self-regulation. Considering the underlying theory (ART and SRT) and the evidence, this finding was unexpected. However, my study had important limitations that may explain my null results at least partly. Limitations occurred primarily with respect to my measurements of self-regulation and neighbourhood greenspace, which I will now discuss in turn.

Measure of Self-Regulation

The first question to ask is: Did I use a valid measure of self-regulation? Considering that self-regulation is a multidimensional construct, a strength of this study was that I included measures of two dimensions, i.e., independence and emotional dysregulation. However, of course, I was not able to measure self-regulation in its full complexity. Therefore, one could argue that greenspace may be associated with other dimensions of self-regulation not considered in this study. Although this is true, it is important to note that previous studies did establish links between greenspace and dimensions of self-regulation similar to the ones in this study. For example, both Bakir-Demir et al. (2019) and Scott et al. (2018) found a positive link between levels of greenspace around homes and schools and children's emotion regulation (termed 'self-regulation' in Scott et al., 2018). Moreover, Scott et al. (2018) found an association with children's independence (termed 'initiative' in their study). So, the question remains: Why did I not find an association of neighbourhood greenspace with self-regulation in my study?

An important limitation of my measure of self-regulation was that the two dimensions were assessed with only five items each. This relatively small number of items may not appropriately capture children's self-regulation capacity. Moreover, items were rated on a three-point scale, which may not allow for enough variance between children. This is especially likely for independence because most children had high scores on this scale. Therefore, my measure of self-regulation, as available in the MCS, may not have been sensitive enough to detect true differences in self-regulation.

Another limitation that may have impacted on the quality of this measure was that it was parent-reported. Parents may want their children to 'look good' or may be biased towards their own expectations. Therefore, parent-reports may be subject to measurement error and, therefore, may not reflect children's true self-regulatory skills. Indeed, research on the link between greenspace and children's mental health showed that the source of information (i.e., child, parent, or teacher) can impact the findings (Feng & Astell-Burt, 2017a). Future studies would benefit from a more comprehensive and more objective measure of children's self-regulation (not limited to a small number of items or parent reports).

Another limitation concerns my measure of independence. A closer look at the five items of this scale reveals that they may not actually measure the same construct. Three items measured children's independence (i.e., 'likes to work things out for self', 'does not need much help with tasks', and ‘chooses activities on their own’), whereas two items seemed to measure attention or executive functioning (i.e., ‘persists in the face of difficult tasks’ and ‘moves to new activity after finishing task’). The latter have been linked to greenspace repeatedly (Amoly et al., 2014; Dadvand et al., 2015; Faber Taylor & Kuo, 2009; Flouri et al., 2019; A. F. Taylor et al., 2002), and one would expect to find a positive association (also considering ART). However, the former (independence) may not be affected by levels of greenspace in the neighbourhood. Although one could imagine that children develop higher levels of independence when they play in green spaces and explore the outdoors, this may be limited due to the global decline in children’s independent outdoor play and mobility (Fyhri et al., 2011; O’Brien & Smith, 2002; Valentine & McKendrck, 1997). Even if children live in areas with many green spaces, they may not use them unsupervised and develop independence. Therefore, because of the different dimensions included in the measure of ‘independence’, this variable may not have been specific enough to capture true differences in self-regulation. Note that I will discuss the problem of measurement error (or information bias) in more detail in my general discussion in Chapter 8.

Measure of Greenspace

The second question I should ask is: Did I use an appropriate measure of greenspace? In the MCS, children’s exposure to greenspace was measured with data from the MEDIx. The MEDIx provides the proportion of greenspace for every ward in the UK. Based on these proportions, wards were divided into deciles. These deciles were then linked to the MCS families based on the ward that they lived in at a given time. While this approach is valid and provides valuable information, it also has limitations.

First, in the UK, wards can be large and varying in size. Two children who live in the same ward are assigned the same value as a proxy for their exposure to greenspace. However, if the ward is large and the distribution of greenspace within the ward is not homogenous, one of the two children may be exposed to more greenspace than the other. A similar problem applies to a situation in that two children live in different wards that fall into the same decile. Again, these children are assigned the same value, although their real exposures may be quite different. In yet another situation, a child who lives at the edge of a ward and very close to an adjacent ward may be exposed to higher or lower levels of greenspace than suggested by their assigned decile (because electoral boundaries do not limit children's mobility across wards). All three scenarios illustrate the problem known as 'exposure misclassification bias' that should be considered in the interpretation of my findings. A greenspace measure based on an egocentric neighbourhood definition may have resulted in a more accurate measure of exposure. I will discuss the problem of exposure misclassification bias in more detail in my general discussion in Chapter 8, as it applies to all my four studies.

It is important to note a second limitation of my measure of greenspace, namely that it included only one dimension of exposure, i.e., quantity, but no other dimensions, such as proximity, quality, or use/usage. These dimensions are important to consider, however, as they may tell us more about children's true exposure to, and experience of, green spaces. For example, the presence of a large park in the neighbourhood may not be enough to improve children's self-regulation because it may be too far away, difficult to access, or unsafe. In these cases, children may not actually visit available greenspace for outdoor play, physical activity, or relaxation, and may, therefore, not benefit as much from it. Although the use of green spaces is not always required, and merely viewing green spaces may also benefit children's self-regulation (A. F. Taylor et al., 2002), I could not test this possibility, as I had no data available that indicated if children could view nature from their homes. In any case, as discussed in my literature review in Chapter 2, it is plausible that factors beyond availability play an important role in the association, so future studies should use a multidimensional approach to uncover the complex relationships between multiple dimensions of greenspace and multiple dimensions of self-regulation. Again, I will discuss the challenge of defining 'exposure' in more detail in my general discussion in Chapter 8.

4.5. Conclusion

I investigated the association of neighbourhood greenspace quantity with children's self-regulation in early childhood. I did not find an association of neighbourhood greenspace with self-regulation, neither with independence nor with emotional dysregulation. Although this finding was unexpected, it is in line with the generally mixed evidence in this area of research. It also highlights the complexity of the association between neighbourhood greenspace and children's self-regulation. Limitations regarding my measures of greenspace and self-regulation may have contributed to my null findings. Future studies should use a multidimensional approach and include measures of greenspace that capture dimensions other than (or additional to) quantity. Also, the wide range of dimensions of self-regulation should be considered. In conclusion, I did not find an association between neighbourhood greenspace quantity and children's self-regulation. More proximal factors, such as the home physical environment, and factors at family and child levels, best explained children's differences in self-regulation.

4.6. Publication

Parts of this chapter have been published (in different form) in the *Journal of Environmental Psychology* (2020). Full citation:

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5. Neighbourhood Greenspace and Mental Well-Being in Early Urban Adolescence

Abstract

I investigated the association between neighbourhood greenspace quantity and mental well-being in 11-year-old adolescents living in urban areas in the UK. In adolescence, children gain more independence from their parents and start to move around their neighbourhoods unsupervised. Greenspace may provide opportunities for adolescents to engage in physical and social activities, which may benefit their mental well-being. However, it is possible that contextual factors modify or moderate this association.

In this study, I used data on self-esteem, happiness, positive mood, negative mood, and antisocial behaviour of 11-year-old adolescents living in urban areas in the UK and participating in the UK Millennium Cohort Study (MCS; *n* = 4,534). Neighbourhood greenspace was defined as the proportion of greenspace at UK ward level. For each of the five outcomes, I ran multiple linear regression models. In fully adjusted models, I included confounders at neighbourhood, family, and child levels. I investigated modification and moderation by perceived area safety, levels of physical activity, and private garden access.

I did not find an association of neighbourhood greenspace quantity with any of the five outcomes, but I did find interaction effects. First, in adolescents who did *not* have access to a private garden, higher levels of greenspace were associated with lower levels of self-esteem and positive mood. Second, in adolescents who reported lower levels of physical activity, higher levels of greenspace were associated with lower levels of negative mood. Third, in adolescents who perceived their areas as unsafe, higher levels of greenspace were associated with more antisocial behaviour.

My findings suggest that high levels of greenspace in the neighbourhood may not be sufficient to promote well-being in young urban adolescents in the UK.

5.1. Introduction

In the first study of my thesis (described in the previous chapter), I used data on 3- to 7-year-old children from Millennium Cohort Study (MCS) Sweeps 2, 3, and 4. In my second study, I used data on a subset of the same sample four years later at the age of 11 years (taken from MCS Sweep 5). This is the first time in the MCS timeline at which the cohort members completed a survey about their lives, providing information about more sensitive topics, such as self-esteem and engagement in antisocial behaviours. Although I did not find an association of greenspace with self-regulation in young children, this does not mean that there could not be an association of greenspace with mental well-being in young adolescents. This study contributes to the literature in two main ways. First, it complements previous research on the association between neighbourhood greenspace and adolescent mental health, also investigating (hedonic) well-being. Second, it investigates potential 'effect' modification and moderation by factors that may influence how much adolescents use green spaces in their neighbourhoods, thereby adding a temporal dimension to exposure (though only indirectly). I will now describe these two contributions in more detail.

Complementing Previous Research

The first main contribution of this study is that it complements previous research on the relationship between neighbourhood greenspace and mental health and well-being in adolescents. I have highlighted in my literature review in Chapter 2 that the evidence to date is inconclusive. It is therefore important to study the relationship further, focusing on different age groups and outcome domains. This is because associations are context-specific, and we should not simply transfer findings from one age group or outcome domain to another. This is also true for studies using data on the same (or almost the same) sample, such as studies using data from the MCS. For example, I did not find an association of neighbourhood greenspace with self-regulation in 3- to 7-year-old children in my previous study, and Flouri et al. (2014) also only found limited evidence for an association of neighbourhood greenspace with mental health in the same age group (though only using data on children from urban England). As mentioned above, this does not mean, however, that there may not be an association of neighbourhood greenspace with similar outcomes in older children (e.g., young adolescents). For example, Flouri et al. (2019) found an association of neighbourhood greenspace with spatial working memory in 11-year-old adolescents in urban England. This study used data on the same age group as the present study but assessed a different outcome domain (i.e., cognition). Therefore, I cannot simply infer that the positive association applies also to other outcome domains (e.g., mental health and well-being). In brief, although childhood and adolescence are overlapping periods in life, they are vastly different (e.g., regarding biological development, independence, and interests). Moreover, it is plausible that not all outcomes are affected equally by greenspace. Therefore, it is important to study associations in different age groups and for different outcome domains.

One outcome domain that has been understudied in the 'greenspace and adolescence' literature is mental well-being. Although many studies investigated outcomes related to well-being (e.g., stress and mental health), only few used measures of positive well-being (e.g., positive affect or happiness). In the present study, I used a range of different outcomes, three of which captured aspects of hedonic well-being: happiness (or life satisfaction), positive affect, and negative affect (Joshanloo et al., 2021).

Another understudied outcome included in this study is self-esteem, a construct related to children's mental health and well-being. Some studies have investigated the link between nature and self-esteem, most of which tested the effect of interventions targeting engagement with nature, such as wilderness therapies, rather than availability of nature (or greenspace) in the neighbourhood. In their literature review on the relationship between nature and child and adolescent mental health, Tillmann et al. (2018) highlight that most studies found non-significant associations. Importantly, in a study on 276 children living in Edinburgh, Scotland, McCracken et al. (2016) found that children's use of green spaces, but not the availability of green spaces in the neighbourhood, was positively associated with children's self-esteem.

Investigating Potential Effect Modification and Moderation

The second main contribution of this study is that it explores contextual factors that may play a role in the association of neighbourhood greenspace with mental health and well-being. I explored modification and moderation by three factors that may influence adolescents' use of green spaces: perceived area safety, physical activity, and access to a private garden. It is likely that individuals who use green spaces in their neighbourhoods more often 'benefit' more from these spaces than their counterparts. This temporal dimension of exposure is often neglected in the literature, which may be explained, at least partly, by the fact that it is more difficult to collect these data. If these data were not part of the initial data collection, it is virtually impossible to collect and link them to the main data afterwards. A few studies assessed the association of visits to, or use of, green spaces and found associations, for example, with self-esteem in adolescents (McCracken et al., 2016) and mental health in children (Amoly et al., 2014; Flouri et al., 2014a; Mygind et al., 2022). Although intentional visits and use are not required for green spaces to be beneficial for adolescent mental health and well-being, for some pathways, especially the 'instoration' pathway, the use of green spaces may be essential. In this study, I explored the potentially modifying and moderating roles of three factors that may influence adolescents' use of green spaces: perceived area safety, physical activity, and private garden access.

Perceptions of the safety of a neighbourhood may be an indicator of how often adolescents visit neighbourhood green spaces. Adolescents who perceive their neighbourhoods as safe may visit nearby green spaces more often than adolescents who perceive their neighbourhoods as unsafe. Adolescents who perceive their neighbourhoods as unsafe may either not be allowed or feel uncomfortable to spend time outside in their neighbourhoods, including in green spaces. This is suggested by studies from the wider literature that found that (perceived) area safety and crime are associated with young people's engagement in outdoor physical activity: high levels of safety and low levels of crime are associated with more engagement in outdoor physical activity (Gómez et al., 2004; Molnar et al., 2004; Ries et al., 2008). The association of neighbourhood greenspace with adolescent mental well-being may, therefore, be moderated by perceived area safety. This is suggested by studies on adults that found that neighbourhood safety, deprivation, and incivility influence people's use of green spaces and can moderate the link between greenspace and well-being (Ambrey, 2016; Chong et al., 2013; A. Jones et al., 2009). Noteworthy, however, Younan et al. (2016) investigated the moderating role of perceived neighbourhood quality (parent-reported) in the association of availability of greenspace in the neighbourhood and aggressive behaviours in adolescents, and did not find a moderating role. Although they did not ask about perceived neighbourhood safety specifically, items assessing quality were mostly safety-related (e.g., covering criminal- and gang-related activities), so the finding is relevant in the context of this study and suggests that perceived neighbourhood safety may *not* moderate the association between neighbourhood greenspace and adolescent well-being. However, importantly, in the study by Younan et al. (2016), neighbourhood quality was reported by the parents. In the present study, perceived area safety was reported by the adolescents themselves.

In addition to influencing use of green spaces, it is possible that perceptions of safety also influence experiences of these spaces. Adolescents who visit green spaces and perceive their areas as safe may have a more positive experience than adolescents who visit green spaces and perceive their areas as unsafe. In other words, perceptions of safety may influence the quality of exposure and, therefore, how much one may benefit from this exposure. This is suggested by a study on the association between active school travel and health-related quality of life in 8- to 14-year-old children, which found that perceived neighbourhood safety moderated the association (G. Martin et al., 2021): 'regular active school travellers' with high perceived neighbourhood (inter-personal and traffic) safety showed higher psychosocial functioning than 'regular active school travellers' with low perceived (inter-personal and traffic) neighbourhood safety. If we apply this to exposure to green spaces, this finding suggests that perceived neighbourhood safety may not only affect how often adolescents visit green spaces but also the quality of these visits.

Adolescents' levels of physical activity may also moderate their use of green spaces. Research suggests that physical activity is one of the main reasons for adolescents to visit green spaces (Bloemsma et al., 2018), so more active adolescents may use green spaces more often than their less active counterparts. Although physical activity has been discussed as a mediator in the link between greenspace and health (Markevych et al., 2017), studies on adults suggest that it could also play a moderating role (Astell-Burt et al., 2013; McEachan et al., 2016). Noteworthy, however, in their study on the association of neighbourhood park area with perceived stress in adolescents, Feda et al. (2015) did not find an interaction between physical activity and park area.

Finally, access to a private garden may also modify the association between neighbourhood greenspace and adolescent mental well-being. Access to a garden has already been shown to benefit the emotional and behavioural adjustment of children in the UK (Flouri et al., 2014b; Richardson et al., 2017), but it may also modify the relationship between neighbourhood greenspace and mental well-being. Access to a garden offers an immediate opportunity for exposure to greenspace, and it is possible that adolescents who have access to a private garden visit *public* green spaces less often than their counterparts. Adolescents who do not have access to a garden, therefore, may benefit more from public green spaces in their neighbourhoods. Such a compensation effect of proximal greenspace (or nature) on visits to other natural environments has been discussed previously (Maat & de Vries, 2006). However, it is also possible that adolescents who have access to a private garden are more connected to nature and, therefore, seek public green spaces more often than those without. This is suggested by studies on adults that found that use of private gardens for relaxation and gardening was linked to use of parks and visits to nature (de Bell et al., 2020; Lin et al., 2014).

The Present Study

In my second study, I investigated the associations of neighbourhood greenspace quantity with self-esteem, happiness, positive mood, negative mood, and antisocial behaviour in 11-year-old adolescents participating in the MCS. Unlike in my first study, I used data on a more selective sub-population (rather than the general population): I included adolescents from urban areas who had never moved during their childhood ('urban stayers'). The reason for this decision will be given in the next section. Further, I investigated the modifying and moderating role of factors that may influence adolescents' use of green spaces: perceived area safety, levels of physical activity, and access to a private garden. In this study, I addressed the following research questions:

1. Is there an association of neighbourhood greenspace quantity with young, urban adolescents' mental well-being?
2. Is this association modified or moderated by other factors that may affect young, urban adolescents' use of green spaces?

I hypothesised that higher levels of neighbourhood greenspace quantity are associated with higher levels of mental well-being (i.e., higher levels of self-esteem, happiness, and positive mood, and lower levels of negative mood and antisocial behaviour), even after full adjustment for confounders. Further, I hypothesised that factors that may influence young, urban adolescents' use of green spaces modify or moderate these associations. Because this study was partly explorative, I did not have more specific hypotheses about which factors may modify or moderate associations with what outcomes.

5.2. Methods

Study Sample

As in my first study, I used data from the UK Millennium Cohort Study (MCS). For more information, please see section 4.2. In this study, I used data of Sweep 5 (collected between January 2012 and February 2013) when children were around 11 years old. Again, in the case of multiple births, I used data of first-born children only. I investigated the associations of neighbourhood greenspace with self-reported self-esteem, happiness, positive mood, negative mood, and antisocial behaviour. My analytic sample included adolescents who had lived in urban areas at Sweep 1, had never changed address until the age of 11 years (Sweep 5), and had valid data on at least one of the five outcomes (n = 4,534). The non-analytic sample included the remaining MCS children (n = 14,709). Restricting my sample to those adolescents who had never moved ('stayers') ensured that my measure of neighbourhood greenspace reflected exposure to greenspace not only at Sweep 5 but throughout childhood until then. It also allowed me to keep the neighbourhood history consistent and to avoid the introduction of bias by possible changes in type of neighbourhood (and neighbourhood greenspace) due to household move. In addition, because the large majority of MCS children is from urban areas (i.e., 80% at Sweep 1), and because urbanicity is known to modify the relationship between greenspace and health (Alderton et al., 2022; R. Mitchell & Popham, 2007), I decided to focus on urban adolescents and excluded rural adolescents from my analysis. Note, however, that I did run a supplementary analysis on 'rural stayers'.

Study Variables

Mental Well-Being

I investigated five outcomes (i.e., self-esteem, happiness, positive mood, negative mood, and antisocial behaviour) that were self-reported at Sweep 5. This is the first time in the MCS that the cohort members completed a questionnaire in which they answered questions about their mental health and well-being that included more sensitive questions about their self-esteem and engagement in antisocial behaviours. Self-esteem was measured with five items of the validated Rosenberg self-esteem scale (Rosenberg, 1965). Happiness (or life satisfaction) was measured with six items asking children about their feelings about different aspects of their lives. This scale has been used elsewhere as a measure of mental well-being (Bannink et al., 2016; Kelly et al., 2016, 2018). In addition to these two scales, the adolescents answered questions that provided further valuable information about their well-being. These questions asked about their feelings in the past four weeks and about their engagement in delinquent and antisocial behaviour. As these items did not belong to clearly defined scales, I derived underlying dimensions from these items, using principal components analysis (PCA), an approach that has been used previously (Flouri & Ioakeimidi, 2018). I will now describe the five study outcomes in more detail.

Self-esteem was measured with five items of the Rosenberg self-esteem scale (Rosenberg, 1965): ‘On the whole I am satisfied with myself’, ‘I feel that I have a number of good qualities’, ‘I am able to do things as well as most other people’, ‘I am a person of value’, and ‘I feel good about myself’. Items were coded from 1 (‘strongly disagree’) to 4 (‘strongly agree’). The self-esteem scale score was the mean of the five items. The Cronbach’s alpha was .75 (indicating acceptable internal consistency).

Happiness was measured with six items: ‘How do you feel about (a) your schoolwork, (b) the way you look, (c) your family, (d) your friends, (e) the school you go to, and (f) your life as a whole?’ Items were coded from 1 (‘not at all happy’) to 7 (‘completely happy’). The happiness scale score was the mean of the six items. The Cronbach’s alpha was .84 (indicating good internal consistency).

Positive and negative mood were measured with six items on the experience of positive and negative feelings in the last month: ‘In the last four weeks, how often did you (a) feel happy, (b) feel worried, (c) feel sad, (d) feel scared, (e) laugh, (f) get angry?’ Items were coded from 1 (‘never’) to 5 (‘almost always’). As the positive and negative items did not necessarily belong to the same scale, I ran a PCA on the six items (after checking that the six items were suitable for PCA; $KMO = .76$). The PCA resulted in two principal components with eigenvalues > 1. For ease of interpretation, I rotated the component solution, using Oblimin oblique rotation. The two components were ‘positive mood’ (with loading items ‘happy’ and ‘laugh’; scores ranging from -5.82 to 1.63), and ‘negative mood’ (with loading items ‘worried’, ‘sad’, ‘scared’, and ‘angry’; scores ranging from -2.48 to 6.36). The correlation between the two component scores was $r = -.22$, $p < .001$.

Antisocial behaviour was measured with seven items: ‘Have you ever been noisy or rude in a public place so that people complained or got you into trouble?’ (no/yes); ‘Have you ever taken something from a shop without paying for it?’ (no/yes); ‘Have you ever written things or sprayed paint on a building, fence or train or anywhere else where you shouldn’t have?’ (no/yes); ‘Have you ever on purpose damaged anything in a public place that didn’t belong to you, for example by burning, smashing or breaking things like cars, bus shelters and rubbish bins?’ (no/yes); ‘How often do you misbehave or cause trouble in class?’ (1 ‘never’ to 4 ‘all of the time’); ‘Have you ever missed school without your parents’ permission even if only for half a day or a single lesson?’ (no/yes); and ‘How often do you hurt or pick on other children on purpose?’ (1 ‘never’ to 6 ‘most days’). I performed a PCA on the seven items (after checking that the items were suitable for PCA, *KMO* = .75). The PCA resulted in two components with eigenvalues > 1 (and I used Oblimin oblique rotation to ease the interpretation of components): ‘delinquent behaviour’ (with loading items ‘shoplifting’, ‘spraying graffiti’, ‘damaging things’, and ‘truancy’; scores ranging from -0.64 to 11.11) and ‘antisocial behaviour’ (with loading items ‘noisy/rude in public’, ‘misbehaving in class’, and ‘bullying other children’; scores ranging from -1.95 to 7.41). The correlation of the two component scores was $r = .31$, $p < .001$. As there was only little variance on the ‘delinquent behaviour’ scale (identified by visual inspection of the distribution), I decided to exclude it from further analyses, resulting in five outcomes considered in this study: self-esteem, happiness, positive mood, negative mood, and antisocial behaviour.

Neighbourhood

As in my first study, neighbourhood greenspace was measured with data from the MEDIx at ward level (in deciles ranging from 1 ‘least green’ to 10 ‘most green’). Further, I included four additional neighbourhood variables: air pollution, deprivation, perceived area safety, and availability of parks or playgrounds. Neighbourhood air pollution was (as in my first study) measured with PM_{10} data at ward level (also taken from the MEDIx). Neighbourhood deprivation was measured, also at ward level, with the MCS strata. For more information on greenspace, air pollution, and deprivation variables, please find the neighbourhood variables in section 4.2 in the previous chapter. Perceived area safety was measured with a single item answered by the adolescents: ‘How safe is it to walk, play or hang out in this area during the day?’; 1 (‘not at all safe’) to 4 (‘very safe’). Finally, availability of parks or playgrounds in the area was measured with a single item also answered by the adolescents: ‘Are there any parks or playgrounds in this area where children your age can play outdoors?’ (no/yes).

Family- and Child-Level Variables

Again, I adjusted for key family- and child-level variables. Family-level variables were maternal education (University education; no/yes), maternal depression (measured with nine items of the Malaise inventory at Sweep 1, with scores ranging from 0 to 9, with higher scores indicating higher levels of depression), intact family structure (whether the child lived with their natural [i.e., biological] parent(s) continuously throughout Sweeps 1 to 5; no/yes), home ownership (whether the family owned its home; no/yes), and access to a private garden (no/yes). Child-level variables were sex (male/female), ethnicity (White, Mixed, Indian, Pakistani and Bangladeshi, Black or Black British, or Other), pubertal status (started puberty; no/yes), and physical activity. Physical activity was measured with a single item answered by the adolescents: ‘How often do you play sports or active games inside or outside, not at school?’; 1 (‘never’) to 5 (‘most days’).

Statistical Analysis

All statistical analyses were conducted in Stata 15. To assess the associations between neighbourhood greenspace and outcomes, I fitted three multiple linear regression models for each of my five outcomes: a minimally adjusted model, a fully adjusted model, and a fully adjusted model with three interaction terms. The minimally adjusted model included greenspace, deprivation, sex, and age. The fully adjusted model added air pollution, availability of parks and playgrounds, perceived area safety, and family- and child-level covariates. The third model added three interaction terms: private garden access * greenspace, physical activity * greenspace, and perceived area safety * greenspace. In all models, I accounted for the complex sampling design of the MCS (i.e., stratification and clustering), and for selective attrition (using Sweep 5 study weights). Under the assumption that missing data were missing at random (MAR), missing data on covariates and outcomes were imputed using multiple imputation by chained equations (MICE; Raghunathan et al., 2001). To this end, I generated 25 imputed datasets and used Rubin's combination rules to pool the individual estimates into a single set of multiply imputed estimates (Rubin, 1987). Most adolescents in my sample had complete data on study variables (82%). The highest missingness observed was for pubertal status (7%).

5.3. Results

Bias Analysis

I tested whether children in the analytic sample (n = 4,534) were different from children in the non-analytic sample (n = 14,709) on the study variables (see Table 5.1). On average, children in the analytic sample lived in less green and more polluted areas and were less likely to have access to a private garden. However, children in the analytic sample were more likely to report that there were parks or playgrounds in the area where children of their age could play. Furthermore, families in the analytic sample were more likely to own their home and to have been intact throughout. For a summary of all the differences between samples, see Table 5.1. Note that the descriptive statistics reported in Table 5.1 are unweighted, and this explains some of the bias observed. The use of study weights in the linear regression models below accounted for bias introduced by selective attrition.

Descriptive Statistics

Descriptive statistics are shown in Table 5.1. On average, adolescents had higher scores on self-esteem, happiness, and positive mood, and lower scores on negative mood and antisocial behaviour. The great majority had access to a private garden. On average, adolescents in my sample perceived their neighbourhoods as safe and reported high levels of physical activity. Compared to the distribution of UK wards, adolescents lived in less green and more polluted areas (i.e., on the fourth and eighth deciles, respectively).

For complete descriptive statistics, please see Table 5.1. For an overview of the correlations between exposures, outcomes, and modifiers and moderators, please see Table 5.2.

Model Results

Minimally and Fully Adjusted Models

The minimally adjusted models are shown in Table 5.3. I did not find an association of greenspace with any of the five outcomes considered. In these models, sex was the best predictor of emotional well-being and behavioural problems: on average, girls had lower self-esteem, showed less antisocial behaviour, and reported higher levels of both positive and negative mood than boys. In the fully adjusted models, shown in Table 5.4, I found a similar pattern. I did not find an association of greenspace with any of the outcomes. However, perceived area safety was associated with all five outcomes. Sex remained a predictor of self-esteem, antisocial behaviour, and positive mood. Adolescent physical activity was associated with all outcomes except for negative mood.

Interactions

To investigate whether the ‘effect’ of greenspace was modified or moderated by contextual factors, I added three interaction terms to each of the five fully adjusted models. Fully adjusted models including interaction terms are shown in Table 5.5. I found four significant interactions. First, access to a private garden modified the associations of greenspace with self-esteem (b = 0.035, SE = 0.016, p = .028, 95% CI: 0.004, 0.066) and positive mood (b = 0.149, SE = 0.067, p = .027, 95% CI: 0.017, 0.280): in adolescents without access to a private garden, higher levels of neighbourhood greenspace were associated with lower levels of self-esteem and positive mood. Second, physical activity moderated the association of greenspace with negative mood (b = 0.033, SE = 0.014, p = .019, 95% CI: 0.005, 0.061): in adolescents who reported lower levels of physical activity, higher levels of greenspace were associated with lower levels of negative mood. Finally, perceived area safety moderated the association of greenspace with antisocial behaviour (*b* = -0.039, *SE* = 0.019, *p* = .035, 95% *CI*: -0.076, -0.003): in adolescents who perceived their areas as unsafe, higher levels of greenspace were associated with higher levels of antisocial behaviour. The interactions are illustrated in Figure 5.1 and Figure 5.2. Note that I used non-imputed data to visualise the interactions. Therefore, the results illustrated in Figure 5.1 and Figure 5.2 may deviate from the results reported in-text and are only provided for ease of interpretation of interactions.

Supplementary Analysis

In a sensitivity analysis, I transformed the continuous exposure variable into a binary variable ('least green' versus all other deciles) to test for potential non-linear associations. As for the continuous exposure variable, in fully adjusted models, I did not find significant associations with self-esteem, happiness, positive mood, negative mood, or antisocial behaviour (all *p*s > .05). This means that I did not find significant differences in outcomes between adolescents in the least green urban wards and adolescents in less deprived urban wards.

Furthermore, to test for the robustness of interactions, I ran sensitivity analyses on subsets of the sample. First, I ran a model only for adolescents without access to a private garden (*n* = 346): I found negative associations of greenspace with self-esteem (*b* = -0.049, *SE* = 0.021, *p* = .023, 95% *CI*: -0.091, -0.007) and positive mood (*b* = -0.186, *SE* = 0.085, *p* = .033, 95% *CI*: -0.356, -0.016), and a positive association with negative mood (*b* = 0.207, *SE* = 0.101, *p* = .044, 95% *CI*: 0.006, 0.409). These results confirm the interactions reported above. Second, I ran a model only for adolescents whose perceived area safety was below average (i.e., smaller than one standard deviation below the mean; *n* = 504): I did not find an association of greenspace with any of the outcomes (all *p*s > .05). This result does not confirm the interaction reported above. Third, I ran a model for adolescents whose reported physical activity levels were below average (i.e., smaller than one standard deviation below the mean; *n* = 593): I did not find an association of greenspace with any of the five outcomes (all *p*s > .05). Again, this result does not confirm the interaction reported above.

In a supplementary analysis, I ran the same models but using data on adolescents from rural areas in the UK who had never moved home during their childhood (*n* = 1,354). Although I did find a similar modification of the association of neighbourhood greenspace with self-esteem by private garden access (*b* = 0.100, *SE* = 0.037, *p* = .009, 95% *CI*: 0.026, 0.172), I did not find the same for other interactions (all *p*s > .05). This could be due to the small sample size and due to low numbers of adolescents without a garden (*n* = 22; 1.6%), who indicated they did not feel safe in their neighbourhoods (*n* = 107; 8.1%), and who indicated that they were active less than once a week (*n* = 111; 8.3%). I should note that I found an association of greenspace with happiness (unlike in my main analysis on urban adolescents), suggesting that, in young adolescents from rural areas in the UK, higher levels of greenspace were associated with lower levels of happiness (*b* = -0.037, *SE* = 0.018, *p* = .043, 95% *CI*: -0.073, -0.001).

Finally, in another supplementary analysis, I investigated the role of other potential modifiers, all of which were already included as covariates in the fully adjusted models: individual sex, maternal education, and availability of parks or playgrounds in the area. These were not included as modifiers in the original study, but I identified them as interesting contextual factors later, so I decided to assess their role post hoc. Sex and SES (here approximated by maternal education) are probably most often assessed in the literature. In developmental psychology, sex differences tend to be of interest, and it is theoretically plausible that the association between neighbourhood greenspace and adolescent mental well-being could be different for girls and boys, for example, because they may use green spaces in different ways (Rivera et al., 2021; A. F. Taylor et al., 2002). SES is an interesting modifier because individuals with a lower SES tend to make fewer visits to green spaces (Burnett et al., 2021). At the same time, it has been proposed that individuals with a lower SES benefit disproportionately from green spaces in their neighbourhoods (R. J. Mitchell et al., 2015). Therefore, individual SES may modify the association between neighbourhood greenspace and adolescent mental well-being in different ways. The availability of parks or playgrounds in the area is another potential (but not common) modifier. It is plausible that adolescents who perceive that there are parks or playgrounds available in their area visit green spaces more often than their counterparts (because the latter may not be aware of green spaces in their area). Despite these theoretically plausible considerations, I did not find significant interactions of neighbourhood greenspace with any of the three variables for any of the five outcomes (all ps $> .05$).

Table 5.1 Bias analysis of study variables between analytic and non-analytic samples

	Analytic sample (n = 4,534)		Non-analytic sample (n = 14,709)		Test
Continuous variables					
	n	*M (SD)*	*n*	*M (SD)*	*F*
Self-esteem (1–4)	4,486	3.41 (0.44)	8,361	3.37 (0.44)	19.04 **
Happiness (1–7)	4,515	5.97 (1.06)	8,405	5.92 (1.08)	7.81 **
Antisocial behaviour (-1.95–7.41)	4,354	-0.05 (1.26)	8,053	0.03 (1.32)	10.32 **
Positive mood (-5.82–1.63)	4,361	0.04 (1.10)	8,069	-0.02 (1.12)	7.36 **
Negative mood (-2.48–6.36)	4,361	-0.02 (1.55)	8,069	0.01 (1.52)	0.78
Greenspace (1–10)	4,534	3.53 (2.10)	8,746	5.19 (2.84)	1,199.40 **
Air pollution (1–10)	4,534	7.01 (2.74)	8,746	5.80 (3.09)	495.50 **
Perceived area safety (1–4)	4,458	3.16 (0.64)	8,295	3.20 (0.65)	11.59 **
Maternal depression (0–9)	4,321	1.63 (1.72)	13,482	1.72 (1.81)	9.21 **
Physical activity (1–5)	4,498	4.37 (0.95)	8,381	4.39 (0.94)	1.23
Age (years)	4,534	11.16 (0.33)	8,753	11.17 (0.33)	9.64 **
Categorical variables					
	n	*%*	*n*	*%*	*Chi²*
England-Advantaged	1,210	26.7	3,618	24.6	8.06 **
England-Disadvantaged	1,164	25.7	3,641	24.8	1.56
England-Ethnic Minority	716	15.8	1,875	12.8	27.57 **
Wales-Advantaged	189	4.2	643	4.4	0.35
Wales-Disadvantaged	490	10.8	1,438	9.8	4.09 *
Scotland-Advantaged	207	4.6	938	6.4	20.32 **
Scotland-Disadvantaged	213	4.7	978	6.7	22.72 **
Northern Ireland-Advantaged	127	2.8	596	4.1	15.00 **
Northern Ireland-Disadvantaged	218	4.8	982	6.7	20.68 **
Available parks in the area	3,950	87.7	7,059	84.2	28.59 **
Access to a garden	4,188	92.4	8,312	95.1	41.76 **
Family owns its home	3,346	75.0	5,088	59.2	321.69 **
Intact family structure	3,519	77.6	10,456	71.1	73.65 **
University education (mother)	1,473	32.5	4,056	27.7	39.50 **
Ethnicity White	3,559	78.5	12,184	83.0	43.83 **
Ethnicity Mixed	133	2.9	461	3.1	0.47
Ethnicity Indian	176	3.9	321	2.2	39.78 **
Ethnicity Pakistani and Bangladeshi	421	9.3	929	6.3	46.85 **
Ethnicity Black or Black British	167	3.7	563	3.8	0.20
Ethnicity Other	78	1.7	226	1.5	0.75
Female	2,254	49.7	7,095	48.2	3.03
Started puberty	2,625	62.0	5,147	62.5	0.32
Male	831	38.9	1,675	40.3	1.18
Female	1,794	85.5	3,472	85.1	0.17

*Note. N*s, *M*s, *SD*s, and %s are all unweighted. *p < .05, **p < .01.

Table 5.2 Correlations between exposures, outcomes, and modifiers and moderators (*n* = 4,534)

	GS	AP	EST	HAP	POS	NEG	ANT	SAF	ACT
AP	-.47 ***								
EST	-.05 **	.02							
HAP	-.01	.00	.44 ***						
POS	.01	-.03	.25 ***	.24 ***					
NEG	-.01	.03	-.32 ***	-.32 ***	-.22 ***				
ANT	-.03 *	.01	-.16 ***	-.23 ***	-.13 ***	.28 ***			
SAF	.09 ***	-.11 ***	.16 ***	.15 ***	.11 ***	-.17 ***	-.08 ***		
ACT	.02	-.06 ***	.17 ***	.12 ***	.13 ***	-.08 ***	.02	.09 ***	
GAR	.17 ***	-.17 ***	-.03	-.01	.03 *	-.03	-.02	.07 ***	.05 **

Note. GS = greenspace, AP = air pollution, EST = self-esteem, HAP = happiness, POS = positive mood, NEG = negative mood, ANT = antisocial behaviour, SAF = perceived area safety, ACT = physical activity, GAR = garden access. *$p < .05$, **$p < .01$, ***$p < .001$.

Table 5.3 Minimally adjusted regression models predicting self-esteem, happiness, positive mood, negative mood, and antisocial behaviour (*n* = 4,534)

	Self-esteem		**Happiness**		**Positive mood**		**Negative mood**		**Antisocial behaviour**	
	b (SE)	95% *CI*	*b (SE)*	95% *CI*	*b (SE)*	95% *CI*	*b (SE)*	95% *CI*	*b (SE)*	95% *CI*
Greenspace	-0.002 (0.005)	[-0.011, 0.007]	-0.008 (0.010)	[-0.029, 0.013]	0.001 (0.012)	[-0.023, 0.024]	-0.010 (0.017)	[-0.044, 0.025]	-0.002 (0.012)	[-0.027, 0.022]
Stratum										
(ref. England-Advantaged)										
England-Disadvantaged	0.032 (0.022)	[-0.011, 0.075]	0.050 (0.052)	[-0.053, 0.153]	-0.066 (0.061)	[-0.186, 0.055]	0.008 (0.088)	[-0.164, 0.181]	0.134 (0.058) *	[0.019, 0.248]
England-Ethnic Minority	0.087 (0.031) **	[0.026, 0.147]	0.179 (0.062) **	[0.056, 0.301]	-0.002 (0.056)	[-0.112, 0.109]	-0.165 (0.121)	[-0.403, 0.072]	0.036 (0.094)	[-0.150, 0.222]
Wales-Advantaged	0.031 (0.037)	[-0.041, 0.103]	0.103 (0.070)	[-0.035, 0.242]	0.010 (0.078)	[-0.144, 0.163]	-0.149 (0.106)	[-0.357, 0.060]	-0.062 (0.099)	[-0.257, 0.132]
Wales-Disadvantaged	-0.017 (0.026)	[-0.067, 0.034]	0.060 (0.063)	[-0.064, 0.184]	0.042 (0.072)	[-0.099, 0.183]	-0.210 (0.089) *	[-0.386, -0.035]	0.077 (0.076)	[-0.073, 0.227]
Scotland-Advantaged	0.039 (0.054)	[-0.067, 0.145]	0.110 (0.107)	[-0.101, 0.321]	0.150 (0.101)	[-0.049, 0.349]	-0.084 (0.117)	[-0.313, 0.145]	0.083 (0.103)	[-0.120, 0.285]
Scotland-Disadvantaged	0.096 (0.042) *	[0.012, 0.179]	0.040 (0.100)	[-0.148, 0.229]	0.091 (0.097)	[-0.100, 0.283]	-0.165 (0.116)	[-0.393, 0.062]	-0.118 (0.120)	[-0.354, 0.118]
Northern Ireland-Advantaged	0.066 (0.035)	[-0.004, 0.136]	0.350 (0.068) ***	[0.216, 0.483]	0.204 (0.117)	[-0.027, 0.435]	-0.241 (0.147)	[-0.530, 0.048]	-0.088 (0.128)	[-0.341, 0.164]
Northern Ireland-Disadvantaged	0.072 (0.037)	[-0.001, 0.144]	0.281 (0.083) **	[0.119, 0.444]	0.179 (0.101)	[-0.020, 0.379]	-0.388 (0.102) ***	[-0.589, -0.187]	0.064 (0.111)	[-0.155, 0.284]
Age	0.026 (0.028)	[-0.028, 0.081]	0.056 (0.060)	[-0.063, 0.174]	0.131 (0.065) *	[0.003, 0.258]	-0.075 (0.084)	[-0.240, 0.091]	0.060 (0.077)	[-0.091, 0.211]
Female	-0.064 (0.017) ***	[-0.098, -0.031]	0.011 (0.037)	[-0.062, 0.084]	0.282 (0.042) ***	[0.199, 0.365]	0.123 (0.057) *	[0.012, 0.234]	-0.558 (0.044) ***	[-0.645, -0.472]
Constant	3.113 (0.306) ***	[2.511, 3.715]	5.285 (0.666) ***	[3.974, 6.597]	-1.586 (0.717) *	[-2.997, -0.175]	0.891 (0.939)	[-0.958, 2.740]	-0.443 (0.868)	[-2.152, 1.266]

Note. Estimates are pooled estimates of 25 imputed datasets. $^*p < .05$, $^{**}p < .01$, $^{***}p < .001$.

Table 5.4 Fully adjusted regression models predicting self-esteem, happiness, positive mood, negative mood, and antisocial behaviour (*n* = 4,534)

	Self-esteem		**Happiness**		**Positive mood**		**Negative mood**		**Antisocial behaviour**	
	b (SE)	95% *CI*	*b (SE)*	95% *CI*	*b (SE)*	95% *CI*	*b (SE)*	95% *CI*	*b (SE)*	95% *CI*
Greenspace	-0.001 (0.005)	[-0.010, 0.009]	-0.005 (0.011)	[-0.026, 0.016]	-0.002 (0.013)	[-0.027, 0.023]	-0.002 (0.018)	[-0.036, 0.033]	-0.004 (0.014)	[-0.031, 0.024]
Stratum										
(ref. England-Advantaged)										
England-Disadvantaged	0.059 (0.021) **	[0.018, 0.101]	0.097 (0.050)	[-0.002, 0.197]	-0.019 (0.062)	[-0.140, 0.103]	-0.068 (0.087)	[-0.238, 0.102]	0.027 (0.057)	[-0.085, 0.140]
England-Ethnic Minority	0.069 (0.034) *	[0.002, 0.137]	0.052 (0.072)	[-0.090, 0.194]	0.096 (0.088)	[-0.078, 0.270]	-0.265 (0.137)	[-0.536, 0.005]	-0.092 (0.106)	[-0.300, 0.116]
Wales-Advantaged	0.052 (0.037)	[-0.020, 0.125]	0.151 (0.072) *	[0.008, 0.294]	0.039 (0.075)	[-0.108, 0.186]	-0.201 (0.109)	[-0.417, 0.014]	-0.122 (0.105)	[-0.328, 0.083]
Wales-Disadvantaged	0.033 (0.026)	[-0.019, 0.085]	0.170 (0.066) **	[0.040, 0.300]	0.095 (0.076)	[-0.054, 0.245]	-0.318 (0.097) **	[-0.510, -0.126]	-0.080 (0.080)	[-0.238, 0.078]
Scotland-Advantaged	0.043 (0.052)	[-0.060, 0.146]	0.117 (0.105)	[-0.089, 0.324]	0.147 (0.111)	[-0.071, 0.366]	-0.063 (0.146)	[-0.350, 0.224]	-0.011 (0.125)	[-0.257, 0.235]
Scotland-Disadvantaged	0.139 (0.043) **	[0.054, 0.224]	0.130 (0.102)	[-0.071, 0.33]	0.144 (0.106)	[-0.065, 0.352]	-0.257 (0.142)	[-0.536, 0.022]	-0.291 (0.136) *	[-0.559, -0.022]
Northern Ireland-Advantaged	0.049 (0.038)	[-0.026, 0.123]	0.299 (0.081) ***	[0.140, 0.458]	0.177 (0.116)	[-0.051, 0.405]	-0.170 (0.154)	[-0.474, 0.134]	-0.077 (0.122)	[-0.317, 0.163]
Northern Ireland-Disadvantaged	0.089 (0.037) *	[0.016, 0.161]	0.321 (0.084) ***	[0.155, 0.486]	0.164 (0.102)	[-0.037, 0.364]	-0.386 (0.115) **	[-0.612, -0.161]	-0.065 (0.113)	[-0.287, 0.156]
Air pollution	0.008 (0.005)	[-0.001, 0.017]	0.013 (0.010)	[-0.007, 0.033]	0.012 (0.012)	[-0.011, 0.036]	-0.013 (0.017)	[-0.046, 0.019]	-0.024 (0.014)	[-0.052, 0.004]
Availability of parks	0.026 (0.027)	[-0.027, 0.080]	-0.031 (0.052)	[-0.133, 0.071]	0.058 (0.066)	[-0.072, 0.188]	0.039 (0.116)	[-0.188, 0.267]	0.012 (0.074)	[-0.133, 0.157]
Perceived area safety	0.101 (0.012) ***	[0.076, 0.126]	0.242 (0.030) ***	[0.183, 0.300]	0.170 (0.033) ***	[0.105, 0.235]	-0.402 (0.047) ***	[-0.495, -0.309]	-0.167 (0.038) ***	[-0.242, -0.092]
Access to garden	-0.031 (0.031)	[-0.092, 0.029]	-0.049 (0.072)	[-0.191, 0.092]	0.116 (0.106)	[-0.093, 0.326]	-0.108 (0.112)	[-0.329, 0.112]	-0.053 (0.108)	[-0.267, 0.160]
Family owns its home	0.031 (0.022)	[-0.013, 0.075]	0.076 (0.050)	[-0.022, 0.173]	0.004 (0.060)	[-0.114, 0.122]	-0.024 (0.085)	[-0.190, 0.143]	-0.177 (0.069) *	[-0.313, -0.040]
Mother has University education	0.003 (0.017)	[-0.031, 0.037]	-0.031 (0.040)	[-0.109, 0.047]	-0.065 (0.042)	[-0.147, 0.018]	0.042 (0.058)	[-0.073, 0.157]	0.008 (0.054)	[-0.099, 0.115]
Maternal depression	-0.006 (0.005)	[-0.015, 0.003]	-0.020 (0.011)	[-0.041, 0.001]	-0.009 (0.012)	[-0.032, 0.014]	0.027 (0.016)	[-0.005, 0.059]	0.032 (0.014) *	[0.005, 0.059]
Intact family structure	0.066 (0.021) **	[0.025, 0.106]	0.157 (0.052) **	[0.055, 0.259]	0.063 (0.060)	[-0.056, 0.182]	-0.113 (0.076)	[-0.262, 0.037]	-0.175 (0.065) **	[-0.303, -0.046]
Started puberty	0.001 (0.017)	[-0.031, 0.034]	-0.057 (0.045)	[-0.146, 0.032]	0.018 (0.051)	[-0.082, 0.117]	0.016 (0.068)	[-0.118, 0.149]	0.042 (0.053)	[-0.062, 0.146]
Physical activity	0.072 (0.010) ***	[0.053, 0.091]	0.102 (0.018) ***	[0.066, 0.138]	0.144 (0.025) ***	[0.096, 0.193]	-0.059 (0.033)	[-0.125, 0.006]	0.051 (0.025) *	[0.002, 0.100]
Ethnicity										
(ref. White)										
Mixed	0.035 (0.063)	[-0.088, 0.158]	0.104 (0.109)	[-0.111, 0.318]	0.042 (0.155)	[-0.262, 0.346]	-0.111 (0.179)	[-0.464, 0.242]	0.027 (0.118)	[-0.205, 0.259]
Indian	-0.020 (0.046)	[-0.111, 0.072]	0.246 (0.087) **	[0.075, 0.417]	-0.086 (0.101)	[-0.285, 0.112]	-0.156 (0.155)	[-0.462, 0.149]	-0.108 (0.117)	[-0.340, 0.123]
Pakistani and Bangladeshi	0.033 (0.031)	[-0.027, 0.094]	0.203 (0.077) **	[0.052, 0.354]	-0.129 (0.092)	[-0.310, 0.053]	0.127 (0.134)	[-0.137, 0.391]	0.184 (0.111)	[-0.034, 0.403]
Black or Black British	0.021 (0.041)	[-0.060, 0.103]	0.153 (0.101)	[-0.045, 0.352]	-0.091 (0.143)	[-0.372, 0.191]	0.095 (0.170)	[-0.241, 0.430]	0.019 (0.101)	[-0.180, 0.218]
Other	0.198 (0.051) ***	[0.098, 0.297]	0.273 (0.114) *	[0.049, 0.498]	-0.113 (0.152)	[-0.413, 0.187]	0.106 (0.194)	[-0.277, 0.488]	-0.095 (0.117)	[-0.325, 0.135]
Age	0.016 (0.028)	[-0.038, 0.071]	0.054 (0.060)	[-0.065, 0.172]	0.105 (0.065)	[-0.024, 0.234]	-0.067 (0.083)	[-0.231, 0.097]	0.042 (0.074)	[-0.104, 0.189]
Female	-0.049 (0.017) **	[-0.082, -0.016]	0.064 (0.042)	[-0.018, 0.146]	0.308 (0.049) ***	[0.211, 0.404]	0.092 (0.069)	[-0.043, 0.228]	-0.573 (0.051) ***	[-0.672, -0.473]
Constant	2.445 (0.317) ***	[1.821, 3.069]	3.900 (0.698) ***	[2.527, 5.273]	-2.753 (0.716) ***	[-4.162, -1.343]	2.551 (0.973) **	[0.635, 4.468]	0.514 (0.859)	[-1.177, 2.204]

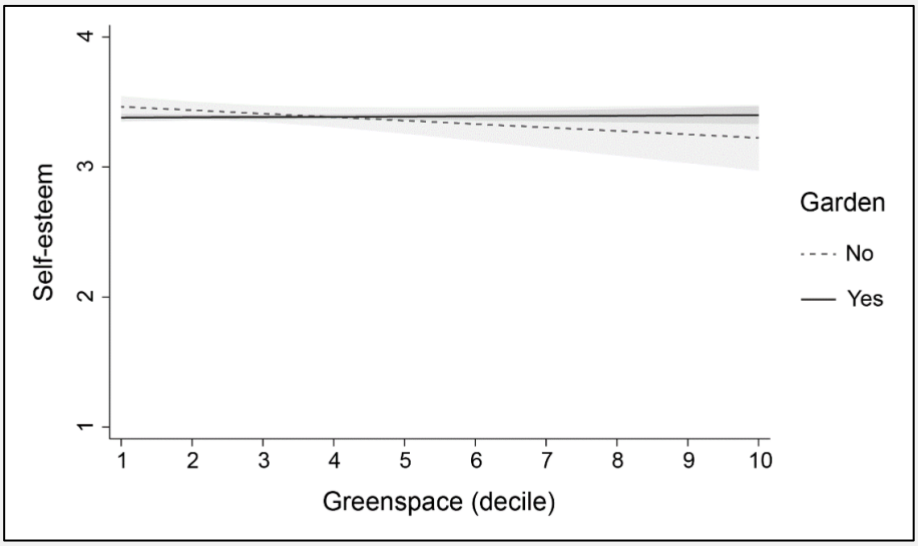
Note. Estimates are pooled estimates of 25 imputed datasets. *$p < .05$, **$p < .01$, ***$p < .001$.

Table 5.5 Fully adjusted regression models including interaction terms (n = 4,534)

	Self-esteem		Happiness		Positive mood		Negative mood		Antisocial behaviour	
	b (SE)	95% *CI*	*b (SE)*	95% *CI*	*b (SE)*	95% *CI*	*b (SE)*	95% *CI*	*b (SE)*	95% *CI*
Greenspace	-0.001 (0.032)	[-0.064, 0.063]	-0.019 (0.079)	[-0.174, 0.136]	-0.159 (0.096)	[-0.348, 0.030]	0.022 (0.122)	[-0.219, 0.263]	0.097 (0.094)	[-0.088, 0.282]
Stratum										
(ref. England-Advantaged)										
England-Disadvantaged	0.062 (0.021) **	[0.021, 0.103]	0.104 (0.050) *	[0.005, 0.203]	-0.007 (0.063)	[-0.130, 0.116]	-0.077 (0.085)	[-0.245, 0.091]	0.027 (0.058)	[-0.087, 0.140]
England-Ethnic Minority	0.066 (0.035)	[-0.002, 0.135]	0.456 (0.074)	[-0.099, 0.191]	0.079 (0.085)	[-0.088, 0.246]	-0.249 (0.138)	[-0.522, 0.023]	-0.082 (0.107)	[-0.293, 0.128]
Wales-Advantaged	0.051 (0.037)	[-0.021, 0.124]	0.147 (0.070) *	[0.008, 0.285]	0.035 (0.076)	[-0.115, 0.184]	-0.200 (0.108)	[-0.413, 0.012]	-0.127 (0.107)	[-0.337, 0.084]
Wales-Disadvantaged	0.035 (0.026)	[-0.017, 0.087]	0.172 (0.066) **	[0.043, 0.302]	0.104 (0.076)	[-0.046, 0.254]	-0.327 (0.097) **	[-0.518, -0.137]	-0.088 (0.080)	[-0.247, 0.070]
Scotland-Advantaged	0.044 (0.053)	[-0.060, 0.148]	0.118 (0.106)	[-0.090, 0.326]	0.149 (0.109)	[-0.066, 0.365]	-0.071 (0.145)	[-0.356, 0.214]	-0.017 (0.124)	[-0.261, 0.228]
Scotland-Disadvantaged	0.144 (0.042) **	[0.061, 0.228]	0.141 (0.103)	[-0.061, 0.344]	0.165 (0.109)	[-0.049, 0.380]	-0.279 (0.144)	[-0.564, 0.005]	-0.298 (0.135) *	[-0.563, -0.032]
Northern Ireland-Advantaged	0.050 (0.037)	[-0.023, 0.123]	0.302 (0.079) ***	[0.146, 0.458]	0.178 (0.119)	[-0.056, 0.412]	-0.171 (0.156)	[-0.479, 0.136]	-0.074 (0.123)	[-0.317, 0.169]
Northern Ireland-Disadvantaged	0.087 (0.037) *	[0.014, 0.159]	0.315 (0.084) ***	[0.150, 0.481]	0.158 (0.102)	[-0.044, 0.359]	-0.379 (0.117) **	[-0.609, -0.149]	-0.066 (0.114)	[-0.290, 0.158]
Air pollution	0.008 (0.005)	[-0.001, 0.017]	0.013 (0.010)	[-0.007, 0.032]	0.012 (0.012)	[-0.011, 0.036]	-0.013 (0.016)	[-0.046, 0.019]	-0.025 (0.014)	[-0.053, 0.004]
Availability of parks	0.030 (0.027)	[-0.024, 0.084]	-0.025 (0.052)	[-0.126, 0.077]	0.070 (0.066)	[-0.059, 0.200]	0.018 (0.114)	[-0.205, 0.242]	0.003 (0.073)	[-0.140, 0.145]
Perceived area safety	0.112 (0.026) ***	[0.061, 0.162]	0.289 (0.054) ***	[0.183, 0.395]	0.131 (0.064) *	[0.006, 0.256]	-0.363 (0.094) ***	[-0.549, -0.178]	-0.026 (0.076)	[-0.177, 0.124]
Access to garden	-0.124 (0.048) *	[-0.219, -0.029]	-0.270 (0.144)	[-0.554, 0.015]	-0.270 (0.148)	[-0.561, 0.021]	0.263 (0.220)	[-0.169, 0.695]	0.022 (0.150)	[-0.274, 0.317]
Family owns its home	0.033 (0.022)	[-0.010, 0.076]	0.079 (0.049)	[-0.018, 0.176]	0.009 (0.059)	[-0.108, 0.126]	-0.035 (0.084)	[-0.201, 0.131]	-0.181 (0.069) *	[-0.318, -0.044]
Mother has University education	0.003 (0.017)	[-0.031, 0.037]	-0.030 (0.039)	[-0.107, 0.047]	-0.067 (0.042)	[-0.150, 0.016]	0.045 (0.059)	[-0.070, 0.160]	0.014 (0.054)	[-0.093, 0.120]
Maternal depression	-0.007 (0.005)	[-0.016, 0.002]	-0.021 (0.011)	[-0.042, 0.000]	-0.011 (0.011)	[-0.033, 0.012]	0.029 (0.016)	[-0.003, 0.060]	0.032 (0.014) *	[0.005, 0.059]
Intact family structure	0.066 (0.021) **	[0.025, 0.107]	0.158 (0.051) **	[0.057, 0.259]	0.063 (0.060)	[-0.054, 0.180]	-0.115 (0.075)	[-0.263, 0.033]	-0.174 (0.065) **	[-0.302, -0.046]
Started puberty	0.002 (0.017)	[-0.030, 0.035]	-0.056 (0.045)	[-0.145, 0.032]	0.019 (0.050)	[-0.079, 0.117]	0.011 (0.067)	[-0.120, 0.142]	0.039 (0.053)	[-0.065, 0.143]
Physical activity	0.091 (0.017) ***	[0.058, 0.124]	0.120 (0.040) **	[0.042, 0.199]	0.156 (0.045) **	[0.067, 0.245]	-0.179 (0.056) **	[-0.289, -0.069]	0.006 (0.043)	[-0.079, 0.092]
Ethnicity										
(ref. White)										
Mixed	0.034 (0.062)	[-0.088, 0.155]	0.102 (0.109)	[-0.112, 0.316]	0.038 (0.150)	[-0.258, 0.335]	-0.100 (0.170)	[-0.435, 0.235]	0.033 (0.116)	[-0.196, 0.262]
Indian	-0.017 (0.046)	[-0.108, 0.074]	0.253 (0.087) **	[0.083, 0.424]	-0.081 (0.102)	[-0.281, 0.119]	-0.165 (0.153)	[-0.467, 0.136]	-0.104 (0.117)	[-0.336, 0.127]
Pakistani and Bangladeshi	0.035 (0.031)	[-0.025, 0.095]	0.208 (0.078) **	[0.054, 0.362]	-0.121 (0.094)	[-0.305, 0.063]	0.120 (0.135)	[-0.146, 0.385]	0.185 (0.111)	[-0.035, 0.404]
Black or Black British	0.012 (0.041)	[-0.068, 0.092]	0.130 (0.102)	[-0.072, 0.331]	-0.139 (0.145)	[-0.425, 0.148]	0.136 (0.174)	[-0.206, 0.477]	0.033 (0.100)	[-0.164, 0.230]
Other	0.187 (0.050) ***	[0.088, 0.286]	0.250 (0.114) *	[0.026, 0.475]	-0.155 (0.154)	[-0.458, 0.148]	0.154 (0.194)	[-0.227, 0.536]	-0.080 (0.113)	[-0.302, 0.142]
Age	0.014 (0.028)	[-0.040, 0.068]	0.049 (0.060)	[-0.069, 0.167]	0.099 (0.066)	[-0.031, 0.229]	-0.056 (0.082)	[-0.219, 0.106]	0.044 (0.074)	[-0.101, 0.189]
Female	-0.049 (0.017) **	[-0.082, -0.016]	0.063 (0.042)	[-0.019, 0.145]	0.303 (0.049) ***	[0.208, 0.399]	0.093 (0.069)	[-0.042, 0.228]	-0.571 (0.050) ***	[-0.670, -0.473]
Greenspace * perceived area safety	-0.003 (0.006)	[-0.015, 0.009]	-0.014 (0.014)	[-0.042, 0.015]	0.010 (0.016)	[-0.020, 0.041]	-0.011 (0.023)	[-0.055, 0.034]	-0.039 (0.019) *	[-0.076, -0.003]
Greenspace * physical activity	-0.005 (0.004)	[-0.014, 0.003]	-0.005 (0.010)	[-0.025, 0.015]	-0.004 (0.012)	[-0.027, 0.019]	0.033 (0.014) *	[0.005, 0.061]	0.013 (0.010)	[-0.007, 0.033]
Greenspace * private garden access	0.035 (0.016) *	[0.004, 0.066]	0.084 (0.060)	[-0.034, 0.201]	0.149 (0.067) *	[0.017, 0.280]	-0.141 (0.087)	[-0.313, 0.031]	-0.030 (0.064)	[-0.155, 0.095]
Constant	2.434 (0.344) ***	[1.757, 3.112]	3.921 (0.744) ***	[2.456, 5.386]	-2.276 (0.786) **	[-3.823, -0.728]	2.517 (1.027) *	[0.495, 4.538]	0.193 (0.897)	[-1.572, 1.958]

Note. Estimates are pooled estimates of 25 imputed datasets. *p < .05, **p < .01, ***p < .001.

Modification of the Association Between Greenspace and Self-Esteem by Private Garden Access



Modification of the Association Between Greenspace and Positive Mood by Private Garden Access

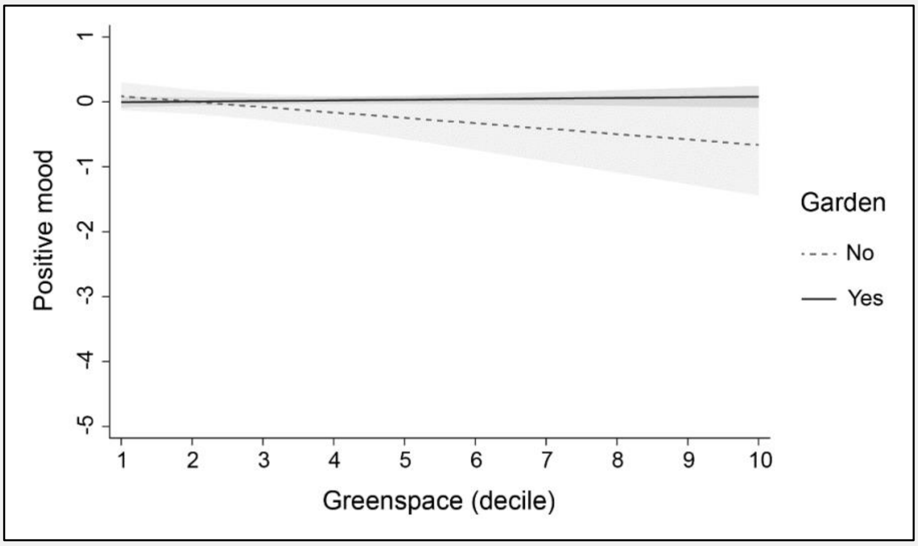
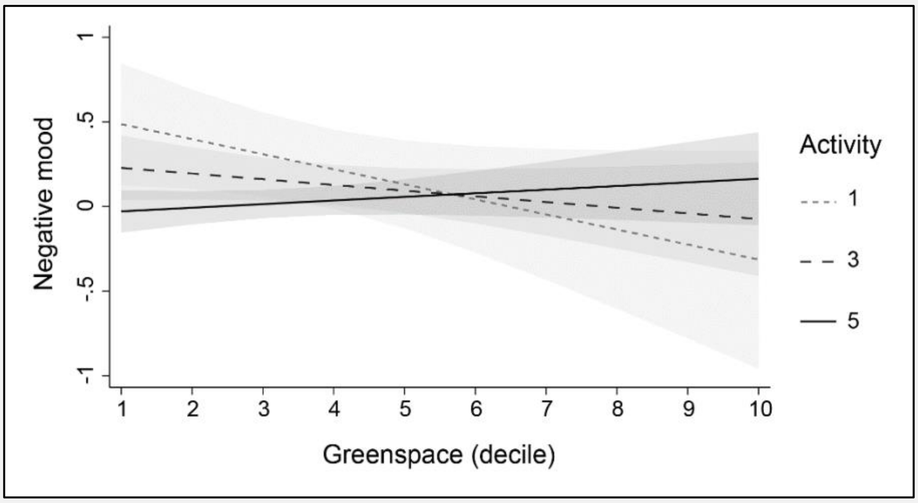


Figure 5.1 Modification by private garden access. Plots show linear predictions. Shaded areas are 95% confidence intervals. Plots are based on non-imputed data. **Top panel:** Modification of the association between greenspace and self-esteem by garden access. **Bottom panel:** Modification of the association between greenspace and positive mood by garden access.

Moderation of the Association Between Greenspace and Negative Mood by Physical Activity



Moderation of the Association Between Greenspace and Antisocial Behaviour by Perceived Area Safety

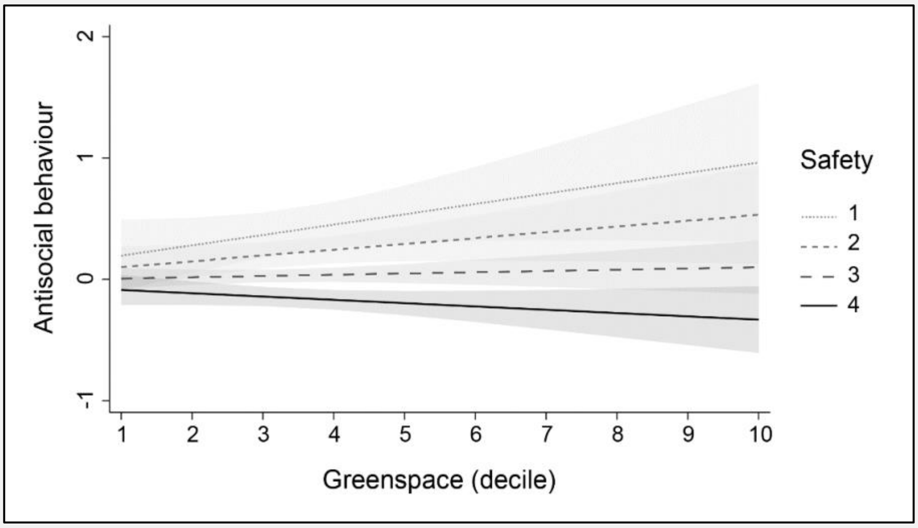


Figure 5.2 Moderation by physical activity and perceived area safety. Plots show linear predictions. Shaded areas are 95% confidence intervals. Plots are based on non-imputed data. Due to the relatively small effects and more than two separate lines per plot, both plots are zoomed in (i.e., the y-axes do not cover the full range of the scales). **Top panel:** Moderation of the association between greenspace and negative mood by physical activity. For visual simplicity, activity levels 2 and 4 are omitted. Activity: 1 (‘never’) to 5 (‘most days’). **Bottom panel:** Moderation of the association between greenspace and antisocial behaviour by perceived area safety. Safety: 1 (‘not at all safe’) to 4 (‘very safe’).

5.4. Discussion

I investigated the association between neighbourhood greenspace quantity and mental well-being in 11-year-old adolescents living in urban areas in the UK, using data from the MCS. Although I did not find a main association of greenspace with any of the five outcomes considered, I did find interaction effects. First, in adolescents who did not have access to a private garden, higher levels of neighbourhood greenspace were associated with lower levels of self-esteem and positive mood. Second, in adolescents who reported lower levels of physical activity, higher levels of greenspace were associated with lower levels of negative mood. Finally, in adolescents who perceived their areas as unsafe, higher levels of greenspace were associated with higher levels of antisocial behaviour. I will now discuss my findings in the context of the previous literature and my study's limitations.

Main Findings

I did not find an association of greenspace with any outcome, neither in the minimally nor in the fully adjusted models. This was unexpected, especially considering previous studies that did find associations between greenspace and several related outcomes in adolescents, including mood (D. Li et al., 2018), stress (Feda et al., 2015), and aggression (Younan et al., 2016). At the same time, this is not the first study to report null results, and my findings fit into the mixed body of evidence discussed earlier. Considering that Flouri et al. (2019) did find an association of neighbourhood greenspace with spatial working memory, using data on the same cohort at the same age, however, it would be wrong to conclude that greenspace does simply not play a role in the well-being of my sample. There are two explanations for my null findings. First, as in my previous study, my measures of exposure and outcome had notable limitations that may explain the null results at least partly. I will describe these limitations later. Second, it is possible that the association of neighbourhood greenspace with mental well-being is context-specific, i.e., influenced by modifying and moderating factors. I tested this and found some evidence for 'effect' modification and moderation, which I will now discuss in more detail.

First, I found that higher levels of neighbourhood greenspace were associated with lower levels of self-esteem and positive mood, but only in adolescents who did not have access to a private garden. This finding was confirmed in a sensitivity analysis for which I ran the main model (without interactions), including only adolescents who did not have access to a private garden. However, it was contrary to my expectation of a protective or promotive function of public greenspace especially for those without access to private greenspace. I expected that those without access to a private garden would seek and benefit from public green spaces more than their counterparts.

One explanation for my finding would be that families in the UK without a private garden are more likely to be disadvantaged. Adolescents without a private garden (likely from disadvantaged families) who live in greener neighbourhoods (likely advantaged) may feel 'relatively deprived'. This is what the theory of relative deprivation would predict (Stouffer et al., 1949), which says that being relatively deprived in comparison to a well-defined reference group (e.g., one's neighbours) causes stress (Winkleby et al., 2006), and this, in turn, can affect health negatively (Åberg Yngwe et al., 2003). A meta-analysis of the impact of relative deprivation on a range of outcomes provides evidence that one's perception of their relative injustice compared to a well-defined reference group can, indeed, impact significantly on their mental health (Smith et al., 2012). In the UK, adolescents' perceived family social status and subjective socio-economic status have been associated with mental health and well-being, such as self-esteem, life satisfaction, and mental health problems (Bannink et al., 2016; Quon & McGrath, 2014; Rivenbark et al., 2020). Without data on adolescents' perceived position relative to their neighbours', however, this explanation is speculative and needs to be tested further.

Another explanation for my finding would be that families in the UK without a private garden are more likely to live in disadvantaged areas, and disadvantaged areas not only have less but also lower-quality greenspace than advantaged areas. Higher levels of this 'low-quality' greenspace may be associated with lower levels of self-esteem and positive mood. I will discuss this explanation in more detail in my general discussion in Chapter 8 where I will revisit the role of private garden access.

Second, I found that higher levels of neighbourhood greenspace were associated with lower levels of negative mood, but only in adolescents who reported little engagement in sports or active games outside of school. I expected that more active adolescents may be exposed to, and benefit more from, nearby green spaces than their counterparts. My finding suggests the opposite, i.e., a ‘protective’ function of neighbourhood greenspace for adolescents who do not usually play sports or active games in their leisure time. One explanation for why there was no association in more active adolescents would be that the question about physical activity did not specify where exactly adolescents were active (except for ‘not at school’). For example, adolescents who report higher levels of physical activity may engage in organised sports, indoors or outdoors, outside their own neighbourhoods. Therefore, they may not be exposed much to green spaces in their neighbourhoods (or at least may not visit them much). Less active adolescents, on the other hand, may spend more time in their own neighbourhoods and may, therefore, benefit more from nearby green spaces. I would like to note that I did not find the same for happiness or positive mood, suggesting that neighbourhood greenspace may be particularly useful for coping with negative mood, although, of course, causal inferences must be made with caution. Future studies should investigate the role of physical activity further, ideally using more comprehensive measures of physical activity that are not based on a single self-reported item. This is especially important because my finding was not confirmed in a sensitivity analysis (for which I ran the main model without interactions, including only adolescents who reported below-average levels of physical activity).

Third, I found that higher levels of greenspace were associated with higher levels of antisocial behaviour, but only in adolescents who perceived their areas as unsafe. I expected that adolescents who perceived their neighbourhoods as safe would benefit more from green spaces than adolescents who perceived their neighbourhoods as unsafe. However, my finding suggests that adolescents who perceive their areas as unsafe may not only not be affected but may be negatively affected by green spaces in their neighbourhoods, although, again, any causal inferences must be made with caution. One explanation for this finding could be that adolescents who live in unsafe neighbourhoods may be exposed to more antisocial behaviour. Exposure to antisocial behaviour is a risk factor for engaging in antisocial behaviour (Murray et al., 2018; Schofield et al., 2012). High levels of (probably low-quality) greenspace in unsafe areas may increase the adolescent's risk of adopting antisocial behaviours even more, for example, by offering opportunities to engage in antisocial acts unmonitored. Again, this explanation is speculative, and more research is needed to shed light on the link between neighbourhood greenspace and (perceived) area safety, and their associations with adolescent mental well-being. This is especially important because my finding was not confirmed in a sensitivity analysis (for which I ran the main model without interactions, including only adolescents who reported below-average levels of perceived area safety).

Study Limitations

I used the same measure of neighbourhood greenspace quantity as in my first study, and the general limitations of this measure apply here too (described in section 4.4). As a reminder, the two main limitations of this measure were its geographic unit or level of aggregation (i.e., ward), and its focus on only one dimension of exposure (i.e., quantity). An additional limitation that I should note for this study is that greenspace was measured with data from 2000 and 2001, i.e., around ten years prior to when my outcomes were measured between 2012 and 2013. Although levels of greenspace in the UK are not expected to change much over a decade, this time gap could have introduced an additional discrepancy between measured and true exposure, contributing to the issue of exposure misclassification.

In addition, I must note several limitations regarding my outcomes. First, all outcomes were self-reported. This could be an advantage for emotional outcomes because adolescents themselves may know better what emotions they experience than, for example, their parents. However, for antisocial behaviour, data could be biased towards social expectations. The anonymous nature of the survey, however, should have reduced this problem. Second, only one of the outcomes, the Rosenberg self-esteem scale, was a validated measure. Reliability and validity are important concepts in psychology and indicate the quality of a measure, namely whether it measures something consistently and accurately. As I relied on the data available in the MCS, some of my outcomes had to be derived from a limited number of items. For the happiness (or life satisfaction) scale, it was clear that the six items measured the same construct, and the scale had already been used in the literature. For positive mood, negative mood, and antisocial behaviour scales, I took steps to ensure that these outcomes were meaningful. First, by basing the item selection on the content of the items, I made sure that each outcome measured a certain construct. Second, by running a PCA on the selected items, I made sure that the items shared an underlying component (or construct). Finally, I assessed the correlations between the outcomes, which were all in the expected directions. Therefore, I expect that my measures captured at least aspects of the intended constructs. Nonetheless, it is important to keep in mind that some of my outcomes may be limited, for example, by a small number of items. Future studies would benefit from using established and validated measures of mental health and well-being.

I would like to note one additional limitation, namely that my analytic sample was selective and not representative of the general population. I restricted my sample to adolescents from urban areas who had lived at the same address throughout their childhood, which limits the generalisability of results. I cannot make inferences about adolescents from rural areas in the UK (though see the supplementary analysis in section 5.3), or about adolescents who had moved during their childhood. Furthermore, my study sample was limited to 11-year-old adolescents. Despite the attractiveness of focusing on young adolescents who just begin to move around their neighbourhoods independently, I should note that I cannot make inferences about other age groups (e.g., later stages of adolescence). Note that I will revisit exposure misclassification, measurement error in outcomes, and generalisability of findings in my general discussion in Chapter 8, as these limitations apply to all my four studies.

5.5. Conclusion

In my second study, I investigated the association of neighbourhood greenspace quantity with the mental well-being of young adolescents living in urban areas in the UK, using data from the MCS. As in my first study, I did not find a main association of greenspace with any of the five outcomes considered. However, I did find interaction effects worth exploring further in future studies. First, in adolescents who did not have access to a private garden, higher levels of neighbourhood greenspace were associated with lower levels of self-esteem and positive mood. Second, in adolescents who reported lower levels of physical activity, higher levels of neighbourhood greenspace were associated with lower levels of negative mood. Third, in adolescents who perceived their neighbourhoods as unsafe, higher levels of neighbourhood greenspace were associated with higher levels of antisocial behaviour. My findings suggest that living in greener areas may not be sufficient to protect or promote the well-being of young, urban adolescents in the UK. Living in a safe area, in contrast, appears to be very important. Nonetheless, greenspace does seem to play a role under certain conditions. These context-specific associations should be explored further in future research, using multidimensional measures of neighbourhood greenspace, and validated measures of mental health and well-being.

5.6. Publication

Parts of this chapter have been published (in different form) in *Frontiers in Psychology* (2021). Full citation:

Mueller, M. A. E., & Flouri, E. (2021). Urban Adolescence: The Role of Neighbourhood Greenspace in Mental Well-Being. *Frontiers in Psychology, 12.* https://doi.org/10.3389/fpsyg.2021.712065

6. Different Types of Green Spaces and Mental Health and Well-Being in Children and Adolescents in London

Abstract

The evidence to date suggests an association of greenspace with children's and adolescents' mental health and well-being. However, one limitation of the literature is the typically crude measure of greenspace quantity or greenness. Most studies do not distinguish between different types of green spaces.

In this study, I investigated the associations of different types of green spaces with mental health and well-being in children (5 and 8 years) and adolescents (10 to 15 years) living in London. I used data from Understanding Society, the UK Household Longitudinal Study (UKHLS). In particular, I used data on 740 children and 1,879 adolescents from UKHLS Waves 1 to 8 (2009–2018). As some individuals had observations at multiple waves, 895 and 4,217 observations were included, respectively. Exposures were proportions of total green land cover, parks & gardens, natural & semi-natural urban greenspaces, outdoor sports facilities, and total green land use in 500 m around postcodes. Mental health and well-being outcomes were Strengths and Difficulties Questionnaire (SDQ) scores, self-esteem, and happiness. For each exposure-outcome combination, I ran a linear regression model, stratified by age. I included confounders at neighbourhood, family, and child levels.

Results were not consistent across analyses, but I identified patterns that are worth exploring further. First, higher levels of greenspace were associated with better mental health and well-being only in older adolescents (13- to 15-year-olds). Second, I found positive associations with mental health and well-being mostly for parks & gardens and outdoor sports facilities.

Overall, my observations should be interpreted with caution, and no definite conclusions can be drawn from this study.

6.1. Introduction

In the first two projects of this thesis, I used a measure of greenspace quantity to assess children's and adolescents' exposure to greenspace in their neighbourhoods. This measure captured any type of greenspace, ranging from verges to woodlands, and told us something about the quantity of greenspace in an area (a UK ward) but nothing about the types of green spaces or greenery that this quantity was composed of. As illustrated in my literature review in Chapter 2, most studies to date have used measures of greenspace quantity or greenness that did not distinguish between different types of green spaces or greenery. Focusing on the mere quantity of greenspace limits our understanding of the relationship between greenspace and health and well-being because different types of green spaces are likely associated with different pathways to health and well-being. Furthermore, depending on individual characteristics, people have different needs and preferences, so some types of green spaces may work well for some but not for others. To inform the development of places for all people, it is important to identify the types of green spaces that benefit a range of different demographics, including children and adolescents. A recent review of studies on the association between natural environments and children's mental health concluded that there was sufficient evidence for a relationship between the Normalized Difference Vegetation Index (NDVI) and children's mental health but not for other measures of exposure, such as different types of green land use (Davis et al., 2021). I came to a similar conclusion in my literature review in Chapter 2.

Empirical Evidence

Some studies have distinguished between different types of green spaces or greenery, and I will now summarise the findings of studies especially relevant for this chapter. Note that I have already discussed these studies earlier in my thesis, so I will only briefly revisit them.

Richardson et al. (2017) calculated proportions of public parks and total natural space (public and private) in 500 m around the homes of young children living in Scotland, UK. Mental health was assessed with the Strengths and Difficulties Questionnaire (SDQ). They found that total natural space was positively associated with prosocial behaviour, but not with other SDQ scales. Public parks, on the other hand, were not associated with any of the outcomes. Despite finding some associations in analyses stratified by sex and household education (as described in my literature review in Chapter 2), the findings do not suggest a general role of either total natural space or public parks in young children's mental health. Interestingly, the researchers did find a robust association between private garden access and mental health, which indicates that private (proximal) greenspace may play a more important role than public (distal) greenspace.

Scott et al. (2018) investigated the associations of nature around schools and homes with socio-emotional and behavioural development in young children in North Carolina, US. They assessed the roles of three exposures: park access, proportion of impervious surface, and proportion of tree canopy. Decreasing levels of impervious surface around schools were associated with improved attachment and initiative, better park access around schools was associated with improved initiative, and increasing levels of tree canopy around homes and schools were associated with better self-regulation and fewer behavioural problems. If causal, these findings suggest that different types of green spaces may have different 'effects' on children's socio-emotional development: better park access was associated with better initiative, and more tree canopy was associated with better self-regulation and fewer behavioural problems.

Markevych et al. (2014) investigated the association between proximity of urban green spaces (i.e., cemeteries, gardens, parks, and plant nurseries) and mental health in young adolescents living in Munich, Germany. They also assessed associations for proximity of forests, and residential greenness. They found a significant association only for proximity of urban green spaces (not forests). If causal, this suggests that young adolescents may benefit more from nearby usable green spaces, such as parks and gardens, than from nearby forests or residential greenness.

Maes et al. (2021) investigated the associations of different types of nature with the mental health, well-being, and cognition of adolescents living in London. Natural space was measured in a range of buffers around homes and schools, and exposure was daytime-weighted. Natural space was distinguished into total natural space, green space versus blue space, and grassland versus woodland. They found that total natural space and green space (but not blue space) were associated with better cognitive outcomes. Moreover, woodland was associated with better cognitive outcomes and mental health. Grassland was associated with better well-being. This study is especially important to keep in mind in the context of this chapter, as it shares many of the main characteristics of my study: the focus on different types of green spaces or greenery, the focus on mental health (also measured with the SDQ) and well-being, and the focus on children and adolescents living in London.

Maes et al.'s (2021) findings suggest that woodland may be more important for adolescent mental health than grassland. Markevych et al.'s (2014) findings, on the other hand, suggest that urban green spaces (e.g., parks) may be more important for adolescent mental health than forests. Of course, there are important differences between the two studies. For example, Maes et al. (2021) used a measure of quantity, whereas Markevych et al. (2014) used a measure of proximity. Maes et al. (2021) defined woodlands as vegetation higher than 1 m, measured with a combination of NDVI and LiDAR data, whereas Markevych et al. (2014) based their definition of ‘forests’ on land use data. Also, noteworthy, Maes et al.'s (2021) study used data on adolescents living in London, UK, whereas Markevych et al.'s (2014) study was set in Munich, Germany. These differences illustrate the great heterogeneity of studies that I have already emphasised in my literature review in Chapter 2.

The four studies described above investigated associations with mental health and well-being, i.e., the outcomes of interest in this thesis, but studies have also assessed influences on other related outcomes, such as academic performance. For example, Donovan et al. (2020) measured the quantity of trees and grass-and-shrubs in 100 m and 200 m around homes and schools, the network distance to the nearest park, and the area of parkland in a 500 m buffer around homes and schools. Academic performance was assessed with maths and reading scores. Higher levels of tree cover in 200 m around the home were associated with higher math scores, and higher levels of tree cover in 100 m around the school were associated with higher reading scores. The researchers did not find associations for grass-and-shrubs, area of parkland, or proximity of parks, which suggests that tree cover in particular may be important for students' academic outcomes. Similarly, Markevych et al. (2019) also investigated the association of home and school greenspace with adolescent academic performance. They used measures of NDVI, tree cover, and different types of land use (i.e., agriculture, forest, and urban green space) in 500 m and 1,000 m around homes and schools. Academic performance was assessed with German and maths grades. Unlike Donovan et al. (2020), they did not find associations between exposures and academic outcomes.

Taken together, no definite conclusions can be drawn about what types of green spaces or greenery may be most beneficial for children and adolescents. There seems to be some evidence that trees may be more beneficial than other types of greenery (e.g., grass). This has been shown in studies on adults too, which have highlighted the importance of trees and biodiversity for mental health and well-being (Astell-Burt & Feng, 2019; Fuller et al., 2007; C. Reid et al., 2017; M. S. Taylor et al., 2015). However, considering the relatively small number of studies, and the inconsistencies between them, the empirical evidence is insufficient.

Theoretical Considerations

Despite the limited empirical evidence, it is theoretically plausible that different types of green spaces have different (primary) functions and, therefore, are linked to different pathways to health and well-being (and their associated outcomes). In other words, there are many types of green spaces and many dimensions of health and well-being, and it can be assumed that not all types of green spaces are linked to all dimensions of health and well-being (at least not equally or in the same way). Moreover, what is required for a greenspace to fulfil a certain function may depend on the socio-demographic group of interest because their characteristics may influence their needs, interests, and preferences. One important characteristic is age. Children, adolescents, and adults all have different needs, interests, and preferences. Therefore, as already noted in my literature review in Chapter 2, one cannot simply generalise findings based on one exposure, outcome, or age group to another exposure, outcome, or age group. It is plausible that these factors (and more) influence the association between greenspace and health. In the present study, I will investigate the associations between different types of green spaces and different outcomes across different age groups. I will now briefly discuss why age may play an important role.

Studying the association between greenspace and mental health and well-being in children and adolescents means investigating a wide age range. Definitions of childhood and adolescence overlap: childhood is defined as the period of 0 to 17 years (Sawyer et al., 2012), and adolescence often is defined as the period of 10 to 19 years (Sawyer et al., 2012), or even 10 to 24 years (Sawyer et al., 2018). In the present study, I used data on children at the age of 5 and 8 years, and adolescents at the age of 10 to 15 years. This means that I investigated an age range of 11 years, and it is important to keep in mind that children and adolescents are in different stages of their development, influencing their needs, interests, and preferences, and, in turn, their use and usage of green spaces. There may be differences related to time (i.e., how often one visits green spaces and for how long), space (i.e., what types of green spaces one visits and where), and activity (i.e., what one does in green spaces and with whom).

One important difference between children and adolescents is their level of independence. A 5-year-old in England, who is typically not allowed to move around their neighbourhood unsupervised (Shaw et al., 2015), may visit green spaces, in their leisure time, only together with their parents. For example, the ‘Monitor of Engagement with the Natural Environment (MENE) Children and Young People’ report suggests that, in 2018 and 2019, 71% of children under the age of 16 years had visited nature (including urban green spaces) in the last month accompanied by adults living in the same household, but only 17% had visited nature in the last month with no adults. However, age seems to play an important role in this. Twelve per cent of 5-year-olds had visited nature without adults, but this number increased to 52% in 15-year-olds (Monitor of Engagement with the Natural Environment, 2019). With increasing age, children and adolescents gain more independence, but even at the age of 10 years, children in England are often not allowed to walk outside alone (Shaw et al., 2015), and this may influence their visits of green spaces. For example, 16% of the children and young people participating in the 'Children's People and Nature Survey in England' reported that one reason for not visiting nature in the last week was that they were not allowed to go out on their own (*The Children's People and Nature Survey for England*, n.d.). Older adolescents have already gone through many stages of childhood and are gaining more and more independence from their parents. At the age of 15 years, adolescents have relatively high levels of independent mobility and are likely to be allowed to move around their neighbourhoods unsupervised (Shaw et al., 2015).

Another important difference between children and adolescents is what they do in green spaces (Monitor of Engagement with the Natural Environment, 2019). Children need safe and stimulating environments to play, learn, and explore, all of which are important for their physical, cognitive, and socio-emotional development. Their primary caregivers need to provide these safe and stimulating environments, and this includes outings to green spaces (Gustafsson et al., 2021; Maggi et al., 2010). Children use green spaces mainly to play, and this is also the main reason for adults to take their children outdoors (Monitor of Engagement with the Natural Environment, 2018). Adolescents use green spaces mainly for physical activity and exercise, and to spend time with their friends (Bloemsma et al., 2018). This is reflected in their preferences. Adolescents report that they value playgrounds, trails, and sports fields, i.e., features facilitating physical and social activities (Rivera et al., 2021; Van Hecke et al., 2018). It should also be noted that, with increasing age and independence, adolescents identify more strongly with their peers and start to engage in risky behaviours, such as drinking and smoking (Christie & Viner, 2005). Green spaces in the neighbourhood may provide opportunity for adolescents to engage in these behaviours unmonitored.

A third important difference between children and adolescents is their level of nature connectedness. Adolescents tend to show lower levels of nature connectedness (i.e., an emotional connection with nature) than children and adults, and it has been suggested that this may be due to their increased sensation-seeking and peer orientation (Kahn & Kellert, 2002; Krettenauer, 2017; Krettenauer et al., 2020). For example, until the age of 10 years, with increasing age, the number of children who enjoy and are interested in nature increases, but then, with further increasing age, the trend seems to be reversed and the number decreases (Monitor of Engagement with the Natural Environment, 2019). This is important to note because nature connectedness may impact use of green spaces (Flowers et al., 2016; Lin et al., 2014), and may also moderate the association of greenspace with mental health and well-being (Liu et al., 2022; L. Martin et al., 2020).

To summarise, it is theoretically plausible that not all types of green spaces are linked equally to all dimensions of health and well-being. Moreover, differences in development suggest that children and adolescents may need and/or prefer different types of green spaces. However, the empirical evidence for potentially differential roles of different types of green spaces in children's and adolescents' mental health and well-being is insufficient. In brief, different types of green spaces have different functions, but 'what works for whom' remains unclear.

The Present Study

I investigated the association of neighbourhood greenspace with mental health and well-being in children (at the age of 5 and 8 years) and adolescents (at the age of 10 to 15 years) living in London. Unlike in my first two studies, I was not restricted to a 'generic' measure of greenspace quantity (including any greenspace and greenery) but could compare the roles of different types of green spaces. Also, data on children and adolescents were taken from Understanding Society, the UK Household Longitudinal Study. Compared to my first two studies, the present study had four strengths. First, I used data on both children and adolescents, and distinguished between eight age groups. Second, I used a validated measure of mental health and also investigated mental well-being in adolescents. Third, I measured greenspace at LSOA level (a smaller geographic unit than the CAS ward I used in my first two studies) and at postcode level (i.e., an even smaller geographic unit). Finally, I distinguished between different indicators of greenspace: proportions of total green land cover, total green land use, parks & gardens, natural & semi-natural urban greenspaces, and outdoor sports facilities. To this day, there is only little evidence for the roles of different types of green spaces in child and adolescent mental health and well-being. Therefore, the present study is an important contribution to the literature. I addressed the following research questions:

1. Is there an association between neighbourhood greenspace quantity and children's and adolescents' mental health and well-being?
2. Is this association different for different measures of greenspace (i.e., proportions of green land cover, green land use, parks & gardens, natural & semi-natural urban greenspaces, and outdoor sports facilities)?

I hypothesised that higher levels of neighbourhood greenspace quantity are associated with higher levels of mental health and well-being (i.e., lower levels of difficulties and higher levels of well-being), even after full adjustment for confounders. Because this study was partly explorative, I did not have more specific hypotheses about which types of green spaces may be associated with what outcomes and in which age group.

6.2. Methods

Study Area

In this project, I focused on the London region which consists of Greater London and the City of London. London is located in the southeast of England and is made up of 33 local government districts: 32 Greater London boroughs and the City of London. These are divided into 4,835 Lower Layer Super Output Areas (LSOAs). A LSOA is a unit of Census geography in the UK with a minimum population of 1,000 and a maximum population of 3,000 (*2011 Census - Office for National Statistics*, n.d.). Noteworthy, because LSOAs are based on population statistics, they vary in size and shape.

Levels of Geography

In this study, I used two levels of geography for the calculation of green land cover and green land use variables: LSOAs and postcodes. For exposures at LSOA level, I used LSOA boundaries from the 2011 Census. My study sample lived in 1,156 LSOAs. For exposures at postcode level, I calculated circular buffers around postcode means. My study sample lived in 1,774 postcodes. For my main analysis, I used a radius of 500 m. This radius falls within the range of radii commonly used in the literature (see my literature review in Chapter 2), and three of the four studies revisited earlier used a 500 m radius (Maes et al., 2021; Markevych et al., 2014; Richardson et al., 2017). At a walking speed of 5 km/h, a distance of 500 m could be completed in 6 minutes. Depending on several factors (e.g., walking speed and road network layout), one may need longer, but even a 10-minute walk would probably be an acceptable 'distance' (Nordbø et al., 2018). A study on young adolescents (with a mean age of 12 years) from New Zealand found that they spent most of their time out of school within 500 m of their homes (Chambers et al., 2017). Although larger buffers would capture even more of children's and adolescents' activity spaces, they would also capture more space that is not actually used (A. Christensen et al., 2021). For these reasons, I decided to use a 500 m buffer for my main analysis. Nonetheless, because it is unclear what buffer size may best approximate exposure, in a sensitivity analysis, I used buffers with radii of 300 m and 1,000 m. For practical reasons, I did not assess smaller or larger buffers. Smaller buffers were more likely to include zero green land use, and a large number of individuals would have been assigned a value of 0%. Larger buffers were associated with a decrease in sample size, as I excluded individuals whose buffers overlapped with London's outer boundary.

Study Sample

For this study, I used data from Understanding Society (University of Essex Institute for Social and Economic Research, 2020, 2021, 2022), the UK Household Longitudinal Study (UKHLS), which includes data on members of approximately 40,000 UK households at Wave 1 (2009–2011). The UKHLS sample consists of four sub-samples: the General Population Sample, the Ethnic Minority Boost Sample, the British Household Panel Survey sample (added in Wave 2), and the Immigrant and Ethnic Minority Boost Sample (added in Wave 6). The General Population Sample is divided into the Great Britain sample, a stratified and clustered probability sample, and the Northern Ireland sample, a simple random sample with twice the selection probability. To this day, there are data for 10 waves available. For this study, I used data on children and adolescents (0 to 15 years) from Waves 1 to 8 (2009–2018). I did not use data from later waves, as these were not available when I applied for 'special licence' and 'secure access' data that I used in this study (e.g., LSOAs and postcode grid references). I used data from the child dataset (based on parent-reports) and the youth dataset (based on self-reports from 10- to 15-year-olds). To these, I linked information on parents, families, and neighbourhoods. More information about the UKHLS data and study design is provided in the UKHLS user guide (Institute for Social and Economic Research, 2020) or on the UKHLS website (*Understanding Society – The UK Household Longitudinal Study*, n.d.). I will now describe child and youth samples in more detail.

Children (5 and 8 years)

The child dataset includes data on children between 0 and 15 years. These data are parent-reported. The mental health outcome considered in this study, the Strengths and Difficulties Questionnaire (SDQ), was assessed at Waves 3 to 8, but only for children at the age of 5 and 8 years. As illustrated in Figure 6.1 (top panel), there were 10,388 observations across Waves 3 to 8, clustered in 8,138 children at the age of 5 and 8 years. However, my analytic sample included only those children who lived in London, had valid data on the study outcome (SDQ) for at least one wave, and had a non-zero study weight (n = 740). Note that I excluded children with a zero study weight because a weight of zero means that these children should not be considered in the analysis. In a weighted analysis, children with a weight of zero would not change the estimated coefficient, but they would change the standard errors and, therefore, associated p-values and confidence intervals. Therefore, to ensure that only children with a non-zero study weight contributed to all estimates, I excluded those with a weight of zero from my analytic sample. As some children had data for more than one wave, there were 895 observations included.

Adolescents (10 to 15 years)

The youth dataset includes data on adolescents between 10 and 15 years. These data are self-reported. Mental health and well-being outcomes considered in this study, the SDQ, self-esteem, and happiness, were measured at Waves 1, 3, 5, and 7 (SDQ); Waves 2, 4, 6, and 8 (self-esteem); and Waves 1 to 8 (happiness). As illustrated in Figure 6.1 (bottom panel), there were 32,404 observations across Waves 1 to 8, clustered in 12,675 adolescents at the age of 10 to 15 years. However, my analytic sample included only those adolescents who lived in London, had valid data on at least one of the three study outcomes (i.e., SDQ, self-esteem, happiness) for at least one wave, and had a non-zero study weight (n = 1,879). As some adolescents had valid data for more than one wave, there were 4,217 observations included. Note, however, that exact numbers depended on the outcome because outcomes were measured at different waves.

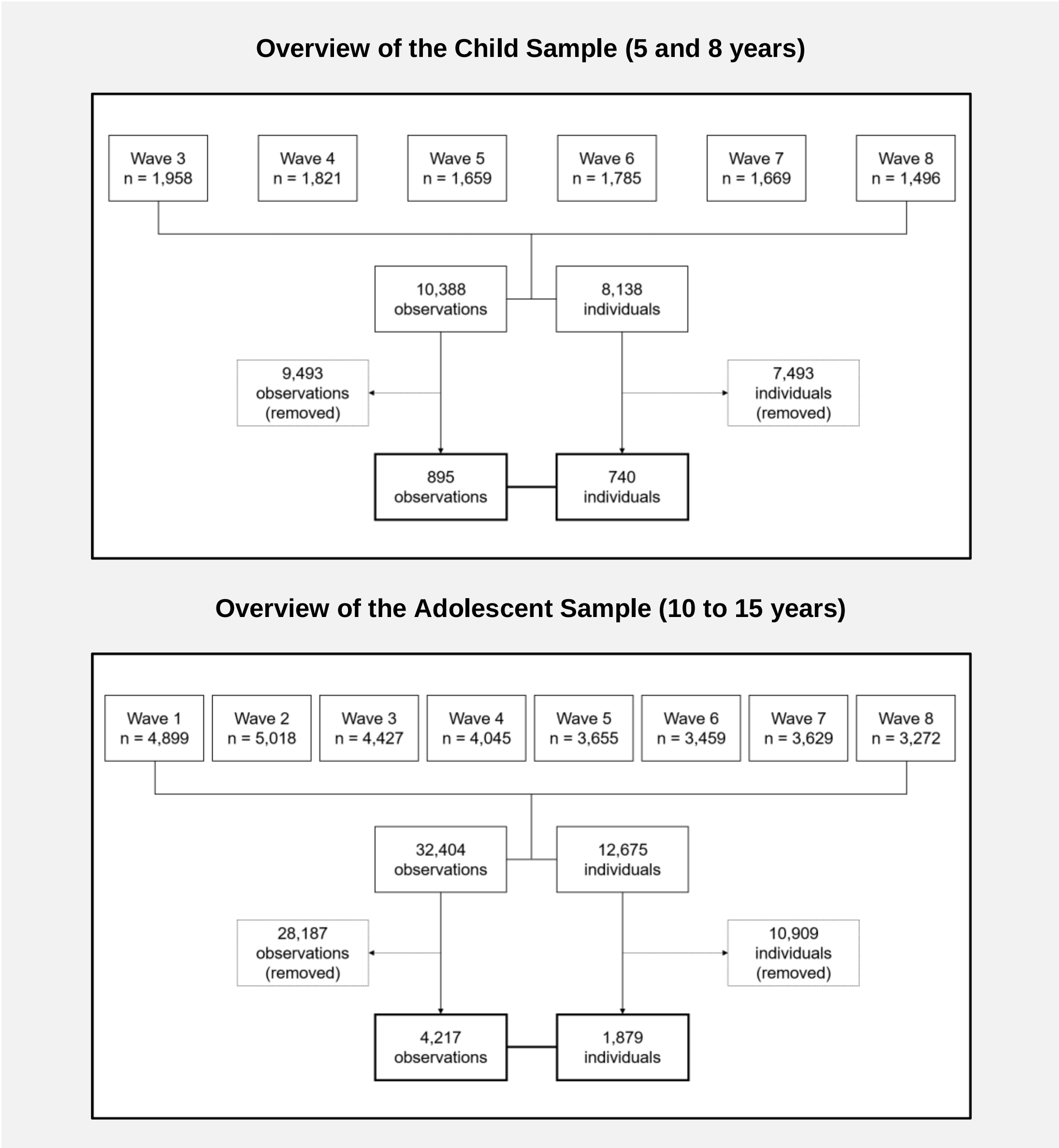


Figure 6.1 Overview of the study samples. Top panel: Across Waves 3 to 8, 10,388 observations were clustered in 8,138 children (at the age of 5 or 8 years). Of these 8,138 children, 740 lived in London, had data on the study outcome (SDQ), and had a valid (non-zero) study weight. There were 895 observations clustered in the 740 children. **Bottom panel:** Across Waves 1 to 8, 32,404 observations were clustered in 12,675 adolescents (at the age of 10 to 15 years). Of these 12,675 adolescents, 1,879 lived in London, had data on at least one of the study outcomes (SDQ, self-esteem, happiness), and had a valid (non-zero) study weight. There were 4,217 observations clustered in the 1,879 adolescents. Noteworthy, because not all outcomes were measured at all waves, the sample sizes differed between outcomes. The SDQ was measured at Waves 1, 3, 5, and 7; self-esteem was measured at Waves 2, 4, 6, and 8; and happiness was measured at Waves 1 to 8.

Study Variables

Mental Health and Well-Being

Adolescents (10- to 15-year-olds)

Mental health was measured with the self-reported Strengths and Difficulties Questionnaire (SDQ) at Waves 1, 3, 5, and 7. The SDQ is a validated and widely used index of emotional and behavioural difficulties, i.e., emotional symptoms, conduct problems, hyperactivity and inattention, and peer relationship problems (R. Goodman, 1997; R. Goodman et al., 1998). Each of the subscales includes five items which are rated on a scale ranging from 0 ('not true') to 2 ('certainly true'). The scale *emotional symptoms* includes the items 'I worry a lot', 'I am often unhappy, downhearted or tearful', 'I have many fears', 'I get a lot of headaches, stomach-aches or sickness', and 'I am nervous in new situations'. The scale *conduct problems* includes the items 'I get very angry and often lose my temper', 'I fight a lot', 'I take things that are not mine from home, school or elsewhere', 'I am often accused of lying or cheating', and 'I usually do as I am told' (reversed). The scale *hyperactivity and inattention* includes the items 'I am restless', 'I am easily distracted', 'I am constantly fidgeting or squirming', 'I think before I do things' (reversed), and 'I finish the work I'm doing' (reversed). The scale *peer relationship problems* includes the items 'I am usually on my own', 'Other children or young people pick on me', 'I get on better with adults than with people my age', 'I have one good friend or more' (reversed), and 'Other people my age generally like me' (reversed). The scores for each subscale range between 0 and 10, and the 20 items of the four subscales can be combined to a total difficulties score ranging from 0 to 40. The Cronbach's alpha values (for Wave 1) were .65 (emotional symptoms), .61 (conduct problems), .64 (hyperactivity and inattention), .53 (peer relationship problems), and .76 (total difficulties). Due to the (especially) low internal consistency, results regarding peer relationship problems should be taken with caution.

Mental well-being was measured with two scales: self-esteem and happiness. Self-esteem was measured with eight items at Waves 2, 4, 6, and

8: ‘I feel I have a number of good qualities’, ‘I don’t have much to be proud of’ (reversed), ‘I certainly feel useless at times’ (reversed), ‘I am as able as most people’, I am a likeable person’, ‘I can usually solve my own problems’, ‘I am inclined to feel I am a failure’ (reversed), and ‘At times I feel I am no good at all’ (reversed). Each item was rated on a scale from 1 (‘strongly disagree’) to 4 (‘strongly agree’). The self-esteem scale score is the mean of the eight items. The Cronbach’s alpha value for the self-esteem scale was .76 (for Wave 2). Happiness (or life satisfaction) was measured with six items at Waves 1 to 8: ‘How do you feel about (a) your schoolwork, (b) your appearance, (c) your family, (d) your friends, (e) your school, and (f) your life as a whole?’ Each item was rated on a scale ranging from 1 (‘not at all happy’) to 7 (‘completely happy’). The happiness scale score was the mean of the six items. The Cronbach’s alpha value for the happiness scale was .76 (for Wave 1).

Children (5- and 8-year-olds)

Mental health was measured with the parent-reported SDQ, but only at Waves 3 to 8, and only for 5- and 8-year-old children. Items and scales are the same as for adolescents (see above). Note, however, that the phrasing of items differed because the SDQ for children was parent-reported. The Cronbach’s alpha values (for Wave 3) were .63 (emotional symptoms), .56 (conduct problems), .69 (hyperactivity and inattention), .29 (peer relationship problems), and .74 (total difficulties). Due to the low internal consistencies, results regarding conduct problems and, especially, peer relationship problems should be taken with caution. Note that there were no measures of self-esteem or happiness for children under the age of 10 years.

Green Land Use

In this project, I used data from Greenspace Information for Greater London, or GiGL (*Greenspace Information for Greater London CIC*, n.d.). GiGL, a community interest company, works with the Greater London Authority (GLA) and the London boroughs to curate and share data on London’s natural environment. The GiGL open space dataset includes information on 12,781 open spaces (version 2020/2021). These open spaces are categorised into 11 categories based on the 2002 Planning Policy Guidance 17 (PPG17; Department for Communities and Local Government, n.d.): parks & gardens; natural & semi-natural urban greenspaces; green corridors; outdoor sports facilities; amenity; children & teenagers; allotments, community gardens, & city farms; cemeteries & churchyards; other urban fringe; civic spaces; and other. These are further divided into 41 subcategories. For a description of all categories, please see Table 6.1. In addition to information on the type of open space, the GiGL open space dataset includes information on other non-spatial attributes, such as type of access (i.e., free, part free, de facto, part de facto, restricted, part restricted, or none) and site designations (i.e., statutory, non-statutory, and landscape designations).

Not all of the 12,781 open spaces are relevant for children and adolescents. I was interested in open spaces that could benefit children's and adolescents' mental health and well-being. To make a decision on what types of open spaces to include, I considered the general functions of greenspace proposed by Markevych et al. (2017), as described in my introduction in Chapter 1: reducing harm, restoring capacities, and building capacities. In theory, most types of open spaces would support at least one of the three pathways. However, many open spaces in London are not public, as they have restricted or no access (e.g., private woodlands, allotments, and equestrian centres). Therefore, children and adolescents may not be allowed to use these spaces. For this reason, I included only those open spaces that could be accessed and used by children and adolescents (and excluded open spaces with restricted or no access). Applying this criterion, I retained 5,845 open spaces. Please see Figure 6.2 for maps of all open spaces (top panel) and 'free access' open spaces (bottom panel) in London.

However, I did not use all 5,845 open spaces but focused on three open space categories: parks & gardens, natural & semi-natural urban greenspaces, and outdoor sports facilities. I focused on these categories for three reasons. First, these are the largest open space categories, covering more of London's area than other open spaces. Therefore, these categories make up a large proportion of London's open space and may have a particular relevance for children and adolescents. Further, some of the other categories (e.g., 'children and teenagers') included only few open spaces or covered only a small area of London. Therefore, it was not practical to investigate the role of all 11 types of open spaces. Second, not all types of open spaces are necessarily green. Some may include vegetation but may not be characterised by it (e.g., civic spaces). The three types of open spaces included in this study can be assumed to be green, at least to some extent, but they are associated with different levels of greenery and naturalness, and have different primary functions (see Table 6.1). On average, natural & semi-natural urban greenspaces are the most natural and biodiverse, parks & gardens are more formal and function (mainly) as spaces for recreation, and outdoor sports facilities are the least natural and function (mainly) as spaces for activity and exercise. Third, related to the primary functions, it is plausible that all three types of open spaces may have benefits for children's and adolescents' mental health and well-being, via mitigation, restoration, and/or instoration pathways. Noteworthy, Houlden et al. (2021), who investigated the role of greenspace in the mental well-being of adults living in London, took a similar approach to using GiGL data. Focusing on these three open space categories reduced the number of open spaces to 2,521. There were 1,327 parks & gardens, 522 natural & semi natural urban greenspaces, and 672 outdoor sports facilities. Potential limitations of this approach will be discussed in the Discussion section (see section 6.4).

LSOAs

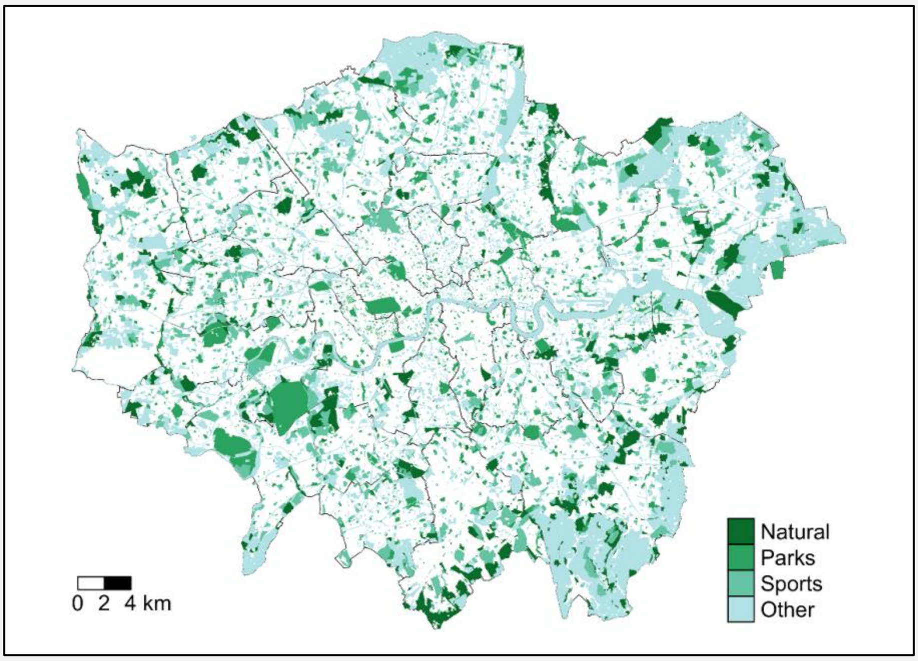
I calculated three proportions for each LSOA, using R as a Geographic Information System (GIS). I used functions from the *tidyverse* package (Wickham et al., 2019) and the *sf* package (Pebesma, 2018) to clean the data, to make geometries topologically valid, and to create exposure variables. All open spaces and LSOAs had geometry information linked to them and shared the same Coordinate Reference System (CRS), the British National Grid (a projected CRS). Using this geometry information, I calculated the spatial intersections of open spaces and LSOAs, and the area of these intersections (in m^2). I used this approach for each of the three subsets to calculate how much area of the LSOAs was covered by each of the three types of green spaces (in %): parks & gardens, natural & semi-natural urban greenspaces, and outdoor sports facilities. Further, I calculated a green land use measure that combined the three types of green spaces into one green land use variable. Please see Figure 6.3 (top panel) for a visualisation of the proportions of ‘free access’ green land use for London LSOAs.

Table 6.1 Greenspace Information for Greater London (GiGL) open space categories

Parks and Gardens	**Parks** refer to traditional public open spaces laid out formally for leisure and recreation. They usually include a mixture of lakes, ponds, lidos, woodland, flower beds, shrubs, ornamental trees, play spaces, toilets, cafes, and car parks. **Formal gardens** refer to spaces with well-defined boundaries that display high standards of horticulture with intricate and detailed landscaping.
Natural and Semi-Natural Urban Greenspaces	**Commons** are publicly accessible open spaces with few, if any, facilities. They will typically be mainly rough open grassland or woodland and are less formal than parks or parkland. **Country parks** are large areas set aside for informal countryside recreation near or within towns and cities. **Private woodland** is woodland not accessible for recreational use and not managed for nature conservation. **Public woodland** is woodland accessible for recreational use but not managed for nature conservation. **Nature reserve** is a category reserved for an open space that is managed primarily for nature conservation.
Green Corridors	Rivers, canals, railways cuttings and railway embankments, disused railway track beds, road islands/verges, and walking/cycling routes.
Outdoor Sports Facilities	A **recreation ground** is an area of mown grass used primarily for informal, unorganised ball games and similar activities (including dog walking). **Playing fields** comprise playing pitches, usually for football, but also for rugby and hockey, and in summer, for cricket. **Golf courses** and **other recreational spaces** are exclusively/predominantly used for organised sports.
Amenity	**Amenity green space** is an expanse of grass used for informal recreation. There will be few, if any, facilities. **Village green** is an expanse of grass in the centre of old villages, often used for cricket. **Hospital grounds** are the grounds of any clinic or health centre. **Educational grounds** are school or college grounds and field study centres where school education is the primary function. **Landscaping around premises** includes communal amenity space around housing estates, community centres, and landscaping around industrial premises. **Reservoirs** are covered reservoirs (unless these form part of a park).
Children and Teenagers	**Play spaces** are sites set aside mainly for children. They will contain the usual assortment of swings, slides, and roundabouts. **Adventure playgrounds** are defined play areas for children in a supervised environment. **Youth areas** are defined areas for teenagers, including skateboard parks, outdoor basketball hoops, and other informal areas.
Allotments, Community Gardens, and City Farms	**Community gardens** (areas that are generally managed and maintained by the local population as a garden), **city farms** (areas that are generally managed and maintained as a small farm by the local population), and **allotments.**
Cemeteries and Churchyards	Cemeteries and churchyards include burial grounds, graveyards, crematorium grounds, and memorial gardens, and gardens or grounds of non-Christian places of worship.
Other Urban Fringe	**Equestrian centres** (include any land used for intensive horse keeping and riding), **agriculture** (includes arable and grazing land, including horse grazing and market gardening), and **nursery/horticulture.**
Civic Spaces	**Civic/market squares** (include tarmac areas or paved open spaces which may or may not include planting) and **other hard surfaced areas.**
Other	Sewage/water works, disused quarry/gravel pit, vacant land, land reclamation, and other space that could not be classified.

Note. Information taken and adapted from Greenspace Information for Greater London (*Greenspace Information for Greater London CIC*, n.d.).

London's Open Spaces



London's 'Free Access' Open Spaces

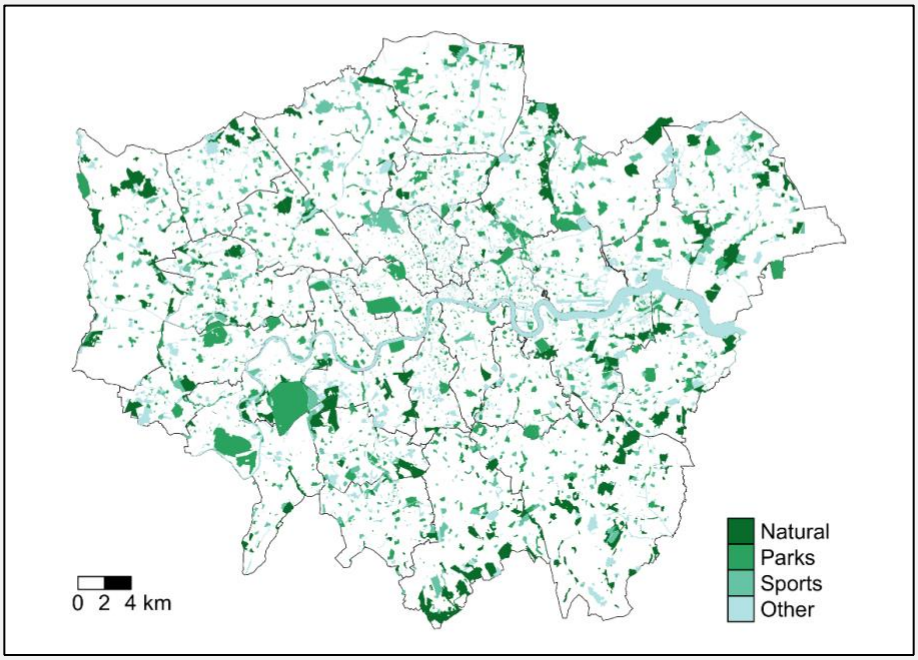


Figure 6.2 Maps of all GiGL open spaces (top) and GiGL open spaces with free or de facto access (bottom). Natural: natural & semi-natural urban greenspaces; Parks: parks & gardens; Sports: outdoor sports facilities; Other: all other open spaces. Maps display GiGL data [2020]. Maps contain National Statistics data © Crown copyright and database right [2015]. Maps contain Ordnance Survey data © Crown copyright and database right [2015].

Postcodes

In addition to calculating exposures at LSOA level, I calculated exposures at postcode level. For each child and adolescent in my study sample, I had a postcode grid reference. I used these as proxies for children's and adolescents' homes. Using the *sf* package in R (Pebesma, 2018), I calculated circular buffers around postcode grid references and spatially intersected these buffers with open spaces to calculate proportions of parks & gardens, natural & semi-natural urban greenspaces, outdoor sports facilities, and the combination of the three types of green land use. As mentioned earlier, I used a 500 m radius to calculate circular buffers. As it is still unclear what radius best approximates actual exposure, and whether different types of green spaces may have a different relevance within different distances, I ran a sensitivity analysis for 300 m and 1,000 m buffers (reported in the appendix). As described above, I did not use smaller or larger radii for practical reasons. Smaller radii were associated with large numbers of 0% green land use. This is because the smaller the buffer, the greater the probability that it does not intersect with 'free-access' green land use. For example, the following are the percentages of buffers with 0% 'free-access' natural or semi-natural urban greenspaces: 46% in 1,000 m; 75% in 500 m; 88% in 300 m; and 97% in 100 m. Similar trends could be observed for parks & gardens and outdoor sports facilities. Larger radii, on the other hand, may not accurately represent children's and adolescents' activity spaces because they capture more space that is not actually used by children and adolescents. Further, because I excluded children and adolescents whose buffers intersected with London's outer boundary, larger buffer sizes were associated with a greater decrease in sample size (because larger buffers on the outskirts of London were more likely to intersect with London's outer boundary).

Green Land Cover

In addition to GiGL data, I used London Green and Blue Cover data which are provided by the GLA (*London Green and Blue Cover - London Datastore*, n.d.). The green and blue cover data are based on 2016 aerial imagery that were supplemented with land use data. The dataset includes information on all areas of green and blue spaces in London. Each green and blue area is captured as a polygon with geometry information linked to it. For this study, I used data on green cover only, which captures even small areas of vegetation, such as tree canopy, private gardens, and green roofs. The green cover data can be used to assess the greenness of an area and are, therefore, a good complement to GiGL open space data (which provide information on types of green spaces but not on greenness). More information on how London green cover was calculated can be found online (*London Green and Blue Cover - London Datastore*, n.d.).

The GLA provide two sets of data, one using a NDVI threshold of .1, the other using a NDVI threshold of .05. In their documentation, the GLA report that the .05 data are more accurate, so I decided to use the .05 data. The green cover data are complex and large (in bytes). Considering data volume and processing time, the GLA had taken measures to reduce the size of the data. One of these was to tile the original file, covering all of London, into multiple smaller files. The GLA chose a 2 km by 2 km tile grid, resulting in a total of 467 tiles. Each of the tiles was provided as a shapefile that contained green and/or blue polygons. As mentioned above, I only used green polygons in my analysis.

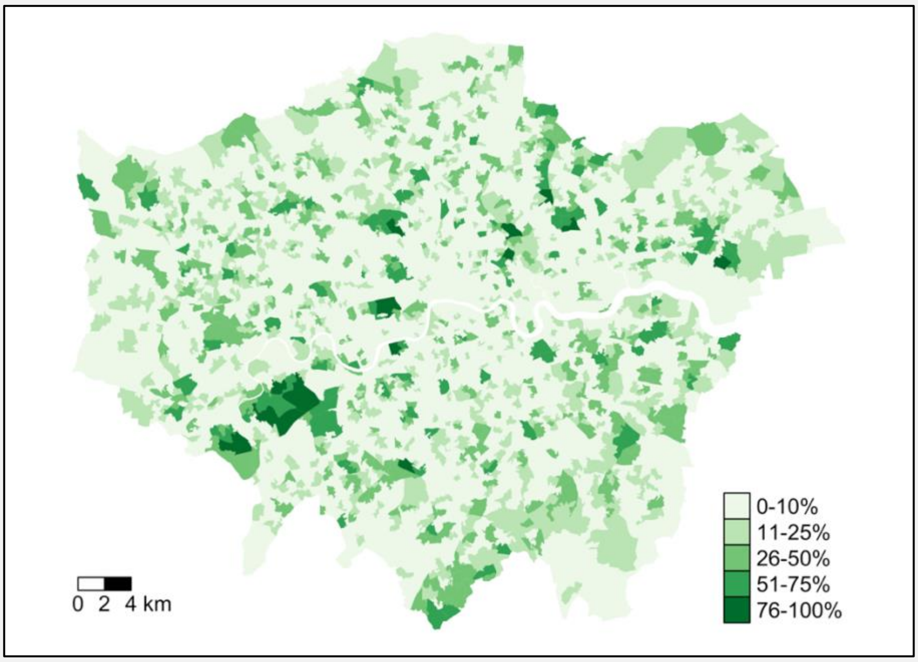
LSOAs

To calculate the proportion of green cover for each of the 4,835 LSOAs, I had to handle the very large size of the data. After importing a shapefile, I simplified the geometries using a function of the *rmapshaper* package (Teucher & Russell, 2022). Simplifying geometries makes the spatial object smaller and easier to work with. The function allowed me to specify the proportion of vertices to keep of the original polygons. The default is set to 5%, but I decided to keep 10% to retain more information. Simplifying the geometry of a polygon changes its area. As I was interested in the proportion of green cover for each LSOA, I wanted to minimise changes in area as much as possible. By keeping 10% of the original vertices, I found a good balance between accuracy and object size. For example, one of the 467 tiles had a size of 684,624 bytes and its polygons covered an area of 883,650 m^2. By simplifying the polygons and keeping 10% of the original vertices, I reduced the object size significantly to 204,880 bytes, but the area covered changed only slightly to 883,401 m^2. Again, I used geometry information to spatially intersect green cover polygons with LSOAs. I then calculated how much area of each LSOA was covered with green land cover (in %). Please see Figure 6.3 (bottom panel) for a visualisation of the proportions of green land cover for London LSOAs.

Postcodes

As for green land use, I calculated proportions of green land cover at postcode level, using circular buffers with a radius of 500 m. I spatially intersected these buffers with the green polygons of the London Green and Blue Cover data and calculated the area of green cover for each circular buffer (in %). Again, I decided to also run analyses for 300 m and 1,000 m buffers (reported in the appendix).

Proportions of 'Free Access' Green Land Use (for London's LSOAs)



Proportions of Green Land Cover (for London's LSOAs)

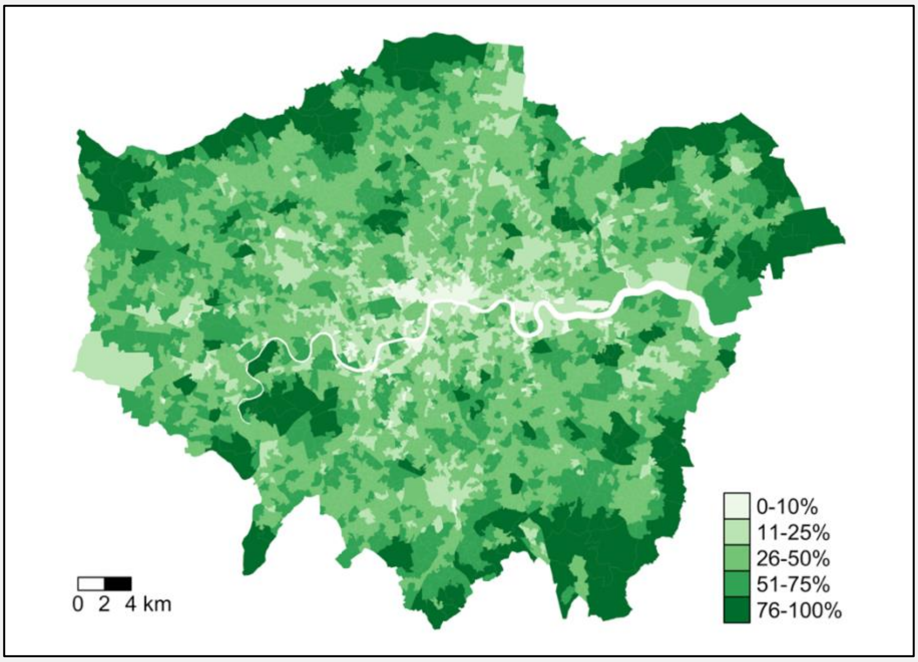


Figure 6.3 Proportions of 'free access' green land use (top) and green land cover (bottom) at LSOA level. The top map is derived from GiGL data [2020]. The bottom map contains UKMap data. Both maps contain National Statistics data © Crown copyright and database right [2015]. Both maps contain Ordnance Survey data © Crown copyright and database right [2015, 2019].

Neighbourhood-Level Confounders

I included three neighbourhood-level confounders: air pollution, deprivation, and LSOA size. Air pollution was measured with NO_2 data provided by the GLA and Transport for London (TfL) for the years 2010, 2013, and 2016 (*Air Quality Data – London Datastore*, n.d.). NO_2 data (alongside other pollutants) are provided as annual mean concentrations (µg/m^3) that have been modelled using the London Air Quality Toolkit (LAQT) model. The LAQT model uses a kernel modelling technique to describe the dispersion from emission sources (i.e., road transport; aviation; river; rail; industry; gas heating; domestic and commercial fuels; biomass burning; cooking emissions; and other sources). The contributions of these sources were summed and mapped on a 20 m by 20 m grid. Model results were validated by evaluating modelled data against fixed site measurements. Using modelled data, I calculated the average annual mean NO_2 concentration for each LSOA (for the LSOA analysis) and each 500 m buffer (for the postcode analysis), calculating the mean concentration of all 20 m by 20 m squares that spatially intersected with each LSOA and circular buffer. I linked the data of all three years (2010, 2013, and 2016) to UKHLS waves. Depending on when UKHLS data were collected, I linked air pollution data from 2010 (Waves 1 and 2), 2013 (Wave 3, 4, and 5), and 2016 (Waves 6, 7, and 8).

Area deprivation was measured with the 2011 Carstairs Deprivation Index at LSOA level (Carstairs & Morris, 1989; B. Wheeler, 2014). The Carstairs Index is the sum of the *z*-scores of four unweighted Census variables: proportions of low social class households; households with no car or van; overcrowded households; and male unemployment. The Carstairs Deprivation Index reflects the level of socio-economic deprivation at LSOA level, with higher sums of *z*-scores indicating higher levels of deprivation.

LSOA size was measured as area in km^2. LSOAs on the outskirts of London tend to be larger and tend to have higher proportions of greenspace than LSOAs in the centre of London. Therefore, I included LSOA area (in km^2) as a confounder in the LSOA-level analysis.

Family- and Child-Level Covariates

Family-level covariates were maternal mental health, maternal education, home ownership, and family structure. Maternal mental health was measured with the 12-item version of the General Health Questionnaire (GHQ). The GHQ scale score ranges from 0 to 36, with higher scores indicating higher psychological distress. Maternal education was measured with a binary variable (if mother had a University education; no/yes). Home ownership (whether the family owned their home; no/yes) and family structure (whether the child lived with two natural [i.e., biological] parents; no/yes) were also measured with binary variables. Child-level covariates were sex (male/female) and ethnicity (White, Mixed, Indian, Pakistani and Bangladeshi, Black, and Other). Because I was using data of multiple waves, I also included a dummy variable for wave. Note that I also considered 'residential mobility' as a covariate. However, there are two reasons why I omitted this variable. First, in the UKHLS, residential mobility was only assessed for adults, not children or adolescents, and the residential mobility variable was not the same across waves. Therefore, I had to combine different variables into one and make several assumptions to infer children's and adolescents' residential mobility from these data. Second, based on these assumptions, across waves, the proportion of children and adolescents from London who had moved was small (i.e., around 5% and 4%, respectively), so I decided to remove the residential mobility variable from my analysis.

Statistical Analysis

I would like to note that most analyses for this study had to be carried out in the UK Data Service (UKDS) SecureLab. This is because postcode grid references are highly sensitive and confidential data that are controlled and not accessible under an End User Licence or a special licence. The UKDS SecureLab is a secure digital environment that can only be accessed from an office desktop PC with a static IP address. To get access to controlled data and the UKDS SecureLab, I had to complete a detailed application form, justifying why I needed access to the SecureLab. I also had to attend an in-person training day and pass a test before I got access to the SecureLab. Due to this thorough process and severe delays caused by the Covid-19 pandemic, it took me about two years to get access to the SecureLab. Once I had access to the SecureLab, I had to request the import of external data, filling in a separate import request form for each dataset I wanted to import. All analyses had to be run in the SecureLab, and to use my outputs outside the SecureLab (e.g., for a paper or this chapter), I had to request the release of outputs. Only after passing disclosure controls by the UKDS, I received my outputs which I then could not change anymore (except I went through the output release process again).

All analyses were conducted in Stata 16. To assess the associations of neighbourhood green land use and green land cover with child and adolescent mental health and well-being, I fitted five linear regression models for each outcome (i.e., one for each of the five exposures). I adjusted each model for air pollution, deprivation, LSOA area (in the LSOA-level analysis), maternal mental health, maternal education, home ownership, family structure, sex, ethnicity, and wave. I stratified each model by age (i.e., I ran each model for the eight age groups separately). The reason for this I will describe below. All models accounted for the complex sampling design of the UKHLS (i.e., clustering and stratification), and for selection into the study and selective attrition over time (using study-specific weights). Noteworthy, because the green land use variables had a large number of 0%s and were skewed, I transformed these exposure variables, using a cube root transformation. The cube root transformation reduces the impact of extreme values while keeping a good level of variation. Note that I did not transform the green land cover variable. Also note that, for the postcode analysis, I only included children and adolescents whose 500 m buffers were fully within London (i.e., did not overlap with London's outer boundary).

Considering the UKHLS's study design, one challenge was to make the most of the child and youth data. In the UKHLS, an individual is considered a child when they are between 0 and 15 years old, and youth when they are between 10 and 15 years old. This means that, depending on age at study entry, some individuals will never be considered a child or youth, some individuals will be considered a child or youth at one wave, and some individuals will be considered a child or youth at multiple waves. Due to this study design, child and youth data are not suitable for longitudinal analyses and there are no longitudinal weights available. To avoid using data of only one wave and to make the most of the data, it is possible to pool the data of the eight cross-sectional datasets into one cross-sectional analysis. This is the approach I have taken for analysing child and youth data. However, because some individuals had child or youth data at multiple waves, some individuals contributed more than one observation to the analysis and, thus, observations were not independent. To address this, I pooled the data of the eight waves and ran separate models for each age group (i.e., 5, 8, 10, 11, 12, 13, 14, and 15 years). This ensured that each model included only one observation per individual. It also allowed me to assess age-specific ‘effects’.

Some covariates had missing data. Under the assumption that missing data were missing at random (MAR), I imputed missing data using multiple imputation by chained equations (MICE; Raghunathan et al., 2001). For each analysis, I generated 25 imputed datasets and used Rubin’s combination rules to pool the individual estimates into a single set of multiply imputed estimates (Rubin, 1987). Around 95% of children (5 and 8 years) had complete data. The highest proportion of missingness observed was for maternal education (around 4%). Around 74% of adolescents (10 to 15 years) had complete data. The highest proportion of missingness observed was for maternal psychological distress (around 24%). Note that these numbers are averages. The exact amount of missingness differed depending on the age and outcome investigated in a given analysis.

Sensitivity Analysis

To test for the robustness of results, I ran a series of sensitivity analyses. First, I ran analyses for buffer sizes of 300 m and 1,000 m. Using multiple buffer sizes is a common approach to assess whether results generalise to smaller (more proximal) and larger (more distal) exposure areas. Second, another way to assess exposure is measuring the distance to the nearest greenspace, thereby focusing on accessibility (not availability). In particular, I assessed whether using distances (to the closest park or garden; natural or semi-natural urban greenspace; and outdoor sports facility) as exposures would lead to different conclusions than using availability (i.e., proportions in 500 m around the home). Finally, I transformed raw green land use data into binary variables (comparing children/adolescents with 0% green land use in their neighbourhood with children/adolescents with at least some green land use), and into variables with three categories (i.e., ‘zero’, ‘some’ [> 0 AND < median], and ‘more’ [> median] green land use). This way I could test for potential non-linear associations.

6.3. Results

In this section, I will report results based on the 500-m-buffer analysis. Results for the LSOA analysis and for sensitivity analyses are reported in the appendix (Appendix 1, Table A6.1.1 to Table A6.4.7). Because the analyses that tested for non-linear associations did not provide additional insight or clarity, and for reasons of parsimony, these results are omitted from the main text and the appendix.

Descriptive Statistics

Table 6.2 and Table 6.3 summarise descriptive statistics for children (5- and 8-year-olds) and adolescents (10- to 15-year-olds). Descriptive statistics include observations across eight waves. Therefore, the numbers 895 and 4,217 do not refer to individuals but to observations, as illustrated in Figure 6.1 above. The samples had generally similar values on study variables. The most pronounced differences could be observed for the SDQ scales, where adolescents appeared to have higher scores (i.e., more problems), and the maternal education variable, where young children seemed to be more likely to have mothers with a University education (59%) than adolescents (41%).

Children and adolescents in the analytic sample may not be representative for children and adolescents in the non-analytic sample. Therefore, as in my previous two studies, I ran a bias analysis to compare analytic and non-analytic samples (also shown in Table 6.2 and Table 6.3). Compared with children in the non-analytic sample, children in the analytic sample had lower scores on the SDQ (i.e., better mental health), lived in more deprived areas, and were more likely to have mothers with a University education. Also, there were differences in ethnicity: children in the non-analytic sample were more likely to be ‘White’ (86%) than children in the analytic sample (57%). Similar differences were found between analytic and non-analytic youth samples. Noteworthy, unlike in my first two studies, descriptive statistics and bias analysis were weighted. This means the bias observed cannot be explained by selection bias, for example, due to selective attrition. Therefore, one should keep in mind that analytic and non-analytic samples differ, so results may not generalise to the rest of the UK.

Table 6.4 and Table 6.5 show correlations between outcomes and exposures, separately for children and adolescents. SDQ outcomes were correlated positively with each other and negatively with self-esteem and happiness. Green land cover and green land use variables were correlated positively. Interestingly, parks & gardens were negatively correlated with natural & semi-natural urban greenspaces and outdoor sports facilities in both samples, whereas the correlation between natural & semi-natural urban greenspaces and outdoor sports facilities was positive only in the adolescent sample. Most importantly there was no significant correlation between any of the outcomes and exposures in the child sample. In the adolescent sample, there were only three significant correlations: both green land cover and green land use were negatively correlated with conduct problems, whereas outdoor sports facilities were positively correlated with happiness. In summary, this suggests that there may be only few associations between green land cover and green land use and children’s and adolescents’ mental health and well-being (in my study sample).

Model Results

In this section, I will describe the regression results for the 500-m-buffer analysis. As mentioned earlier, LSOA analysis and sensitivity analyses are reported in the appendix (Appendix 1, Table A6.1.1 to Table A6.4.7).

Model results for the 500-m-buffer analysis are shown in Table 6.6 to Table 6.12. Each of the seven tables shows results for one of the seven outcomes and is organised by age. For each age, the tables display estimates for each of the five exposures. Note that all estimates are taken from fully adjusted models; however, for reasons of parsimony, I report the five estimates of interest only. Overall, there were only few statistically significant associations, as already suggested by the correlation analysis above. Unlike in the correlation analysis, however, these associations were not all 'positive'. Some coefficients suggest a 'negative' association, i.e., that more greenspace was associated with poorer mental health and well-being. I will now summarise my results briefly. Note that below I use the terms 'positive' and 'negative' to refer to the sign of the association between two variables. An overview of my study results is also provided in Table 6.13 (which, once again, highlights that I observed only few associations relative to the large number of models).

For conduct problems, I found negative associations with green land use in 13-year-olds, and outdoor sports facilities in 14-year-olds. ***For emotional symptoms,*** I found negative associations with green land use and parks & gardens in 13-year-olds, and outdoor sports facilities in 15-year-olds. Noteworthy, I also found positive associations with green land use and parks & gardens in 15-year-olds (suggesting that more greenspace is linked to more problems). ***For hyperactivity and inattention,*** I found negative associations with green land use and parks & gardens in 13-year-olds, and outdoor sports facilities in 14-year-olds. Noteworthy, I also found positive associations with green land cover in 10- and 11-year-olds, and with parks & gardens in 12-year-olds. ***For peer relationship problems,*** I found a negative association with parks & gardens in 13-year-olds. Noteworthy, I also found positive associations with green land use and natural & semi-natural urban greenspaces in 10-year-olds. ***For total difficulties,*** I found negative associations with green land use and parks & gardens in 13-year-olds, and outdoor sports facilities in 14-year-olds. Noteworthy, I also found a positive association with green land cover in 10-year-olds. ***For self-esteem,*** I found a positive association with natural & semi-natural urban greenspaces in 15-

year-olds. ***For happiness,*** I found positive associations with green land use and outdoor sports facilities in 14-year-olds, and green land use in 15-year-olds.

The mixed nature of the results makes it difficult to summarise the main findings. Across outcomes and age groups, there was no consistent pattern of results. However, interestingly, the direction of associations seemed to be different for younger and older adolescents. Except for the positive associations of green land use and parks & gardens with emotional symptoms in 15-year-old adolescents, similar ‘negative’ associations (suggesting a negative association between greenspace and mental health) were only evident in 10- to 12-year-olds. In contrast, in 13- to 15-year-olds, I found ‘positive’ associations between greenspace and mental health and well-being, except for the two ‘negative’ associations in 15-year-olds mentioned above. It seems that older urban adolescents ‘benefit’ from green spaces in their neighbourhoods, whereas younger urban adolescents seem to show more mental health problems when they live in neighbourhoods with more greenspace or greenery.

To test whether this pattern was not an artefact driven by a few (extreme) observations, I ran an additional sensitivity analysis investigating associations with SDQ outcomes in younger and older adolescents separately for each wave (see Table A6.5 in Appendix 1). I grouped 10- to 12-year-olds and 13- to 15-year-olds and, for each wave, ran models for each of the two groups. For Waves 1 and 3, I found ‘positive’ associations in 13- to 15-year-olds. For Wave 7, I found a ‘positive’ association in 13- to 15-year-olds, and several ‘negative’ associations in 10- to 12-year-olds. For Wave 5, however, I found a ‘negative’ association in 13- to 15-year-olds and a ‘positive’ association in 10- to 12-year-olds. Although the sensitivity analysis supported the observation that greenspace may be more ‘beneficial’ for older than for younger adolescents (except for in Wave 5), it should be noted that specific associations were not the same across waves. For example, although I found ‘positive’ associations in 13- to 15-year-olds in both Waves 1 and 3, the specific significant associations were not the same.

In addition to the 500-m-buffer analysis, I ran models using green land cover and green land use exposures measured at different levels of aggregation: LSOA, 300 m buffer, and 1,000 m buffer. Further, I ran models using distances to the closest green land use, park or garden, natural or semi-natural urban greenspace, and outdoor sports facility. I will not describe these results in detail, but tables can be found in the appendix (Appendix 1, Table A6.1.1 to Table A6.4.7). The results of LSOA and 300-m-buffer analyses were similar to the results of the main analysis. The results of 1,000-m-buffer and distance analyses were slightly different and showed generally fewer significant associations. I can summarise that none of the sensitivity analyses provided a clearer pattern of associations than the main analysis. Findings remained mixed and inconsistent across analyses.

Table 6.2 Bias analysis between analytic and non-analytic child samples (5- and 8-year-olds)

	Analytic sample (n = 895)		Non-analytic sample (n = 9,493)		Test
Continuous variables					
	n	*M (SD)*	*n*	*M (SD)*	*F*
SDQ CP (0–10)	895	1.52 (1.55)	7,445	1.78 (1.68)	5.61 *
SDQ ES (0–10)	895	1.62 (1.83)	7,422	1.80 (2.02)	2.05
SDQ HA (0–10)	895	3.32 (2.43)	7,410	3.82 (2.61)	9.55 **
SDQ PP (0–10)	895	1.33 (1.62)	7,430	1.37 (1.68)	0.12
SDQ TD (0–40)	895	7.79 (5.26)	7,352	8.73 (5.95)	5.26 *
Green land cover [%] [1]	881	40.78 (12.71)	-	-	-
Green land use [%] [1]	881	8.88 (9.56)	-	-	-
Parks/gardens [%] [1]	881	4.63 (6.93)	-	-	-
Natural/semi-natural spaces [%] [1]	881	2.37 (6.89)	-	-	-
Outdoor sports facilities [%] [1]	881	1.88 (3.99)	-	-	-
Air pollution [mean NO_2] [1]	881	34.54 (4.54)	-	-	-
Area deprivation [Carstairs z-score]	895	1.38 (3.39)	8,175	-0.03 (3.11)	56.14 ***
Maternal psychological distress (0–36)	893	11.00 (5.67)	7,804	11.58 (5.72)	1.76
Age [years]	895	6.50 (1.50)	9,493	6.46 (1.50)	0.40
Categorical variables					
	n	*%*	*n*	*%*	*F* [2]
University education (mother)	497	58.60	3,699	42.34	19.84 ***
Family owns its home	417	49.10	5,764	57.34	5.97 *
Intact family structure	692	75.37	7,082	74.80	0.03
Ethnicity White	284	57.34	6,602	85.69	143.90 ***
Ethnicity Mixed	155	13.94	789	6.48	26.35 ***
Ethnicity Indian	83	6.53	328	1.95	23.17 ***
Ethnicity Pakistani and Bangladeshi	132	4.99	934	2.67	6.49 *
Ethnicity Black or Black British	181	11.92	468	2.00	94.91 ***
Ethnicity Other	60	5.29	215	1.21	42.46 ***
Female	447	52.46	4,603	49.26	0.99

Note. CP = conduct problems; ES = emotional symptoms; HA = hyperactivity/inattention; PP = peer problems; TD = total difficulties. Data are taken from Waves 3 to 8. Sample sizes refer to observations (not individuals). Some individuals have multiple observations across waves, and these multiple observations are included in the descriptive statistics above. Descriptive statistics by wave and by age group differ slightly, but the overall descriptive statistics in this table give an appropriate overview of the sample characteristics. *N*s are unweighted. *M*s, *SD*s, and *%*s are weighted. [1] Values are for 500 m buffers around postcodes. [2] Design-based *F* statistic (i.e., corrected weighted Chi^2 statistic). *p < .05, **p < .01, ***p < .001.

Table 6.3 Bias analysis between analytic and non-analytic adolescent samples (10- to 15-year-olds)

	Analytic sample (*n* = 4,217)		Non-analytic sample (*n* = 28,187)		Test
Continuous variables					
	n	*M (SD)*	*n*	*M (SD)*	*F*
SDQ CP (0–10)	2,281	2.13 (1.73)	14,119	2.21 (1.81)	1.54
SDQ ES (0–10)	2,281	2.64 (2.14)	14,118	2.88 (2.26)	7.28 **
SDQ HA (0–10)	2,279	3.70 (2.18)	14,115	4.06 (2.34)	22.18 ***
SDQ PP (0–10)	2,279	1.61 (1.54)	14,120	1.82 (1.70)	16.01 ***
SDQ TD (0–40)	2,276	10.09 (5.29)	14,106	10.97 (5.80)	17.79 ***
Self-esteem (1–4)	1,881	3.17 (0.44)	13,819	3.11 (0.44)	8.65 **
Happiness (1–7)	4,202	5.89 (0.87)	28,072	5.81 (0.85)	6.61 *
Green land cover [%] [1]	4,123	38.54 (11.79)	-	-	-
Green land use [%] [1]	4,123	8.69 (9.25)	-	-	-
Parks/gardens [%] [1]	4,123	4.85 (6.97)	-	-	-
Natural/semi-natural spaces [%] [1]	4,123	2.06 (6.10)	-	-	-
Outdoor sports facilities [%] [1]	4,123	1.79 (3.93)	-	-	-
Air pollution [mean NO_2] [1]	4,123	35.32 (5.65)	-	-	-
Area deprivation [Carstairs z-score]	4,217	1.90 (3.49)	23,358	-0.32 (3.04)	135.32 ***
Maternal psychological distress (0–36)	3,203	11.76 (5.96)	24,613	11.96 (5.90)	0.75
Age [years]	4,217	12.42 (1.69)	28,187	12.54 (1.69)	9.59 **
Categorical variables					
	n	%	*n*	%	*F* [2]
University education (mother)	1,560	41.42	10,308	40.05	0.29
Family owns its home	1,805	48.38	19,498	66.45	35.44 ***
Intact family structure	2,826	64.18	18,073	62.77	0.26
Ethnicity White	1,182	53.58	23,262	90.65	359.93 ***
Ethnicity Mixed	534	10.23	1,031	2.85	82.07 ***
Ethnicity Indian	310	6.29	824	1.76	54.23 ***
Ethnicity Pakistani and Bangladeshi	824	7.64	1,980	2.75	47.27 ***
Ethnicity Black or Black British	1,097	17.49	692	1.03	567.74 ***
Ethnicity Other	270	4.77	340	0.96	61.23 ***
Female	2,120	50.75	14,025	49.50	0.36

Note. CP = conduct problems; ES = emotional symptoms; HA = hyperactivity/inattention; PP = peer problems; TD = total difficulties. Data are taken from Waves 1 to 8. Sample sizes refer to observations (not individuals). Some individuals have multiple observations across waves, and these multiple observations are included in the descriptive statistics above. Descriptive statistics by wave and by age group differ slightly, but the overall descriptive statistics in this table give an appropriate overview of the sample characteristics. *N*s are unweighted. *M*s, *SD*s, and %s are weighted. [1] Values are for 500 m buffers around postcodes. [2] Design-based *F* statistic (i.e., corrected weighted Chi^2 statistic). **p* < .05, ***p* < .01, ****p* < .001.

Table 6.4 Correlations between outcomes and exposures (children; n = 895)

	SDQ CP	SDQ ES	SDQ HA	SDQ PP	SDQ TD	Green LC [1]	Green LU [1]	P/G [1]	N/SN UG [1]
SDQ ES	0.343 ***								
SDQ HA	0.436 ***	0.327 ***							
SDQ PP	0.252 ***	0.363 ***	0.231 ***						
SDQ TD	0.688 ***	0.716 ***	0.779 ***	0.610 ***					
Green LC [1]	-0.016	-0.063	-0.001	-0.056	-0.044				
Green LU [1]	0.004	-0.042	0.017	-0.036	-0.016	0.500 ***			
P/G [1]	0.060	0.012	0.012	-0.032	0.017	0.230 ***	0.674 ***		
N/SN UG [1]	-0.065	-0.058	0.008	-0.011	-0.038	0.368 ***	0.496 ***	-0.139 ***	
OSF [1]	-0.010	-0.036	0.006	-0.007	-0.015	0.208 ***	0.364 ***	-0.090 **	-0.007

Note. CP = conduct problems; ES = emotional symptoms; HA = hyperactivity/inattention; PP = peer problems; TD = total difficulties; LC = land cover; LU = land use; P/G = parks/gardens; N/SN UG = natural/semi-natural urban greenspaces; OSF = outdoor sports facilities. Data are taken from Waves 3 to 8. The sample size refers to observations (not individuals). Some individuals have multiple observations across waves, and these multiple observations are included in the correlations above. The sample size used to establish a given correlation depends on the variables involved in that correlation; the smallest sample size is n = 881. [1] Exposures are measured in 500 m buffers around postcodes. *p < .05, **p < .01, ***p < .001.

Table 6.5 Correlations between outcomes and exposures (adolescents; n = 4,217)

	SDQ CP	SDQ ES	SDQ HA	SDQ PP	SDQ TD	Self-esteem	Happiness	Green LC [1]	Green LU [1]	P/G [1]	N/SN UG [1]
SDQ ES	0.260 ***										
SDQ HA	0.513 ***	0.303 ***									
SDQ PP	0.200 ***	0.355 ***	0.179 ***								
SDQ TD	0.707 ***	0.717 ***	0.754 ***	0.574 ***							
Self-esteem	-	-	-	-	-						
Happiness	-0.374 ***	-0.397 ***	-0.367 ***	-0.293 ***	-0.521 ***	0.538 ***					
Green LC [1]	-0.058 **	-0.010	0.029	-0.025	-0.020	-0.033	0.013				
Green LU [1]	-0.049 *	-0.017	-0.012	0.005	-0.028	-0.016	0.023	0.541 ***			
P/G [1]	-0.022	-0.006	-0.014	-0.010	-0.019	-0.027	-0.004	0.266 ***	0.669 ***		
N/SN UG [1]	-0.036	0.002	0.009	0.032	0.002	0.000	0.002	0.343 ***	0.491 ***	-0.137 ***	
OSF [1]	-0.027	-0.030	-0.014	-0.010	-0.030	0.011	0.058 ***	0.306 ***	0.440 ***	-0.074 ***	0.074 ***

Note. CP = conduct problems; ES = emotional symptoms; HA = hyperactivity/inattention; PP = peer problems; TD = total difficulties; LC = land cover; LU = land use; P/G = parks/gardens; N/SN UG = natural/semi-natural urban greenspaces; OSF = outdoor sports facilities. Data are taken from Waves 1 to 8. The sample size refers to observations (not individuals). Some individuals have multiple observations across waves, and these multiple observations are included in the correlations above. The sample size used to establish a given correlation depends on the variables involved in that correlation; the smallest sample size is n = 1,839. There are no correlations between self-esteem and SDQ scales because these outcomes were measured at different waves. Values of 0.000 represent values > 0 AND < 0.001. [1] Exposures are measured in 500 m buffers around postcodes. *p < .05, **p < .01, ***p < .001.

Table 6.6 Regression results for conduct problems (500-m-buffer analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 365)				
Green land cover	-0.015	0.013	[-0.041, 0.010]	0.227
Green land use	0.024	0.127	[-0.229, 0.278]	0.850
Parks/gardens	0.151	0.105	[-0.058, 0.360]	0.154
Natural/semi-natural spaces	-0.092	0.111	[-0.314, 0.129]	0.410
Outdoor sports facilities	0.052	0.128	[-0.203, 0.307]	0.685
14 years (*n* = 349)				
Green land cover	-0.004	0.014	[-0.032, 0.024]	0.774
Green land use	-0.195	0.172	[-0.537, 0.148]	0.261
Parks/gardens	-0.071	0.129	[-0.329, 0.186]	0.583
Natural/semi-natural spaces	-0.084	0.184	[-0.450, 0.281]	0.647
Outdoor sports facilities	-0.291	0.140	[-0.570, -0.012]	0.041
13 years (*n* = 378)				
Green land cover	-0.019	0.018	[-0.056, 0.017]	0.295
Green land use	-0.286	0.131	[-0.547, -0.026]	0.032
Parks/gardens	-0.105	0.108	[-0.321, 0.110]	0.334
Natural/semi-natural spaces	-0.130	0.132	[-0.393, 0.133]	0.327
Outdoor sports facilities	-0.250	0.166	[-0.581, 0.081]	0.137
12 years (*n* = 392)				
Green land cover	0.004	0.009	[-0.014, 0.023]	0.659
Green land use	0.153	0.185	[-0.215, 0.522]	0.410
Parks/gardens	0.111	0.101	[-0.089, 0.312]	0.272
Natural/semi-natural spaces	0.044	0.176	[-0.306, 0.395]	0.802
Outdoor sports facilities	-0.055	0.135	[-0.324, 0.214]	0.686
11 years (*n* = 368)				
Green land cover	-0.010	0.012	[-0.033, 0.013]	0.407
Green land use	-0.217	0.132	[-0.480, 0.047]	0.106
Parks/gardens	0.027	0.136	[-0.243, 0.297]	0.841
Natural/semi-natural spaces	-0.250	0.198	[-0.643, 0.144]	0.211
Outdoor sports facilities	-0.261	0.192	[-0.643, 0.121]	0.178
10 years (*n* = 375)				
Green land cover	0.001	0.013	[-0.025, 0.027]	0.959
Green land use	-0.027	0.247	[-0.519, 0.464]	0.912
Parks/gardens	-0.120	0.163	[-0.445, 0.205]	0.464
Natural/semi-natural spaces	0.075	0.137	[-0.199, 0.348]	0.583
Outdoor sports facilities	0.134	0.181	[-0.227, 0.496]	0.461
8 years (*n* = 451)				
Green land cover	0.000	0.009	[-0.018, 0.019]	0.962
Green land use	-0.030	0.121	[-0.270, 0.210]	0.806
Parks/gardens	0.235	0.121	[-0.005, 0.475]	0.055
Natural/semi-natural spaces	-0.274	0.176	[-0.624, 0.076]	0.123
Outdoor sports facilities	-0.244	0.129	[-0.501, 0.013]	0.063
5 years (*n* = 430)				
Green land cover	0.005	0.008	[-0.011, 0.022]	0.528
Green land use	0.078	0.158	[-0.236, 0.392]	0.624
Parks/gardens	-0.023	0.107	[-0.236, 0.190]	0.827
Natural/semi-natural spaces	0.067	0.185	[-0.300, 0.435]	0.717
Outdoor sports facilities	0.185	0.117	[-0.046, 0.417]	0.115

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. Values of 0.000 represent values > 0 AND < 0.001. The green land cover variable is based on raw data [%], whereas the green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should therefore not be compared to the size of a green land use coefficient.

Table 6.7 Regression results for emotional symptoms (500-m-buffer analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 365)				
Green land cover	0.013	0.010	[-0.006, 0.032]	0.172
Green land use	0.264	0.105	[0.056, 0.473]	0.014
Parks/gardens	0.290	0.111	[0.070, 0.510]	0.010
Natural/semi-natural spaces	0.318	0.189	[-0.059, 0.695]	0.097
Outdoor sports facilities	-0.359	0.164	[-0.686, -0.032]	0.032
14 years (*n* = 349)				
Green land cover	0.009	0.015	[-0.022, 0.040]	0.562
Green land use	-0.329	0.256	[-0.838, 0.181]	0.203
Parks/gardens	0.048	0.185	[-0.319, 0.416]	0.794
Natural/semi-natural spaces	-0.334	0.304	[-0.938, 0.270]	0.274
Outdoor sports facilities	-0.228	0.233	[-0.692, 0.236]	0.332
13 years (*n* = 378)				
Green land cover	-0.025	0.019	[-0.063, 0.013]	0.198
Green land use	-0.312	0.106	[-0.522, -0.102]	0.004
Parks/gardens	-0.290	0.135	[-0.558, -0.021]	0.035
Natural/semi-natural spaces	-0.105	0.137	[-0.379, 0.169]	0.449
Outdoor sports facilities	0.084	0.199	[-0.313, 0.480]	0.676
12 years (*n* = 392)				
Green land cover	-0.006	0.014	[-0.034, 0.021]	0.643
Green land use	0.030	0.217	[-0.401, 0.461]	0.889
Parks/gardens	0.081	0.145	[-0.206, 0.368]	0.576
Natural/semi-natural spaces	0.018	0.218	[-0.416, 0.451]	0.936
Outdoor sports facilities	0.007	0.137	[-0.265, 0.280]	0.957
11 years (*n* = 368)				
Green land cover	0.002	0.011	[-0.021, 0.024]	0.876
Green land use	0.011	0.202	[-0.391, 0.412]	0.957
Parks/gardens	-0.094	0.139	[-0.371, 0.183]	0.503
Natural/semi-natural spaces	0.047	0.213	[-0.377, 0.471]	0.826
Outdoor sports facilities	0.028	0.267	[-0.502, 0.558]	0.916
10 years (*n* = 375)				
Green land cover	0.032	0.019	[-0.006, 0.070]	0.096
Green land use	0.137	0.305	[-0.470, 0.744]	0.654
Parks/gardens	0.068	0.190	[-0.312, 0.447]	0.724
Natural/semi-natural spaces	0.238	0.424	[-0.607, 1.083]	0.576
Outdoor sports facilities	-0.252	0.228	[-0.706, 0.202]	0.273
8 years (*n* = 451)				
Green land cover	0.007	0.026	[-0.044, 0.059]	0.772
Green land use	-0.138	0.198	[-0.533, 0.256]	0.488
Parks/gardens	0.121	0.259	[-0.395, 0.636]	0.643
Natural/semi-natural spaces	-0.214	0.219	[-0.649, 0.222]	0.332
Outdoor sports facilities	-0.146	0.242	[-0.626, 0.334]	0.547
5 years (*n* = 430)				
Green land cover	0.010	0.013	[-0.016, 0.036]	0.457
Green land use	0.136	0.167	[-0.196, 0.467]	0.419
Parks/gardens	-0.006	0.166	[-0.336, 0.325]	0.974
Natural/semi-natural spaces	0.272	0.171	[-0.067, 0.611]	0.115
Outdoor sports facilities	-0.058	0.187	[-0.429, 0.314]	0.758

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. The green land cover variable is based on raw data [%], whereas the green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should therefore not be compared to the size of a green land use coefficient.

Table 6.8 Regression results for hyperactivity and inattention (500-m-buffer analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 365)				
Green land cover	0.005	0.011	[-0.017, 0.028]	0.630
Green land use	0.162	0.137	[-0.111, 0.435]	0.240
Parks/gardens	0.062	0.143	[-0.223, 0.347]	0.665
Natural/semi-natural spaces	0.033	0.127	[-0.220, 0.287]	0.793
Outdoor sports facilities	-0.005	0.161	[-0.325, 0.315]	0.975
14 years (*n* = 349)				
Green land cover	0.004	0.017	[-0.029, 0.037]	0.827
Green land use	-0.024	0.260	[-0.541, 0.492]	0.925
Parks/gardens	0.233	0.204	[-0.172, 0.638]	0.256
Natural/semi-natural spaces	-0.208	0.470	[-1.141, 0.726]	0.660
Outdoor sports facilities	-0.589	0.204	[-0.994, -0.183]	0.005
13 years (*n* = 378)				
Green land cover	-0.021	0.019	[-0.058, 0.017]	0.272
Green land use	-0.322	0.128	[-0.577, -0.067]	0.014
Parks/gardens	-0.299	0.120	[-0.538, -0.061]	0.015
Natural/semi-natural spaces	-0.137	0.169	[-0.473, 0.198]	0.418
Outdoor sports facilities	0.128	0.172	[-0.215, 0.471]	0.459
12 years (*n* = 392)				
Green land cover	0.007	0.012	[-0.018, 0.031]	0.584
Green land use	0.183	0.182	[-0.178, 0.544]	0.316
Parks/gardens	0.235	0.112	[0.012, 0.458]	0.039
Natural/semi-natural spaces	-0.118	0.158	[-0.433, 0.196]	0.456
Outdoor sports facilities	0.135	0.137	[-0.137, 0.407]	0.327
11 years (*n* = 368)				
Green land cover	0.028	0.011	[0.007, 0.049]	0.009
Green land use	0.077	0.132	[-0.186, 0.340]	0.561
Parks/gardens	-0.068	0.120	[-0.307, 0.171]	0.573
Natural/semi-natural spaces	0.136	0.190	[-0.242, 0.514]	0.476
Outdoor sports facilities	0.057	0.213	[-0.367, 0.481]	0.790
10 years (*n* = 375)				
Green land cover	0.037	0.012	[0.013, 0.061]	0.003
Green land use	0.126	0.202	[-0.276, 0.528]	0.534
Parks/gardens	0.117	0.154	[-0.191, 0.424]	0.451
Natural/semi-natural spaces	0.057	0.268	[-0.477, 0.592]	0.832
Outdoor sports facilities	0.084	0.150	[-0.214, 0.382]	0.575
8 years (*n* = 451)				
Green land cover	0.019	0.023	[-0.027, 0.064]	0.419
Green land use	-0.031	0.246	[-0.519, 0.458]	0.901
Parks/gardens	-0.059	0.236	[-0.528, 0.410]	0.804
Natural/semi-natural spaces	-0.052	0.190	[-0.429, 0.325]	0.786
Outdoor sports facilities	-0.156	0.233	[-0.620, 0.307]	0.505
5 years (*n* = 430)				
Green land cover	0.020	0.028	[-0.036, 0.075]	0.480
Green land use	0.303	0.244	[-0.181, 0.787]	0.217
Parks/gardens	0.027	0.267	[-0.503, 0.556]	0.920
Natural/semi-natural spaces	0.476	0.384	[-0.087, 1.040]	0.097
Outdoor sports facilities	-0.041	0.263	[-0.563, 0.482]	0.877

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. The green land cover variable is based on raw data [%], whereas the green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should therefore not be compared to the size of a green land use coefficient.

Table 6.9 Regression results for peer relationship problems (500-m-buffer analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 365)				
Green land cover	-0.008	0.006	[-0.019, 0.004]	0.209
Green land use	0.073	0.089	[-0.103, 0.249]	0.410
Parks/gardens	0.083	0.090	[-0.096, 0.262]	0.358
Natural/semi-natural spaces	0.152	0.079	[-0.006, 0.310]	0.060
Outdoor sports facilities	-0.115	0.110	[-0.335, 0.105]	0.300
14 years (*n* = 349)				
Green land cover	0.001	0.010	[-0.018, 0.020]	0.912
Green land use	0.000	0.178	[-0.355, 0.355]	0.999
Parks/gardens	-0.152	0.106	[-0.362, 0.059]	0.156
Natural/semi-natural spaces	0.153	0.131	[-0.108, 0.414]	0.246
Outdoor sports facilities	-0.078	0.106	[-0.288, 0.132]	0.461
13 years (*n* = 378)				
Green land cover	-0.007	0.008	[-0.022, 0.009]	0.407
Green land use	-0.011	0.106	[-0.222, 0.199]	0.917
Parks/gardens	-0.161	0.073	[-0.306, -0.016]	0.031
Natural/semi-natural spaces	0.099	0.127	[-0.155, 0.352]	0.440
Outdoor sports facilities	0.188	0.104	[-0.020, 0.395]	0.075
12 years (*n* = 392)				
Green land cover	0.009	0.007	[-0.006, 0.024]	0.217
Green land use	0.054	0.090	[-0.125, 0.234]	0.549
Parks/gardens	-0.019	0.077	[-0.173, 0.134]	0.804
Natural/semi-natural spaces	0.160	0.109	[-0.057, 0.377]	0.146
Outdoor sports facilities	0.122	0.090	[-0.058, 0.302]	0.181
11 years (*n* = 368)				
Green land cover	-0.004	0.010	[-0.023, 0.015]	0.677
Green land use	0.161	0.154	[-0.144, 0.467]	0.297
Parks/gardens	0.040	0.113	[-0.186, 0.266]	0.725
Natural/semi-natural spaces	0.010	0.188	[-0.365, 0.384]	0.959
Outdoor sports facilities	0.161	0.254	[-0.344, 0.666]	0.527
10 years (*n* = 375)				
Green land cover	0.021	0.011	[-0.000, 0.043]	0.055
Green land use	0.244	0.120	[0.006, 0.483]	0.045
Parks/gardens	0.016	0.095	[-0.174, 0.206]	0.865
Natural/semi-natural spaces	0.439	0.162	[0.116, 0.763]	0.008
Outdoor sports facilities	0.125	0.162	[-0.198, 0.449]	0.443
8 years (*n* = 451)				
Green land cover	0.022	0.022	[-0.022, 0.067]	0.323
Green land use	-0.054	0.174	[-0.399, 0.292]	0.759
Parks/gardens	0.029	0.208	[-0.385, 0.443]	0.889
Natural/semi-natural spaces	0.029	0.170	[-0.309, 0.366]	0.865
Outdoor sports facilities	-0.133	0.204	[-0.537, 0.272]	0.516
5 years (*n* = 430)				
Green land cover	0.012	0.021	[-0.029, 0.053]	0.573
Green land use	0.129	0.122	[-0.114, 0.371]	0.295
Parks/gardens	0.071	0.162	[-0.251, 0.392]	0.664
Natural/semi-natural spaces	0.149	0.169	[-0.186, 0.485]	0.380
Outdoor sports facilities	-0.003	0.149	[-0.300, 0.293]	0.983

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. Values of 0.000 represent values > 0 AND < 0.001; values of -0.000 represent values < 0 AND > -0.001. The green land cover variable is based on raw data [%], whereas the green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should therefore not be compared to the size of a green land use coefficient.

Table 6.10 Regression results for total difficulties (500-m-buffer analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 365)				
Green land cover	-0.004	0.029	[-0.062, 0.054]	0.883
Green land use	0.524	0.345	[-0.163, 1.211]	0.133
Parks/gardens	0.587	0.329	[-0.066, 1.241]	0.078
Natural/semi-natural spaces	0.411	0.354	[-0.293, 1.115]	0.248
Outdoor sports facilities	-0.427	0.418	[-1.259, 0.406]	0.311
14 years (*n* = 349)				
Green land cover	0.010	0.031	[-0.052, 0.071]	0.756
Green land use	-0.548	0.530	[-1.601, 0.506]	0.304
Parks/gardens	0.059	0.353	[-0.644, 0.761]	0.869
Natural/semi-natural spaces	-0.473	0.876	[-2.215, 1.269]	0.591
Outdoor sports facilities	-1.186	0.430	[-2.041, -0.330]	0.007
13 years (*n* = 378)				
Green land cover	-0.072	0.056	[-0.184, 0.041]	0.208
Green land use	-0.932	0.341	[-1.611, -0.252]	0.008
Parks/gardens	-0.856	0.309	[-1.472, -0.239]	0.007
Natural/semi-natural spaces	-0.273	0.386	[-1.042, 0.495]	0.481
Outdoor sports facilities	0.149	0.417	[-0.682, 0.980]	0.721
12 years (*n* = 392)				
Green land cover	0.014	0.029	[-0.043, 0.071]	0.632
Green land use	0.421	0.477	[-0.527, 1.369]	0.380
Parks/gardens	0.408	0.296	[-0.179, 0.996]	0.171
Natural/semi-natural spaces	0.104	0.514	[-0.918, 1.125]	0.841
Outdoor sports facilities	0.210	0.335	[-0.455, 0.874]	0.533
11 years (*n* = 368)				
Green land cover	0.016	0.028	[-0.039, 0.072]	0.557
Green land use	0.033	0.413	[-0.790, 0.855]	0.937
Parks/gardens	-0.094	0.306	[-0.703, 0.514]	0.759
Natural/semi-natural spaces	-0.057	0.600	[-1.251, 1.137]	0.925
Outdoor sports facilities	-0.014	0.789	[-1.584, 1.555]	0.985
10 years (*n* = 375)				
Green land cover	0.091	0.033	[0.025, 0.156]	0.007
Green land use	0.480	0.666	[-0.846, 1.806]	0.473
Parks/gardens	0.081	0.363	[-0.644, 0.805]	0.825
Natural/semi-natural spaces	0.810	0.782	[-0.747, 2.368]	0.303
Outdoor sports facilities	0.092	0.405	[-0.715, 0.899]	0.821
8 years (*n* = 451)				
Green land cover	0.049	0.063	[-0.077, 0.175]	0.443
Green land use	-0.252	0.501	[-1.248, 0.743]	0.616
Parks/gardens	0.325	0.621	[-0.908, 1.560]	0.601
Natural/semi-natural spaces	-0.510	0.556	[-1.615, 0.594]	0.361
Outdoor sports facilities	-0.679	0.579	[-1.829, 0.471]	0.244
5 years (*n* = 430)				
Green land cover	0.046	0.056	[-0.065, 0.158]	0.410
Green land use	0.645	0.468	[-0.285, 1.575]	0.172
Parks/gardens	0.068	0.530	[-0.983, 1.120]	0.897
Natural/semi-natural spaces	0.965	0.627	[-0.281, 2.210]	0.127
Outdoor sports facilities	0.083	0.491	[-0.891, 1.058]	0.865

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. The green land cover variable is based on raw data [%], whereas the green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should therefore not be compared to the size of a green land use coefficient.

Table 6.11 Regression results for self-esteem (500-m-buffer analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 293)				
Green land cover	-0.000	0.004	[-0.008, 0.007]	0.912
Green land use	0.067	0.071	[-0.074, 0.208]	0.347
Parks/gardens	0.013	0.052	[-0.091, 0.117]	0.808
Natural/semi-natural spaces	0.088	0.033	[0.023, 0.154]	0.009
Outdoor sports facilities	0.024	0.043	[-0.061, 0.109]	0.579
14 years (*n* = 306)				
Green land cover	0.001	0.002	[-0.002, 0.005]	0.417
Green land use	0.040	0.024	[-0.008, 0.088]	0.100
Parks/gardens	0.019	0.016	[-0.013, 0.051]	0.243
Natural/semi-natural spaces	0.013	0.033	[-0.054, 0.080]	0.698
Outdoor sports facilities	0.022	0.027	[-0.033, 0.076]	0.428
13 years (*n* = 338)				
Green land cover	-0.003	0.002	[-0.008, 0.001]	0.177
Green land use	-0.054	0.050	[-0.154, 0.046]	0.284
Parks/gardens	-0.050	0.031	[-0.112, 0.011]	0.109
Natural/semi-natural spaces	-0.010	0.074	[-0.158, 0.139]	0.897
Outdoor sports facilities	-0.024	0.045	[-0.113, 0.065]	0.596
12 years (*n* = 298)				
Green land cover	-0.003	0.003	[-0.010, 0.003]	0.342
Green land use	-0.045	0.036	[-0.116, 0.026]	0.213
Parks/gardens	0.005	0.030	[-0.055, 0.065]	0.863
Natural/semi-natural spaces	-0.052	0.054	[-0.160, 0.057]	0.342
Outdoor sports facilities	-0.005	0.062	[-0.129, 0.120]	0.940
11 years (*n* = 336)				
Green land cover	-0.001	0.002	[-0.005, 0.003]	0.661
Green land use	0.007	0.028	[-0.048, 0.063]	0.788
Parks/gardens	-0.024	0.020	[-0.064, 0.016]	0.230
Natural/semi-natural spaces	0.025	0.022	[-0.020, 0.070]	0.279
Outdoor sports facilities	0.016	0.039	[-0.062, 0.093]	0.689
10 years (*n* = 264)				
Green land cover	-0.001	0.003	[-0.008, 0.005]	0.694
Green land use	0.016	0.051	[-0.086, 0.119]	0.749
Parks/gardens	0.013	0.041	[-0.069, 0.095]	0.751
Natural/semi-natural spaces	-0.033	0.076	[-0.185, 0.119]	0.662
Outdoor sports facilities	0.082	0.046	[-0.010, 0.173]	0.079

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. Values of -0.000 represent values < 0 AND > -0.001. The green land cover variable is based on raw data [%], whereas the green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should therefore not be compared to the size of a green land use coefficient.

Table 6.12 Regression results for happiness (500-m-buffer analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 663)				
Green land cover	0.002	0.004	[-0.005, 0.009]	0.561
Green land use	0.098	0.044	[0.012, 0.185]	0.026
Parks/gardens	0.057	0.049	[-0.039, 0.153]	0.240
Natural/semi-natural spaces	0.075	0.088	[-0.099, 0.248]	0.397
Outdoor sports facilities	0.031	0.050	[-0.068, 0.130]	0.540
14 years (*n* = 663)				
Green land cover	0.004	0.004	[-0.004, 0.013]	0.318
Green land use	0.095	0.041	[0.015, 0.176]	0.021
Parks/gardens	-0.012	0.042	[-0.095, 0.071]	0.771
Natural/semi-natural spaces	0.116	0.071	[-0.023, 0.255]	0.102
Outdoor sports facilities	0.127	0.049	[0.029, 0.225]	0.011
13 years (*n* = 725)				
Green land cover	0.005	0.003	[-0.002, 0.011]	0.173
Green land use	0.013	0.054	[-0.095, 0.120]	0.812
Parks/gardens	-0.006	0.040	[-0.084, 0.073]	0.888
Natural/semi-natural spaces	0.003	0.084	[-0.162, 0.168]	0.972
Outdoor sports facilities	0.048	0.068	[-0.086, 0.181]	0.482
12 years (*n* = 699)				
Green land cover	-0.009	0.005	[-0.018, 0.000]	0.060
Green land use	-0.008	0.064	[-0.133, 0.117]	0.902
Parks/gardens	-0.028	0.052	[-0.130, 0.074]	0.583
Natural/semi-natural spaces	-0.022	0.071	[-0.162, 0.117]	0.754
Outdoor sports facilities	0.038	0.069	[-0.099, 0.175]	0.582
11 years (*n* = 710)				
Green land cover	-0.005	0.003	[-0.012, 0.001]	0.091
Green land use	-0.076	0.042	[-0.159, 0.006]	0.069
Parks/gardens	-0.059	0.035	[-0.128, 0.010]	0.091
Natural/semi-natural spaces	-0.033	0.069	[-0.170, 0.104]	0.634
Outdoor sports facilities	0.060	0.052	[-0.042, 0.162]	0.246
10 years (*n* = 644)				
Green land cover	-0.006	0.003	[-0.013, 0.001]	0.101
Green land use	-0.058	0.048	[-0.153, 0.036]	0.226
Parks/gardens	-0.040	0.039	[-0.117, 0.038]	0.313
Natural/semi-natural spaces	-0.096	0.069	[-0.232, 0.040]	0.164
Outdoor sports facilities	0.048	0.052	[-0.054, 0.151]	0.355

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. Values of 0.000 represent values > 0 AND < 0.001. The green land cover variable is based on raw data [%], whereas the green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should therefore not be compared to the size of a green land use coefficient.

Table 6.13 Overview of study results

	SDQ CP	SDQ ES	SDQ HA	SDQ PP	SDQ TD	Self-esteem	Happiness
15 years							
Green land cover							
Green land use							
Parks/gardens							
Natural/semi-natural spaces							
Outdoor sports facilities							
14 years							
Green land cover							
Green land use							
Parks/gardens							
Natural/semi-natural spaces							
Outdoor sports facilities							
13 years							
Green land cover							
Green land use							
Parks/gardens							
Natural/semi-natural spaces							
Outdoor sports facilities							
12 years							
Green land cover							
Green land use							
Parks/gardens							
Natural/semi-natural spaces							
Outdoor sports facilities							
11 years							
Green land cover							
Green land use							
Parks/gardens							
Natural/semi-natural spaces							
Outdoor sports facilities							
10 years							
Green land cover							
Green land use							
Parks/gardens							
Natural/semi-natural spaces							
Outdoor sports facilities							

	SDQ CP	SDQ ES	SDQ HA	SDQ PP	SDQ TD	Self-esteem	Happiness
8 years							
Green land cover							
Green land use							
Parks/gardens							
Natural/semi-natural spaces							
Outdoor sports facilities							
5 years							
Green land cover							
Green land use							
Parks/gardens							
Natural/semi-natural spaces							
Outdoor sports facilities							

Note. This table provides an overview of my study results. It highlights that there were only few significant associations relative to the number of models. It also illustrates the potential role of age: positive associations between greenspace and mental health and well-being were only observed in older adolescents (13- to 15-year-olds). CP = conduct problems; ES = emotional symptoms; HA = hyperactivity/inattention; PP = peer problems; TD = total difficulties.

X Suggesting a positive association between greenspace and health.

X No association.

X Suggesting a negative association between greenspace and health.

6.4. Discussion

In the third study of my thesis, I investigated the associations between different types of green spaces and mental health and well-being in children (5- and 8-year-olds) and adolescents (10- to 15-year-olds) living in London. I distinguished between total green land cover, total green land use, parks & gardens, natural & semi-natural urban greenspaces, and outdoor sports facilities. Across age groups and outcomes, I did not find consistent associations that would allow for clear conclusions about what types of green spaces may be most 'beneficial' for children's and adolescents' mental health and well-being. However, I made some observations that I will now discuss in more detail because they provide interesting insights and raise questions for future research. I will also discuss important limitations of my study.

Main Observations

The first observation is that there were only few associations between green land cover and children's and adolescents' mental health and well-being, and all of these associations were 'negative'. Higher levels of green land cover were associated with more problems, specifically with more hyperactivity and inattention in 10- and 11-year-olds. This finding is not in line with the positive association between neighbourhood greenness, assessed with the NDVI, and mental health reported in previous studies that I have discussed in my literature review in Chapter 2.

The green land cover variable in my study was based on a combination of NDVI and land cover data, capturing the greenness of an area. The advantage of this measure was that it captured any type of greenery rather than only designated open (green) spaces. This means it also captured greenery that may not be used by children and adolescents but that may have 'passive' positive effects on their mental health and well-being. For example, children and adolescents may not use a green roof, but they may still benefit from its air purifying properties. At the same time, the inclusion of any vegetation also bore the risk of exposure misclassification bias. For example, two children may have the same amount of green land cover in their neighbourhoods, but one child may be surrounded by private woodland (that they are not allowed to access), whereas the other child may be surrounded by public woodland (that they are allowed to access). Their exposure to greenspace (intentional or incidental) may therefore be very different. Furthermore, because my measure of green land cover did not distinguish between dense and sparse vegetation, every type of vegetation (e.g., grassland and woodland) had the same ‘weight’. Therefore, although the green land cover measure was a proxy for the greenness of an area, it did not provide information about the type and quality of this greenness. Unlike the green land use measures used in my study, the green land cover measure also did not capture the function and usability of the greenery.

Exposure misclassification bias may explain why I did not find a positive association between green land cover and children’s and adolescents’ mental health and well-being. It is unclear, however, why higher levels of green land cover were associated with higher levels of hyperactivity and inattention in 10- and 11-year-olds. One explanation could be that young adolescents are still restricted in their independent mobility and may spend a lot of their spare time close to their homes in their own neighbourhoods. If their neighbourhoods have high levels of green land cover, which may not be available for them to use (e.g., agriculture, private woodlands, or golf courses), they may not go outside much to play and be active. This, in turn, may be associated with higher levels of hyperactivity and inattention. Although I found similar findings in my 300 m and 1,000 m sensitivity analyses, my explanation for this finding is, of course, speculative. In fact, the finding that higher levels of parks & gardens were associated with higher levels of hyperactivity and inattention in 12-year-olds is not in line with my explanation (because parks & gardens are free to access and usable spaces). Therefore, the role of green land cover and green land use in (early) adolescence needs further investigation.

The second observation is that there was a pattern of ‘positive’ associations (i.e., higher levels of greenspace were associated with better mental health) in older adolescents, and ‘negative’ associations (i.e., higher levels of greenspace were associated with worse mental health) in younger adolescents. If these associations were causal, older adolescents (13- to 15-year-olds) seemed to 'benefit' from green land use (especially parks & gardens and outdoor sports facilities) across outcomes, whereas younger adolescents (10- to 12-year-olds) seemed to 'dis-benefit' from green land use and, as mentioned above, green land cover (however, only in terms of hyperactivity and inattention, and peer relationship problems). The only exception of this were positive associations of total green land use and parks & gardens with emotional symptoms in 15-year-olds (suggesting that more parks & gardens were associated with more emotional symptoms).

The differences between age groups were generally supported in sensitivity analyses, especially in the 300-m-buffer analysis. Noteworthy, the positive associations of green land use with mental health problems in 15-year-olds were also supported and, indeed, extended in sensitivity analyses. In both the LSOA analysis and the 300 m analysis (but not the 1,000 m analysis), more parks & gardens were associated with more conduct problems in 15-year-olds. Similarly, a further distance to the nearest park or garden was linked to lower levels of conduct problems. This suggests that living in close proximity to a park or garden in London is linked to more conduct problems in older adolescents. In 13- and 14-year-olds, however, availability and proximity of parks & gardens and outdoor sports facilities seemed to be linked to fewer mental health problems.

The third observation, related to the previous observation, is that green land use was positively associated with mental well-being (i.e., self-esteem and happiness) only in older adolescents (14- and 15-year-olds), and this was generally supported in sensitivity analyses (especially in LSOA and 300 m analyses). This suggests that older adolescents living in greener areas in London not only show fewer mental health problems but also more well-being. This is important to note because mental health and well-being are related but not the same constructs. This is also suggested by Maes et al.'s (2021) study showing an association between woodland and mental health, and an association between grassland and well-being.

Although individual associations were not robust, the pattern of associations described in the previous paragraphs suggests that the role of green land use is not the same across age groups. If associations were causal, older adolescents seemed to ‘benefit’ more from green land use than younger adolescents, in terms of both mental health and well-being. This observation is in line with studies that found that associations were different across age groups. For example, Madzia et al. (2019) found different associations for neighbourhood greenness for 7-year-olds and 12-year-olds, Feng and Astell-Burt (2017) found different associations for neighbourhood greenspace quantity and quality across childhood (4–5 to 12–13 years), and Bezold et al. (2018) found stronger associations in middle school students than in high school students.

As described earlier, it is plausible that greenspace influences children and adolescents differently, due to different developmental stages and associated needs, interests, and preferences. In the introduction, I highlighted three differences between children and adolescents that may play a role in this: levels of independence, usage of green spaces, and levels of nature connectedness. In London, young adolescents may still depend on their parents to take them outside, whereas older adolescents may be allowed to move around their neighbourhoods unsupervised and in a wider radius. With increasing age, adolescents spend more time away from home, without their parents and with their peers. Public green spaces may, therefore, become more important in later stages of adolescence. My findings suggest that parks & gardens and outdoor sports facilities, in particular, may be ‘beneficial’ for the mental health and well-being of older adolescents. This is plausible because these spaces (unlike natural & semi-natural urban greenspaces) offer features that attract adolescents, such as playgrounds and sports fields (Rivera et al., 2021; Van Hecke et al., 2018). Adolescents report that they use green spaces mostly for social and physical activities (Bloemsma et al., 2018); parks & gardens and outdoor sports facilities offer opportunities for exactly these activities. The potential dip in nature connectedness in adolescence may explain why older adolescents do not seem to ‘benefit’ as much from natural & semi-natural urban greenspaces.

Why more parks & gardens were associated with more emotional problems and, in the sensitivity analysis, conduct problems in 15-year-olds is unclear. This observation could suggest a change in older adolescents (e.g., a change in interests), or it could have to do with the characteristics of parks & gardens in London. Living in close proximity to a park or garden does not mean that these green spaces are of 'high quality'. Urban parks can be in poor condition, for example, they may be littered or characterised by antisocial behaviour (Reeves, 2000). Older adolescents may pay more attention to the quality of parks, and, in older adolescents, the quality of parks may be especially associated with internalising symptoms (e.g., emotional symptoms), as suggested by Feng and Astell-Burt's (2017) study. Potentially low-quality, urban parks may, therefore, be associated with poorer mental health (i.e., more internalising symptoms) in older adolescents. This explanation, again, is speculative, and more research investigating the role of quality in the association between greenspace and children's and adolescents' mental health is needed. In the next chapter, I will investigate the role of quality more directly.

A final observation I would like to note is that there were no associations between exposures and outcomes in children (with only a few exceptions in sensitivity analyses). As the mental health outcomes in children were parent-reported, these results should not be compared directly to results in adolescents. Nonetheless, they seem to suggest that neighbourhood greenspace may not seem to play a role in the mental health of younger children in London. This observation is in line with other studies from the UK which did not find robust associations of neighbourhood greenspace with mental health in young children in England (Flouri et al., 2014b) and Scotland (Richardson et al., 2017). It is also in line with the first study of this thesis in which I did not find an association between neighbourhood greenspace and self-regulation in 3- to 7-year-old children in the UK. One explanation for this would be that younger children play more in their own garden (if available) than in public places (Dodd et al., 2021), which may limit the role of neighbourhood green spaces in their mental health. This is also supported by the studies by Flouri et al. (2014) and Richardson et al.

(2017) that found consistent associations between private garden access and young children's mental health in urban England and Scotland.

Study Limitations

I should note several study limitations. First, my study was limited to the London region. London is a large urban area in the southeast of England, so findings cannot be generalised to rural areas. Furthermore, London may not be representative of urban areas across the world (or even Europe). Therefore, studies in other areas of the world are needed to test whether findings are generalisable across geographies and cultures. I will discuss the issue of generalisibality again in my general discussion in Chapter 8. Second, the focus on London (rather than the whole of the UK) resulted in a great decrease in sample size. The relatively small sample size made it more difficult to detect small 'effects' (due to low statistical power). Third, a related limitation is the large number of tests performed in my study. Due to multiple outcomes, exposures, and age groups, I had to run multiple tests, which increased the probability of a type 1 error. However, due to the generally small 'effect' and sample sizes, and to avoid a type 2 error, I did not correct for multiple tests. I argue this is a fair approach, especially because I am carefully interpreting patterns of associations (not individual associations).

Fourth, this study was prone to exposure misclassification bias for several reasons: (a) I only had data on the residential neighbourhood but not on other relevant environments (e.g., the school); (b) the neighbourhood was defined as a circular buffer around a postcode mean (or as a LSOA); (c) greenspace data were from 2016 (green land cover) and 2020 (green land use), whereas UKHLS data were from 2009–2018; and (d) I did not have data on children's and adolescents' actual use or usage of green spaces. Taken these points together, I have to assume that my exposure variables could only approximate individual true exposure. Note that I will revisit the issue of exposure misclassification in my general discussion in Chapter 8. Fifth, focusing on three types of open spaces (i.e., parks & gardens, natural & semi-natural urban greenspaces, and outdoor sports facilities) meant excluding other types of open (green) spaces that could be relevant for children’s and adolescents’ mental health and well-being. For example, I did not include data on more informal green spaces that may be used, especially by adolescents, to ‘hang out’ with friends. Further, I did not include green spaces that may be provided specifically for communities to be able to spend time in the outdoors (e.g., allotments). In other words, my study was limited to three types of open spaces, but other types of open spaces may be relevant for children’s and adolescents’ mental health and well-being, and interesting for policy and planning. Finally, although I distinguished between different types of green spaces, I did not include information on specific characteristics (e.g., types of vegetation or facilities) or dimensions of quality (e.g., safety or cleanliness). Arguably, these may be important factors that may influence children’s and adolescents’ visits of green spaces and what they get out of these visits. As mentioned earlier, I will investigate the role of quality in the next chapter.

6.5. Conclusion

I investigated the associations between different types of green spaces and mental health and well-being in children (5 and 8 years) and adolescents (10 to 15 years) living in London, using data from Understanding Society. Although results were not consistent across exposures, outcomes, and ages, and I cannot discuss individual associations, I identified patterns of associations that are worth exploring further. First, higher levels of greenspace were associated with better mental health and well-being only in older adolescents (13- to 15-year-olds). Second, I found positive associations with mental health and well-being mainly for parks & gardens and outdoor sports facilities. Third, I did not find associations between exposures and outcomes in children. However, overall, findings need to be interpreted with caution, and no clear conclusions can be drawn from this study. Future studies would benefit from larger general population samples and should aim to minimise exposure misclassification bias. They should also assess the role of specific characteristics and the quality of green spaces.

6.6. Publication

Parts of this chapter have been published (in different form) in *Cities & Health* (2023). Full citation:

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7. The Potential Roles of Neighbourhood Quality and Greenspace Quality

Abstract

The quality of green spaces may play an important role in how children and adolescents use these spaces and in how much they benefit from them.

In this study, I investigated the roles of both neighbourhood quality and greenspace quality in the mental health and well-being of adolescents (10- to 15-year-olds) living in London. As in the previous study, I used data on 1,879 adolescents, taken from Understanding Society, the UK Household Longitudinal Study (UKHLS), Waves 1 to 8 (2009–2018). As some individuals had observations at multiple waves, 4,217 observations were included in my analysis. In the first part of this study, I used the same exposures as in the last study but added a perceived neighbourhood quality variable as a covariate and as a moderator. In the second part of this study, I changed my primary exposure of interest to a binary variable assessing access to 'high-quality' green spaces. As in the last study, mental health and well-being outcomes were Strengths and Difficulties Questionnaire (SDQ) scores, self-esteem, and happiness. I ran linear regression models, stratified by age, and adjusted for neighbourhood, family, and child confounders.

I found positive associations between perceived neighbourhood quality and mental health and well-being (except for conduct problems). Furthermore, adolescents who perceived their neighbourhoods to be of 'lower quality' seemed to 'benefit' more from green spaces in their neighbourhoods than their counterparts. I did not find an association between access to 'high-quality' green spaces and adolescent mental health and well-being.

My findings suggest that perceived neighbourhood quality may play a more important role in adolescent mental health and well-being than living nearby 'high-quality' green spaces.

7.1. Introduction

In the previous chapter, I investigated the associations of different types of green spaces with children's and adolescents' mental health and well-being. Although findings were inconclusive, this was an important step forward from studies assessing the role of quantity without distinguishing between different types of green spaces. Different types of green spaces have different functions and, therefore, may affect the mental health and well-being of children and adolescents in different ways. However, there are not only differences between parks & gardens, natural & semi-natural urban greenspaces, and outdoor sports facilities, but also between green spaces that share the same open space category. For example, two green spaces may be categorised as a park but may differ in quality: one park may be large and well maintained, whereas the other may be small and littered. Although this may sound like an extreme example, it is not unrealistic, especially not in an urban setting. Another example would be two parks that are both objectively 'high-quality' parks, but one may be more suited for children and the other may be more suited for the elderly. Therefore, distinguishing between different types of green spaces does not capture all the nuances that may influence if and how people use green spaces, and how these green spaces may influence their health and well-being (Knobel, Maneja, et al., 2021). Reviews of the extant literature tend to conclude that more research is needed into the role of quality (Collins et al., 2020; Ekkel & de Vries, 2017; Houlden, Jani, et al., 2021).

Definition of Quality

Investigating the role of greenspace quality in health and well-being brings with it the problem of defining 'quality'. The term 'quality' has a positive connotation, however, there is a spectrum that ranges from poor/low quality to good/high quality. At the same time, quality is a multi-dimensional construct and cannot be reduced to only one dimension (Gidlow et al., 2018; Knobel, Dadvand, et al., 2021; Knobel et al., 2019). Moreover, quality is highly subjective: preferences and needs depend on individual (or group) characteristics, and what makes a 'high-quality' greenspace depends on whom you ask. Despite this underlying complexity, one could define ‘quality’ more generally as the attributes of a given space that affect people’s use and interaction with that space (Knobel, Dadvand, et al., 2021). A ‘high-quality’ greenspace may be used more often, and may affect health and well-being more positively, than a ‘low-quality’ greenspace.

When one thinks about the quality of a space, one can come up with several factors that may play a role, and these factors can be combined into dimensions of quality. Gidlow et al. (2018) distinguish eight quality domains: accessibility, recreational facilities, amenities, aesthetics (natural), aesthetics (non-natural), significant natural features, incivilities, and usability. In a more recent paper, Knobel et al. (2021) distinguished 11 quality dimensions that add even more nuances: surroundings, access, facilities, amenities, aesthetics and attractions, incivilities, safety, potential usage, land covers, animal biodiversity, and bird biodiversity. These examples show that there are many dimensions to consider in the assessment of greenspace quality. All these dimensions may affect use of, and interaction with, green spaces, and how green spaces may affect mental health and well-being.

Empirical Evidence

There are only few studies investigating the role of greenspace quality; and studies investigating the role of greenspace quality in child and adolescent mental health and well-being are scarce (Nguyen et al., 2021). Due to the many dimensions of quality, there is a great range of quality measures in the literature. In their systematic literature review on greenspace quality and health, Nguyen et al. (2021) categorise quality in ten domains: environment and land cover type; natural features; infrastructure and amenities; size; shape, pattern, and connectivity; safety; cleanliness and absence of incivilities; peacefulness; perceived quality; and a combination of features. Most of the reviewed studies used data on adults, and most studies on children investigated physical activity or physical health outcomes (not mental health and well-being).

In addition to the few studies that distinguished different types of land use or land cover (see the previous chapter), a few studies investigated the role of perceived quality in children's mental health and well-being, as already described in my literature review in Chapter 2. Feng and Astell-Burt (2017) found that parents' perceptions of the quality of green spaces in their neighbourhoods were associated with their children's internalising, externalising, and total difficulties. For internalising difficulties, the relevance of greenspace quality became more important with age. The same research group found that parents' perceptions of the quality of green spaces in their neighbourhoods also affected children's prosocial behaviour (Putra et al., 2021a). Further, Feng et al. (2022) found that the availability of 'high-quality' green spaces (as reported by the parents) was also associated with lower levels of internalising, externalising, and total difficulties in older adolescents. Noteworthy, they also found that personality traits may play a role in the association (as already described in Chapter 2).

In all these studies, perceptions of greenspace quality were assessed with a single item that asked parents about how much they agreed with the statement that there were 'good' green spaces in their area. This subjectivity, of course, limits our ability to make inferences about the role of certain objective factors because we do not know *why* parents thought green spaces in their neighbourhoods were 'good'.

Akpınar (2021) also studied the role of perceptions of green spaces in mental health and well-being, though not parents' perceptions but professionals' perceptions. They asked two landscape architects to rate sensory dimensions of green spaces (i.e., nature, serene, space, rich in species, social, prospect, culture, and refuge) and associated these ratings with measures of perceived restoration, mental health, and stress of young users of these green spaces. Perceived restoration was measured with the Perceived Restorative Components Scale for children (PRCS-C) which assesses fascination, being away-physical, compatibility, being away-psychological, and extent. Mental health and stress were assessed with one item each. They found that nature was positively associated with perceived restorativeness; refuge was positively associated with perceived restorativeness and negatively associated with stress; space was negatively associated with perceived restorativeness; and prospect was positively associated with mental health and negatively associated with stress. Again, these findings suggest that perceptions of certain characteristics (here 'sensory dimensions') may be associated with mental health and related outcomes in adolescents.

Taken together, the studies suggest that perceived quality of (neighbourhood) green spaces may be associated with mental health and well-being in children and adolescents. Noteworthy, studies on adults report similar findings: higher perceived quality of public open spaces (Francis et al., 2012) and neighbourhood greenspace (Feng & Astell-Burt, 2018; Pope et al., 2015) is associated with lower levels of psychological distress. However, because subjective perceptions of quality do not provide much insight about the objective characteristics that make a 'high-quality' greenspace for children and adolescents, we still have a limited understanding of the role of neighbourhood greenspace quality in children's and adolescents' mental health and well-being.

Theoretical Considerations

One way to approach the question about what objective characteristics make a 'good' greenspace for children and adolescents is to simply ask children and adolescents about their preferences. Van Hecke et al. (2018) conducted a literature review to assess what characteristics of public open spaces influence adolescents' use of these spaces and concluded that activity-related characteristics, such as trails, age-appropriate playgrounds, and sports fields, appeared more important than safety and aesthetics for adolescents' use of public open spaces. These characteristics provide opportunities for the things that adolescents typically like to do in green spaces: physical activity and spending time with friends (Bloemsma et al., 2018). Nevertheless, although activity-related characteristics seem to stand out as key factors, maintenance and greenness may influence adolescents' use of green spaces too (Lyons et al., 2022). Moreover, not only physical factors but social factors too are important. Although the review by van Hecke et al. (2018) did not reveal quantitative support for the role of safety, qualitative studies do suggest that safety and other social factors, such as the presence of family and friends, influence adolescents' use of public open spaces (Baran et al., 2014; Van Hecke et al., 2016). Furthermore, studies suggest that preferences depend on individual factors, such as sex, age, and levels of physical activity (Akpınar, 2020; Baran et al., 2014; Flowers et al., 2019; Mertens et al., 2019). Moreover, for young children, parents' preferences and perceptions matter too because young children's exposure to greenspace typically depends on their parents taking them to these spaces (Skar et al., 2016). Alderton et al. (2022) report that the availability of playgrounds and toilets is a critical factor for parents to bring their children to public open spaces.

Asking children and adolescents about their preferences provides valuable information on the features that may improve the quality of green spaces for children and adolescents and impact their use of these spaces. However, the link to mental health and well-being is missing, and we do not know if, and to what extent, the presence of attractive, preferred features actually influences mental health and well-being. Although it is plausible that the availability of preferred features leads to more frequent use, in turn, leading to better mental health and well-being, studies did not actually test this causal link.

Another way to assess the quality of a greenspace is by using formal designations. A site designation typically is not limited to a single characteristic but indicates whether a space fulfils certain criteria that relate to a certain value (such as ecological, scientific, or aesthetic values). Depending on the type of designation, a space is protected by law (statutory designation) or recognised in local planning decisions (non-statutory designation). Sometimes, spaces have more than one designation, and different designations reflect different dimensions of quality. In a nutshell, a space that receives a site designation must fulfil criteria that make this space more valuable on a certain dimension than a space without a site designation. This understanding makes it possible to assess the role of greenspace quality in child and adolescent mental health and well-being, for example, by assessing whether children and adolescents with access to designated ('high-quality') green spaces have better mental health and well-being than children and adolescents without access to these spaces.

In a study on adults, Wyles et al. (2019) used designations as indicators for high environmental quality and tested whether visits to natural spaces with a designation were linked to greater nature connectedness and psychological restoration than visits to natural spaces without a designation. They used a binary variable to measure whether people visited an area with 'protected or designated area' status (e.g., Areas of Outstanding Natural Beauty, Sites of Special Scientific Interest, and National and Local Nature Reserves). They found that visits to designated areas were associated with higher levels of nature connectedness and higher perceived psychological restoration than visits to non-designated areas.

Similarly, though not at individual but area level, Wheeler et al. (2015) found that the density of protected or designated sites (i.e., Sites of Special Scientific Interest, Special Areas of Conservation, Special Protection Areas, Local Nature Reserves, National Nature Reserves, and Ramsar designated wetlands) in LSOAs (England and Wales) and data zones (Scotland) was associated with population health: a higher density of protected or designated sites was associated with better health.

In a more recent study, Knight et al. (2022) investigated the association between access to nature of 'high ecological quality' with mental well-being in adults living in London, using the same exposure variable that I used in the second part of this study. They found that living beyond 1,000 m walking distance of a green or blue space with high ecological quality (i.e., having poor access to 'high-quality' green spaces) was associated with lower levels of life satisfaction in adults in London.

The three studies suggest that visiting green spaces with 'high ecological quality', living in an area with a high density of these spaces, or living near these spaces may be associated with higher levels of nature connectedness and restoration, better health, and higher life satisfaction in adults. In the second part of the present study, I will investigate whether access to green spaces with ‘high ecological quality’ is also associated with better mental health and well-being in adolescents living in London.

In the first part of the present study, however, I will assess the role of *neighbourhood* quality in the association between greenspace and mental health and well-being in adolescents. As suggested by Knobel et al. (2021), it is not only the characteristics of a greenspace itself that determines its quality but also the characteristics of the surroundings of the greenspace. In the study of the role of neighbourhood greenspace in mental health and well-being, the quality of the neighbourhood may influence children’s and adolescents’ visits to green spaces and may also be an indicator of the quality of these spaces. For example, children and adolescents living in unsafe neighbourhoods, as perceived by themselves or their parents, may not feel comfortable or may not be allowed to move around and visit green spaces in their neighbourhoods (although the evidence for this link is not yet conclusive; Zougheibe et al., 2021). Further, in disadvantaged neighbourhoods, there may be only little investment in public open spaces, so green spaces in these areas may not be well maintained or may lack important features, in turn, making them unattractive for children and adolescents. Therefore, in addition to investigating the role of the quality of greenspace itself, it is worth to investigate the role of the quality of the surroundings (i.e., the neighbourhood) in the association between greenspace and mental health and well-being. Noteworthy, in their study on the association between neighbourhood greenness and adolescent aggressive behaviour (described in my literature review in Chapter 2), Younan et al. (2016) did *not* find a moderating role of neighbourhood quality.

The Present Study

In the present study, I assessed the role of neighbourhood quality (Part A) and greenspace quality (Part B) in mental health and well-being. This study is based on the previous study. However, in this chapter, I will focus on adolescents (i.e., 10- to 15-year-olds) because some of the additional variables were not available for children. For Part B, supplementary analyses on children will be provided in the appendix, where possible. In the first part of this study (Part A), I investigated whether adolescents' perceptions of the quality of their neighbourhoods moderated the association between neighbourhood greenspace and mental health and well-being. This part of the study was based on the idea that the quality of the neighbourhood may affect adolescents' use of green spaces and may also be an indicator of the quality of these spaces. In the second part of this study (Part B), I assessed the role of greenspace quality more directly, using an indicator of access to green spaces with 'high ecological quality' as the primary exposure (described in more detail below). In this study, I addressed the following research questions:

1. Does perceived neighbourhood quality moderate the association between neighbourhood greenspace and adolescents' mental health and well-being?
2. Is there an association between access to 'high-quality' green spaces (i.e., living within or beyond 1,000 m from 'high-quality' green spaces) and adolescents' mental health and well-being?

For Part A, I hypothesised that perceived neighbourhood quality moderates the association between greenspace and adolescent mental health and well-being. More specifically, I hypothesised that positive associations between neighbourhood greenspace and mental health and well-being are amplified in adolescents who report high neighbourhood quality. For Part B, I hypothesised that living beyond 1,000 m from 'high-quality' green spaces is associated with poorer mental health and lower levels of well-being. Because this study was partly explorative, I did not have more specific hypotheses about associations with certain outcomes or for certain age groups.

7.2. Methods

Study Area

As in the previous chapter, I will focus on the London region. For details, please see section 6.2.

Levels of Geography

In this chapter, I will focus on the postcode level and omit the LSOA analysis. This is because the postcode represents more accurately where an adolescent lives and, therefore, allows for a more accurate assessment of their exposure to neighbourhood greenspace. I will focus on the main 500-m-buffer analysis. This is because, in the previous chapter, sensitivity analyses did not provide much additional insight, so, for reasons of parsimony, I decided to omit these from the Part A analysis. Note that, in the Part B analysis, I will use a different measure of exposure, so this decision does not affect the Part B analysis.

Study Sample

In this chapter, I used data on the same study sample as in the previous chapter, taken from Understanding Society, the UK Household Longitudinal Study (UKHLS), albeit focusing on adolescents (10- to 15-year-olds) only. This is because perceived neighbourhood quality, a variable used in the first part of this study, was not available for children (5- and 8-year-olds). For the second part of this study, however, I will provide supplementary results for children in the appendix. For a more detailed description of the study sample, please see section 6.2.

Study Variables

Mental health and well-being outcomes, green land cover and green land use exposures, and neighbourhood, family, and child covariates were the same as in the previous chapter. In addition to these, I included two more variables: in Part A, I added a variable assessing adolescents' perceptions of the quality of their neighbourhoods (as a covariate and as a moderator). In Part B, I added a variable assessing access to green spaces with 'high ecological quality' as the main exposure. I will now describe these variables in turn. For detailed descriptions of other variables, please see section 6.2.

Perceived neighbourhood quality was assessed with three questions asked in the youth self-completion questionnaire at Waves 3, 5, and 7: 'Do you like living in this neighbourhood?' (no/yes); 'How much do you worry that you might be a victim of a crime?' (1 'not a worry at all' to 4 'a big worry'); and, 'How safe would you feel walking alone in this area after dark?' (1 'very unsafe' to 4 'very safe'). To create one measure of perceived neighbourhood quality, I ran a principal components analysis (PCA) on the three items. The sampling adequacy was acceptable (*KMO* = .56). The three items loaded on a single component with an eigenvalue > 1 (with loadings of .46, -.62, and .64, respectively). Higher values on the perceived neighbourhood quality variable (i.e., higher component scores) corresponded to higher perceived neighbourhood quality. I used this variable in the first part of this study, assessing whether perceived neighbourhood quality moderated the associations of green land cover and green land use with adolescent mental health and well-being.

Access to green spaces with 'high ecological quality' was assessed with a binary variable. This was based on data on so-called Areas of Deficiency (AoDs) in Access to Sites of Importance for Nature Conservation (SINCs), provided by GiGL. A SINC is recognised for the important habitat it supports and is defined by a panel of local ecological professionals. Sites designated as SINCs are sites with 'high ecological quality', measured as wealth of wildlife (*Greenspace Information for Greater London CIC*, n.d.). AoDs are areas where people have to walk more than 1,000 m to reach a SINC of Metropolitan or Borough importance (*Greenspace Information for Greater London CIC*, n.d.). GiGL calculated these areas, running sophisticated spatial analyses using walking (rather than straight-line) distances to SINCs. AoDs cover around 21% of London's area. Using postcode grid references and spatially joining them with AoDs, using the *sf* package in R (Pebesma, 2018), I assessed whether an adolescent lived in an AoD (no/yes). Living in an AoD was an indicator of having poor access to green spaces with ‘high ecological quality’. I used this binary variable as the primary exposure in the second part of this study, assessing the role of access to ‘high-quality’ green spaces in adolescent mental health and well-being.

Statistical Analysis

As for my previous study, analyses for this study had to be carried out in the UK Data Service (UKDS) SecureLab. All analyses were conducted in Stata 16. As mentioned earlier, this study is divided into two parts. In the first part (Part A), I assessed the role of perceived neighbourhood quality in the associations of green land cover and green land use with adolescent mental health and well-being. As in the previous chapter, I ran linear regression models for each outcome. However, for reasons of parsimony, I decided to focus on two exposures, green land cover and green land use, and included both in the same model (rather than running a separate model for each exposure). Results for the additional exposures, parks & gardens, natural & semi-natural urban greenspaces, and outdoor sports facilities, are provided in the appendix (see Tables A7.1.1 to A7.1.5 in Appendix 2). Furthermore, because questions about the neighbourhood were only asked at Waves 3, 5, and 7, I included data of these three waves only. This resulted in a decrease in sample size and meant that I could not assess the role of perceived neighbourhood quality in the association of neighbourhood greenspace with self-esteem (because self-esteem was measured at Waves 2, 4, 6, and 8). Taken all these considerations together, I fitted one linear regression model (including green land cover and green land use variables) for each of the six outcomes (i.e., five Strengths and Difficulties Questionnaire [SDQ] scales and happiness). As in the previous study, models were adjusted for air pollution, deprivation, maternal mental health, maternal education, home ownership, family structure, sex, ethnicity, and wave. To these, I added perceived neighbourhood quality as a covariate. To investigate the moderating role of perceived neighbourhood quality in the association of neighbourhood greenspace (i.e., green land cover and green land use) with mental health and well-being, I fitted six additional models, adding two interaction terms to each of the six original models. The interaction terms were perceived neighbourhood quality * green land cover, and perceived neighbourhood quality * green land use.

In the second part of this study (Part B), I investigated the role of access to ‘high-quality’ green spaces in adolescent mental health and well-being. For this part, I used the same models as in the previous chapter, exchanging the five original exposures with one novel exposure, access to green spaces with ‘high ecological quality’ (i.e., whether one lived in an AoD; no/yes). Therefore, I fitted one model for each outcome, adjusting for the same set of confounders and covariates. Note, however, that I added green land cover as a covariate to adjust for the greenness of the neighbourhood. In a sensitivity analysis, I also added perceived neighbourhood quality (see Tables A7.2.1 to A7.2.6 in Appendix 2). I also ran the original models, not adjusted for perceived neighbourhood quality, for children (i.e., 5- and 8-year-olds; see Tables A7.3.1 to A7.3.5 in Appendix 2).

As in the previous chapter, I made the following decisions. First, I pooled data of eight waves. Second, I ran separate models for each age group. Third, green land use variables (but not the green land cover variable) were cube root transformed. Fourth, I imputed missing data for covariates. Finally, I accounted for the UKHLS’s complex sampling design. For more information on these decisions, please see section 6.2.

7.3. Results

Descriptive Statistics

Descriptive statistics and a bias analysis are shown in Table 7.1. This table is based on Table 6.3, with additional rows for the two added variables, perceived neighbourhood quality (under continuous variables) and access to green spaces with ‘high ecological quality’ (i.e., lives in an AoD; under categorical variables). Compared to adolescents in the non-analytic sample, on average, adolescents in the analytic sample perceived their neighbourhoods to be of lower quality. Further, around 28% of the analytic sample lived in an AoD (i.e., had poor access to green spaces with ‘high ecological quality’).

Table 7.2 shows correlations between outcomes and exposures. This table is based on Table 6.5, with additional correlations for perceived neighbourhood quality and access to green spaces with ‘high ecological quality’. Perceived neighbourhood quality was correlated with mental health and well-being but not with greenspace (except for natural & semi-natural urban greenspaces). Access to green spaces with ‘high ecological quality’ was correlated with other greenspace exposures but not with mental health and well-being (except for hyperactivity and inattention).

Table 7.1 Bias analysis between analytic and non-analytic samples

	Analytic sample (*n* = 4,217)		Non-analytic sample (*n* = 28,187)		Test
Continuous variables					
	n	*M (SD)*	*n*	*M (SD)*	*F*
SDQ CP (0–10)	2,281	2.13 (1.73)	14,119	2.21 (1.81)	1.54
SDQ ES (0–10)	2,281	2.64 (2.14)	14,118	2.88 (2.26)	7.28 **
SDQ HA (0–10)	2,279	3.70 (2.18)	14,115	4.06 (2.34)	22.18 ***
SDQ PP (0–10)	2,279	1.61 (1.54)	14,120	1.82 (1.70)	16.01 ***
SDQ TD (0–40)	2,276	10.09 (5.29)	14,106	10.97 (5.80)	17.79 ***
Self-esteem (1–4)	1,881	3.17 (0.44)	13,819	3.11 (0.44)	8.65 **
Happiness (1–7)	4,202	5.89 (0.87)	28,072	5.81 (0.85)	6.61 *
Green land cover [%] [1]	4,123	38.54 (11.79)	-	-	-
Green land use [%] [1]	4,123	8.69 (9.25)	-	-	-
Parks/gardens [%] [1]	4,123	4.85 (6.97)	-	-	-
Natural/semi-natural spaces [%] [1]	4,123	2.06 (6.10)	-	-	-
Outdoor sports facilities [%] [1]	4,123	1.79 (3.93)	-	-	-
Air pollution [mean NO_2] [1]	4,123	35.32 (5.65)	-	-	-
Area deprivation [Carstairs z-score]	4,217	1.90 (3.49)	23,358	-0.32 (3.04)	135.32 ***
Maternal psychological distress (0–36)	3,203	11.76 (5.96)	24,613	11.96 (5.90)	0.75
Age [years]	4,217	12.42 (1.69)	28,187	12.54 (1.69)	9.59 **
Perceived neighbourhood quality (-4.24–1.62)	1,409	-0.20 (1.26)	10,003	0.02 (1.16)	17.41 ***
Categorical variables					
	n	%	*n*	%	*F* [2]
University education (mother)	1,560	41.42	10,308	40.05	0.29
Family owns its home	1,805	48.38	19,498	66.45	35.44 ***
Intact family structure	2,826	64.18	18,073	62.77	0.26
Ethnicity White	1,182	53.58	23,262	90.65	359.93 ***
Ethnicity Mixed	534	10.23	1,031	2.85	82.07 ***
Ethnicity Indian	310	6.29	824	1.76	54.23 ***
Ethnicity Pakistani and Bangladeshi	824	7.64	1,980	2.75	47.27 ***
Ethnicity Black or Black British	1,097	17.49	692	1.03	567.74 ***
Ethnicity Other	270	4.77	340	0.96	61.23 ***
Female	2,120	50.75	14,025	49.50	0.36
Lives in an AoD	1,184	27.66	-	-	-

Note. CP = conduct problems; ES = emotional symptoms; HA = hyperactivity/inattention; PP = peer problems; TD = total difficulties; AoD = Area of Deficiency. Data are taken from Waves 1 to 8. Sample sizes refer to observations (not individuals). Some individuals have multiple observations across waves, and these multiple observations are included in the descriptive statistics above. Descriptive statistics by wave and by age group differ slightly, but the overall descriptive statistics in this table give an appropriate overview of the sample characteristics. *N*s are unweighted. *M*s, *SD*s, and %s are weighted. [1] Values are for 500 m buffers around postcodes. [2] Design-based *F* statistic (i.e., corrected weighted Chi^2 statistic). **p* < .05, ***p* < .01, ****p* < .001.

Table 7.2 Correlations between outcomes and exposures (n = 4,217)

	SDQ CP	SDQ ES	SDQ HA	SDQ PP	SDQ TD	Self-esteem	Happiness	Green LC [1]	Green LU [1]	P/G [1]	N/SN UG [1]	OSF [1]	PNQ
SDQ ES	0.260 ***												
SDQ HA	0.513 ***	0.303 ***											
SDQ PP	0.200 ***	0.355 ***	0.179 ***										
SDQ TD	0.707 ***	0.717 ***	0.754 ***	0.574 ***									
Self-esteem	-	-	-	-	-								
Happiness	-0.374 ***	-0.397 ***	-0.367 ***	-0.293 ***	-0.521 ***	0.538 ***							
Green LC [1]	-0.058 **	-0.010	0.029	-0.025	-0.020	-0.033	0.013						
Green LU [1]	-0.049 *	-0.017	-0.012	0.005	-0.028	-0.016	0.023	0.541 ***					
P/G [1]	-0.022	-0.006	-0.014	-0.010	-0.019	-0.027	-0.004	0.266 ***	0.669 ***				
N/SN UG [1]	-0.036	0.002	0.009	0.032	0.002	0.000	0.002	0.343 ***	0.491 ***	-0.137 ***			
OSF [1]	-0.027	-0.030	-0.014	-0.010	-0.030	0.011	0.058 ***	0.306 ***	0.440 ***	-0.074 ***	0.074 ***		
PNQ	-0.094 ***	-0.309 ***	-0.147 ***	-0.191 ***	-0.270 ***	-	0.235 ***	0.010	0.003	-0.036	0.063 *	-0.010	
AoD	0.017	-0.034	-0.044 *	-0.017	-0.032	0.019	0.026	-0.175 ***	-0.203 ***	-0.115 ***	-0.165 ***	-0.043 **	-0.043

Note. CP = conduct problems; ES = emotional symptoms; HA = hyperactivity/inattention; PP = peer problems; TD = total difficulties; LC = land cover; LU = land use; P/G = parks/gardens; N/SN UG = natural/semi-natural urban greenspaces; OSF = outdoor sports facilities; PNQ = perceived neighbourhood quality; AoD = Area of Deficiency. Data are taken from Waves 1 to 8. The sample size refers to observations (not individuals). Some individuals have multiple observations across waves, and these multiple observations are included in the correlations above. The sample size used to establish a given correlation depends on the variables involved in that correlation; the smallest sample size is n = 1,370. There are no correlations between self-esteem and SDQ scales, and between PNQ and self-esteem, because these variables were measured at different waves. Values of 0.000 represent values > 0 AND < 0.001. [1] Exposures are measured in 500 m buffers around postcodes. *p < .05, **p < .01, ***p < .001.

Model Results

The Role of Perceived Neighbourhood Quality

Regression model results for the first part of this study (Part A) are provided in Table 7.3 to Table 7.14. For each outcome, there are two tables: one including only the main effects of green land cover, green land use, and perceived neighbourhood quality; the other also including interaction effects. The first set of tables (i.e., models excluding interactions; Table 7.3 to Table 7.8) suggests an association between perceived neighbourhood quality and mental health and well-being across age groups and outcomes (except for conduct problems). Higher levels of perceived neighbourhood quality were associated with better mental health and well-being (i.e., fewer problems and more happiness). The second set of tables (i.e., models including interactions; Table 7.9 to Table 7.14) suggests that perceived neighbourhood quality may also play a moderating role in the associations between neighbourhood green land cover and green land use and mental health and well-being (though not consistently across age groups and outcomes). To ease the interpretation of results, I plotted significant interactions (see Figure 7.1 to Figure 7.4). Note, however, that these plots are based on non-imputed data and are only provided for illustrative purposes. Also note that, for reasons of visual clarity, I only plotted two lines (for two values of the continuous scale ranging from -4.2 to 1.6, where a higher score indicates higher perceived neighbourhood quality). An overview of results of the interaction analysis is provided in Table 7.15.

In 10-year-olds (see Figure 7.1), perceived neighbourhood quality moderated the associations of green land use with conduct problems and total difficulties, and green land cover with happiness. In neighbourhoods with 0% green land use, adolescents who perceived their neighbourhoods to be of ‘lower quality’ (represented by one line for a perceived neighbourhood quality value of -1.5) had higher levels of conduct problems and total difficulties than adolescents who perceived their neighbourhoods to be of ‘higher quality’ (represented by one line for a perceived neighbourhood quality value of 1.5). However, with increasing levels of green land use, mental health levels seemed to converge: for adolescents who perceived their neighbourhoods to be of ‘lower quality’, more green land use was associated with less problems. For adolescents who perceived their neighbourhoods to be of ‘higher quality’, more green land use was associated with more problems. By contrast, increasing levels of green land cover did not seem to be associated with happiness in adolescents who perceived their neighbourhoods to be of ‘higher quality’. However, in adolescents who perceived their neighbourhoods to be of ‘lower quality’, more green land cover was associated with lower levels of happiness.

In 12-year-olds (see Figure 7.2), perceived neighbourhood quality moderated the associations of green land use with conduct problems, emotional symptoms, and total difficulties. As for 10-year-olds, with increasing levels of green land use, levels of difficulties of adolescents who perceived their neighbourhoods to be of ‘lower quality’ and adolescents who perceived their neighbourhoods to be of ‘higher quality’ converged. This appeared to be due to a decrease of problems in the former and an increase of problems in the latter.

In 13-year-olds (see Figure 7.3), perceived neighbourhood quality moderated the associations of green land use and green land cover with hyperactivity and inattention; however, the moderation appeared to be in opposite directions. Increasing levels of green land use were associated with decreasing levels of hyperactivity and inattention in adolescents who perceived their neighbourhoods to be of ‘higher quality’ (but not their counterparts). Increasing levels of green land cover were associated with increasing levels of hyperactivity and inattention in adolescents who perceived their neighbourhoods to be of ‘higher quality’, and with decreasing levels of hyperactivity and inattention in adolescents who perceived their neighbourhoods to be of ‘lower quality’.

In 15-year-olds (see Figure 7.4), perceived neighbourhood quality moderated the associations of green land cover with conduct problems, emotional symptoms, peer relationship problems, total difficulties, and happiness. In adolescents who perceived their neighbourhoods to be of ‘lower quality’, increasing levels of green land cover were associated with decreasing levels of difficulties and increasing levels of happiness. The opposite was observed for adolescents who perceived their neighbourhoods to be of ‘higher quality’.

Table 7.3 Regression results for conduct problems

	b	*SE*	95% *CI*	*p*
15 years (*n* = 215)				
Green land cover	-0.028	0.014	[-0.055, -0.000]	0.050
Green land use	0.273	0.135	[0.000, 0.546]	0.050
Perceived neighbourhood quality	-0.082	0.053	[-0.189, 0.025]	0.128
14 years (*n* = 227)				
Green land cover	0.030	0.023	[-0.016, 0.076]	0.191
Green land use	-0.199	0.307	[-0.819, 0.422]	0.522
Perceived neighbourhood quality	-0.134	0.176	[-0.489, 0.221]	0.451
13 years (*n* = 227)				
Green land cover	-0.009	0.008	[-0.026, 0.008]	0.295
Green land use	-0.244	0.116	[-0.478, -0.010]	0.042
Perceived neighbourhood quality	-0.078	0.116	[-0.313, 0.158]	0.508
12 years (*n* = 266)				
Green land cover	-0.008	0.015	[-0.038, 0.023]	0.615
Green land use	0.220	0.293	[-0.367, 0.807]	0.456
Perceived neighbourhood quality	-0.144	0.241	[-0.627, 0.339]	0.553
11 years (*n* = 203)				
Green land cover	0.006	0.016	[-0.027, 0.040]	0.710
Green land use	-0.284	0.260	[-0.811, 0.243]	0.281
Perceived neighbourhood quality	-0.146	0.196	[-0.544, 0.251]	0.460
10 years (*n* = 221)				
Green land cover	0.004	0.012	[-0.021, 0.028]	0.773
Green land use	-0.051	0.349	[-0.763, 0.661]	0.884
Perceived neighbourhood quality	-0.224	0.125	[-0.480, 0.032]	0.084

Note. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets. Values of 0.000 represent values > 0 AND < 0.001; values of -0.000 represent values < 0 AND > -0.001. The green land cover variable is based on raw data [%], whereas the green land use variable is based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should not be compared to the size of the green land use coefficient.

Table 7.4 Regression results for emotional symptoms

	b	*SE*	95% *CI*	*p*
15 years (*n* = 215)				
Green land cover	-0.003	0.015	[-0.035, 0.028]	0.823
Green land use	0.354	0.190	[-0.030, 0.738]	0.070
Perceived neighbourhood quality	-0.421	0.094	[-0.611, -0.230]	0.000
14 years (*n* = 227)				
Green land cover	0.051	0.017	[0.017, 0.085]	0.004
Green land use	-0.436	0.268	[-0.979, 0.106]	0.112
Perceived neighbourhood quality	-0.515	0.180	[-0.878, -0.152]	0.007
13 years (*n* = 227)				
Green land cover	-0.020	0.011	[-0.042, 0.001]	0.064
Green land use	-0.174	0.127	[-0.430, 0.083]	0.179
Perceived neighbourhood quality	-0.420	0.216	[-0.857, 0.017]	0.059
12 years (*n* = 266)				
Green land cover	-0.021	0.015	[-0.051, 0.009]	0.171
Green land use	0.183	0.319	[-0.456, 0.822]	0.569
Perceived neighbourhood quality	-0.639	0.215	[-1.070, -0.209]	0.004
11 years (*n* = 203)				
Green land cover	0.018	0.020	[-0.022, 0.058]	0.372
Green land use	0.116	0.323	[-0.540, 0.771]	0.723
Perceived neighbourhood quality	-0.704	0.174	[-1.057, -0.352]	0.000
10 years (*n* = 221)				
Green land cover	0.024	0.025	[-0.027, 0.074]	0.343
Green land use	0.036	0.388	[-0.756, 0.828]	0.927
Perceived neighbourhood quality	-0.453	0.127	[-0.714, -0.193]	0.001

Note. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets. Values of 0.000 represent values > 0 AND < 0.001. The green land cover variable is based on raw data [%], whereas the green land use variable is based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should not be compared to the size of the green land use coefficient.

Table 7.5 Regression results for hyperactivity and inattention

	b	*SE*	95% *CI*	*p*
15 years (*n* = 215)				
Green land cover	0.006	0.018	[-0.030, 0.042]	0.734
Green land use	0.141	0.241	[-0.347, 0.629]	0.562
Perceived neighbourhood quality	-0.270	0.108	[-0.490, -0.051]	0.017
14 years (*n* = 227)				
Green land cover	0.018	0.024	[-0.030, 0.066]	0.459
Green land use	0.332	0.389	[-0.455, 1.119]	0.398
Perceived neighbourhood quality	-0.236	0.264	[-0.769, 0.298]	0.377
13 years (*n* = 227)				
Green land cover	-0.024	0.010	[-0.044, -0.004]	0.022
Green land use	-0.401	0.114	[-0.631, -0.170]	0.001
Perceived neighbourhood quality	-0.408	0.103	[-0.617, -0.200]	0.000
12 years (*n* = 266)				
Green land cover	-0.006	0.021	[-0.048, 0.036]	0.775
Green land use	0.167	0.310	[-0.454, 0.788]	0.593
Perceived neighbourhood quality	-0.251	0.189	[-0.630, 0.129]	0.191
11 years (*n* = 203)				
Green land cover	0.041	0.014	[0.013, 0.069]	0.005
Green land use	-0.137	0.186	[-0.514, 0.240]	0.465
Perceived neighbourhood quality	-0.424	0.186	[-0.801, -0.048]	0.028
10 years (*n* = 221)				
Green land cover	0.049	0.017	[0.015, 0.082]	0.006
Green land use	-0.124	0.268	[-0.671, 0.423]	0.646
Perceived neighbourhood quality	-0.202	0.081	[-0.368, -0.035]	0.019

Note. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets. Values of 0.000 represent values > 0 AND < 0.001. The green land cover variable is based on raw data [%], whereas the green land use variable is based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should not be compared to the size of the green land use coefficient.

Table 7.6 Regression results for peer relationship problems

	b	*SE*	95% *CI*	*p*
15 years (*n* = 215)				
Green land cover	-0.014	0.009	[-0.032, 0.004]	0.122
Green land use	0.212	0.112	[-0.015, 0.439]	0.066
Perceived neighbourhood quality	-0.140	0.055	[-0.252, -0.028]	0.016
14 years (*n* = 227)				
Green land cover	0.006	0.026	[-0.046, 0.059]	0.803
Green land use	-0.092	0.464	[-1.029, 0.845]	0.844
Perceived neighbourhood quality	-0.043	0.160	[-0.367, 0.280]	0.788
13 years (*n* = 227)				
Green land cover	-0.009	0.009	[-0.029, 0.010]	0.325
Green land use	0.023	0.116	[-0.212, 0.259]	0.842
Perceived neighbourhood quality	-0.300	0.139	[-0.580, -0.019]	0.037
12 years (*n* = 266)				
Green land cover	0.014	0.006	[0.001, 0.027]	0.032
Green land use	-0.020	0.109	[-0.239, 0.198]	0.852
Perceived neighbourhood quality	-0.339	0.145	[-0.630, -0.048]	0.023
11 years (*n* = 203)				
Green land cover	-0.003	0.013	[-0.030, 0.024]	0.824
Green land use	0.218	0.232	[-0.252, 0.688]	0.352
Perceived neighbourhood quality	-0.432	0.247	[-0.933, 0.069]	0.089
10 years (*n* = 221)				
Green land cover	0.002	0.018	[-0.035, 0.039]	0.910
Green land use	0.394	0.146	[0.095, 0.692]	0.011
Perceived neighbourhood quality	-0.257	0.112	[-0.486, -0.029]	0.029

Note. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets. The green land cover variable is based on raw data [%], whereas the green land use variable is based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should not be compared to the size of the green land use coefficient.

Table 7.7 Regression results for total difficulties

	b	*SE*	95% *CI*	*p*
15 years (*n* = 215)				
Green land cover	-0.039	0.038	[-0.115, 0.037]	0.303
Green land use	0.980	0.502	[-0.037, 1.998]	0.059
Perceived neighbourhood quality	-0.914	0.217	[-1.354, -0.474]	0.000
14 years (*n* = 227)				
Green land cover	0.105	0.056	[-0.008, 0.218]	0.067
Green land use	-0.395	1.010	[-2.436, 1.649]	0.698
Perceived neighbourhood quality	-0.928	0.401	[-1.738, -0.117]	0.026
13 years (*n* = 227)				
Green land cover	-0.062	0.019	[-0.102, -0.023]	0.003
Green land use	-0.795	0.213	[-1.227, -0.363]	0.001
Perceived neighbourhood quality	-1.206	0.304	[-1.822, -0.590]	0.000
12 years (*n* = 266)				
Green land cover	-0.020	0.048	[-0.116, 0.075]	0.671
Green land use	0.549	0.889	[-1.232, 2.330]	0.539
Perceived neighbourhood quality	-1.372	0.743	[-2.860, 0.115]	0.070
11 years (*n* = 203)				
Green land cover	0.062	0.043	[-0.024, 0.149]	0.153
Green land use	-0.087	0.600	[-1.305, 1.131]	0.886
Perceived neighbourhood quality	-1.707	0.569	[-2.861, -0.553]	0.005
10 years (*n* = 221)				
Green land cover	0.078	0.038	[0.001, 0.155]	0.047
Green land use	0.254	0.894	[-1.572, 2.080]	0.778
Perceived neighbourhood quality	-1.136	0.297	[-1.744, -0.529]	0.001

Note. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets. Values of 0.000 represent values > 0 AND < 0.001. The green land cover variable is based on raw data [%], whereas the green land use variable is based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should not be compared to the size of the green land use coefficient.

Table 7.8 Regression results for happiness

	b	*SE*	95% *CI*	*p*
15 years (*n* = 215)				
Green land cover	-0.003	0.005	[-0.014, 0.008]	0.559
Green land use	-0.017	0.039	[-0.095, 0.062]	0.666
Perceived neighbourhood quality	0.150	0.039	[0.071, 0.229]	0.000
14 years (*n* = 227)				
Green land cover	-0.008	0.010	[-0.029, 0.012]	0.421
Green land use	0.114	0.119	[-0.126, 0.354]	0.343
Perceived neighbourhood quality	0.230	0.062	[0.104, 0.355]	0.001
13 years (*n* = 227)				
Green land cover	0.008	0.005	[-0.003, 0.019]	0.139
Green land use	0.033	0.062	[-0.091, 0.158]	0.592
Perceived neighbourhood quality	0.115	0.051	[0.012, 0.218]	0.030
12 years (*n* = 266)				
Green land cover	-0.006	0.010	[-0.026, 0.014]	0.564
Green land use	-0.037	0.171	[-0.381, 0.306]	0.828
Perceived neighbourhood quality	0.172	0.058	[0.055, 0.289]	0.005
11 years (*n* = 203)				
Green land cover	-0.009	0.005	[-0.018, 0.001]	0.077
Green land use	-0.124	0.076	[-0.278, 0.030]	0.110
Perceived neighbourhood quality	0.334	0.059	[0.213, 0.454]	0.000
10 years (*n* = 221)				
Green land cover	-0.015	0.005	[-0.025, -0.005]	0.005
Green land use	-0.020	0.061	[-0.145, 0.105]	0.743
Perceived neighbourhood quality	0.149	0.031	[0.086, 0.212]	0.000

Note. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets. Values of 0.000 represent values > 0 AND < 0.001. The green land cover variable is based on raw data [%], whereas the green land use variable is based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should not be compared to the size of the green land use coefficient.

Table 7.9 Regression results for conduct problems (including interaction terms)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 215)				
Green land cover	-0.030	0.012	[-0.054, -0.005]	0.018
Green land use	0.295	0.112	[0.068, 0.521]	0.012
Perceived neighbourhood quality	-0.706	0.331	[-1.376, -0.036]	0.039
Quality * Green land cover	0.020	0.009	[0.002, 0.037]	0.032
Quality * Green land use	-0.057	0.093	[-0.247, 0.132]	0.544
14 years (*n* = 227)				
Green land cover	0.033	0.025	[-0.019, 0.084]	0.204
Green land use	-0.208	0.290	[-0.795, 0.378]	0.477
Perceived neighbourhood quality	0.015	0.680	[-1.359, 1.389]	0.982
Quality * Green land cover	-0.007	0.025	[-0.057, 0.044]	0.797
Quality * Green land use	0.060	0.129	[-0.201, 0.322]	0.643
13 years (*n* = 227)				
Green land cover	-0.006	0.012	[-0.029, 0.018]	0.629
Green land use	-0.266	0.133	[-0.535, 0.003]	0.052
Perceived neighbourhood quality	-0.377	0.327	[-1.038, 0.285]	0.256
Quality * Green land cover	0.011	0.012	[-0.012, 0.035]	0.337
Quality * Green land use	-0.083	0.154	[-0.396, 0.229]	0.592
12 years (*n* = 266)				
Green land cover	-0.002	0.021	[-0.045, 0.040]	0.908
Green land use	0.184	0.302	[-0.420, 0.788]	0.544
Perceived neighbourhood quality	0.140	0.950	[-1.764, 2.044]	0.884
Quality * Green land cover	-0.023	0.027	[-0.078, 0.031]	0.394
Quality * Green land use	0.340	0.115	[0.110, 0.570]	0.005
11 years (*n* = 203)				
Green land cover	0.004	0.017	[-0.030, 0.037]	0.829
Green land use	-0.263	0.260	[-0.790, 0.265]	0.319
Perceived neighbourhood quality	-0.455	0.850	[-2.180, 1.270]	0.596
Quality * Green land cover	-0.003	0.021	[-0.046, 0.040]	0.890
Quality * Green land use	0.252	0.233	[-0.221, 0.726]	0.287
10 years (*n* = 221)				
Green land cover	0.008	0.009	[-0.010, 0.027]	0.362
Green land use	0.082	0.236	[-0.399, 0.564]	0.729
Perceived neighbourhood quality	-0.503	0.421	[-1.363, 0.358]	0.242
Quality * Green land cover	-0.012	0.007	[-0.027, 0.003]	0.124
Quality * Green land use	0.377	0.163	[0.043, 0.710]	0.028

Note. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets. The green land cover variable is based on raw data [%], whereas the green land use variable is based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should not be compared to the size of the green land use coefficient.

Table 7.10 Regression results for emotional symptoms (including interaction terms)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 215)				
Green land cover	-0.005	0.015	[-0.035, 0.025]	0.736
Green land use	0.391	0.175	[0.036, 0.745]	0.032
Perceived neighbourhood quality	-0.941	0.255	[-1.457, -0.425]	0.001
Quality * Green land cover	0.025	0.008	[0.008, 0.041]	0.005
Quality * Green land use	-0.237	0.127	[-0.494, 0.019]	0.069
14 years (*n* = 227)				
Green land cover	0.043	0.016	[0.010, 0.076]	0.013
Green land use	-0.412	0.320	[-1.060, 0.235]	0.206
Perceived neighbourhood quality	-1.037	0.439	[-1.925, -0.148]	0.023
Quality * Green land cover	0.020	0.016	[-0.012, 0.052]	0.220
Quality * Green land use	-0.145	0.292	[-0.736, 0.446]	0.623
13 years (*n* = 227)				
Green land cover	-0.017	0.013	[-0.044, 0.010]	0.203
Green land use	-0.195	0.155	[-0.508, 0.119]	0.217
Perceived neighbourhood quality	-0.671	0.636	[-1.957, 0.616]	0.298
Quality * Green land cover	0.010	0.018	[-0.026, 0.047]	0.566
Quality * Green land use	-0.088	0.177	[-0.446, 0.270]	0.621
12 years (*n* = 266)				
Green land cover	-0.013	0.020	[-0.052, 0.026]	0.498
Green land use	0.136	0.322	[-0.509, 0.782]	0.674
Perceived neighbourhood quality	-0.150	0.922	[-1.997, 1.698]	0.872
Quality * Green land cover	-0.034	0.021	[-0.075, 0.007]	0.106
Quality * Green land use	0.450	0.155	[0.139, 0.761]	0.005
11 years (*n* = 203)				
Green land cover	0.015	0.019	[-0.024, 0.053]	0.444
Green land use	0.137	0.286	[-0.442, 0.717]	0.634
Perceived neighbourhood quality	-1.279	0.740	[-2.780, 0.222]	0.092
Quality * Green land cover	0.002	0.025	[-0.049, 0.053]	0.935
Quality * Green land use	0.294	0.255	[-0.224, 0.812]	0.257
10 years (*n* = 221)				
Green land cover	0.092	0.024	[-0.021, 0.078]	0.243
Green land use	0.106	0.343	[-0.593, 0.806]	0.758
Perceived neighbourhood quality	-0.964	0.334	[-1.646, -0.282]	0.007
Quality * Green land cover	0.009	0.009	[-0.010, 0.028]	0.343
Quality * Green land use	0.082	0.163	[-0.250, 0.414]	0.619

Note. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets. The green land cover variable is based on raw data [%], whereas the green land use variable is based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should not be compared to the size of the green land use coefficient.

Table 7.11 Regression results for hyperactivity and inattention (including interaction terms)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 215)				
Green land cover	0.003	0.023	[-0.044, 0.050]	0.894
Green land use	0.193	0.260	[-0.334, 0.720]	0.463
Perceived neighbourhood quality	-1.215	0.319	[-1.862, -0.568]	0.001
Quality * Green land cover	0.038	0.021	[-0.005, 0.081]	0.083
Quality * Green land use	-0.282	0.381	[-1.054, 0.490]	0.464
14 years (*n* = 227)				
Green land cover	0.007	0.027	[-0.047, 0.062]	0.782
Green land use	0.338	0.382	[-0.436, 1.111]	0.383
Perceived neighbourhood quality	-1.397	0.940	[-3.296, 0.502]	0.145
Quality * Green land cover	0.030	0.021	[-0.013, 0.073]	0.170
Quality * Green land use	0.020	0.211	[-0.406, 0.447]	0.923
13 years (*n* = 227)				
Green land cover	-0.016	0.008	[-0.032, 0.001]	0.067
Green land use	-0.461	0.122	[-0.707, -0.214]	0.001
Perceived neighbourhood quality	-0.730	0.374	[-1.488, 0.028]	0.058
Quality * Green land cover	0.025	0.011	[0.003, 0.046]	0.025
Quality * Green land use	-0.358	0.126	[-0.614, -0.102]	0.007
12 years (*n* = 266)				
Green land cover	-0.003	0.026	[-0.055, 0.048]	0.896
Green land use	0.152	0.321	[-0.491, 0.796]	0.637
Perceived neighbourhood quality	-0.020	0.752	[-1.526, 1.486]	0.979
Quality * Green land cover	-0.012	0.022	[-0.056, 0.031]	0.568
Quality * Green land use	0.140	0.142	[-0.146, 0.426]	0.329
11 years (*n* = 203)				
Green land cover	0.039	0.014	[0.012, 0.067]	0.007
Green land use	-0.148	0.186	[-0.525, 0.228]	0.429
Perceived neighbourhood quality	-1.394	0.534	[-2.478, -0.310]	0.013
Quality * Green land cover	0.025	0.018	[-0.011, 0.061]	0.172
Quality * Green land use	-0.002	0.242	[-0.493, 0.490]	0.995
10 years (*n* = 221)				
Green land cover	0.051	0.018	[0.015, 0.087]	0.008
Green land use	-0.078	0.275	[-0.641, 0.484]	0.778
Perceived neighbourhood quality	-0.396	0.303	[-1.015, 0.222]	0.201
Quality * Green land cover	0.000	0.009	[-0.019, 0.019]	0.993
Quality * Green land use	0.098	0.171	[-0.251, 0.446]	0.570

Note. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets. Values of 0.000 represent values > 0 AND < 0.001. The green land cover variable is based on raw data [%], whereas the green land use variable is based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should not be compared to the size of the green land use coefficient.

Table 7.12 Regression results for peer relationship problems (including interaction terms)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 215)				
Green land cover	-0.017	0.010	[-0.037, 0.002]	0.083
Green land use	0.227	0.107	[0.010, 0.443]	0.041
Perceived neighbourhood quality	-1.005	0.185	[-1.381, -0.629]	0.000
Quality * Green land cover	0.020	0.009	[0.002, 0.039]	0.029
Quality * Green land use	0.078	0.136	[-0.199, 0.355]	0.572
14 years (*n* = 227)				
Green land cover	0.008	0.019	[-0.031, 0.046]	0.689
Green land use	-0.110	0.408	[-0.934, 0.714]	0.789
Perceived neighbourhood quality	-0.231	0.311	[-0.861, 0.399]	0.463
Quality * Green land cover	-0.001	0.021	[-0.043, 0.041]	0.962
Quality * Green land use	0.138	0.339	[-0.546, 0.822]	0.686
13 years (*n* = 227)				
Green land cover	-0.008	0.011	[-0.030, 0.014]	0.453
Green land use	0.021	0.130	[-0.243, 0.284]	0.874
Perceived neighbourhood quality	-0.788	0.452	[-1.701, 0.126]	0.089
Quality * Green land cover	0.007	0.014	[-0.021, 0.035]	0.598
Quality * Green land use	0.105	0.145	[-0.187, 0.398]	0.471
12 years (*n* = 266)				
Green land cover	0.016	0.011	[-0.006, 0.038]	0.154
Green land use	-0.031	0.122	[-0.275, 0.214]	0.801
Perceived neighbourhood quality	-0.144	0.502	[-1.149, 0.861]	0.775
Quality * Green land cover	-0.010	0.023	[-0.057, 0.037]	0.670
Quality * Green land use	0.107	0.232	[-0.358, 0.572]	0.647
11 years (*n* = 203)				
Green land cover	-0.006	0.013	[-0.033, 0.021]	0.635
Green land use	0.231	0.222	[-0.220, 0.683]	0.305
Perceived neighbourhood quality	-1.290	0.626	[-2.560, -0.019]	0.047
Quality * Green land cover	0.012	0.016	[-0.020, 0.043]	0.455
Quality * Green land use	0.235	0.196	[-0.163, 0.633]	0.239
10 years (*n* = 221)				
Green land cover	0.006	0.019	[-0.032, 0.044]	0.757
Green land use	0.484	0.153	[0.173, 0.795]	0.003
Perceived neighbourhood quality	-0.508	0.311	[-1.143, 0.127]	0.113
Quality * Green land cover	-0.005	0.012	[-0.030, 0.019]	0.663
Quality * Green land use	0.234	0.123	[-0.018, 0.486]	0.067

Note. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets. Values of 0.000 represent values > 0 AND < 0.001. The green land cover variable is based on raw data [%], whereas the green land use variable is based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should not be compared to the size of the green land use coefficient.

Table 7.13 Regression results for total difficulties (including interaction terms)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 215)				
Green land cover	-0.049	0.043	[-0.136, 0.038]	0.262
Green land use	1.105	0.504	[0.083, 2.127]	0.035
Perceived neighbourhood quality	-3.867	0.771	[-5.430, -2.303]	0.000
Quality * Green land cover	0.103	0.033	[0.037, 0.169]	0.003
Quality * Green land use	-0.499	0.639	[-1.794, 0.797]	0.440
14 years (*n* = 227)				
Green land cover	0.091	0.063	[-0.037, 0.219]	0.158
Green land use	-0.393	0.946	[-2.304, 1.519]	0.680
Perceived neighbourhood quality	-2.649	1.621	[-5.926, 0.628]	0.110
Quality * Green land cover	0.042	0.038	[-0.036, 0.120]	0.279
Quality * Green land use	0.074	0.501	[-0.939, 1.087]	0.883
13 years (*n* = 227)				
Green land cover	-0.047	0.021	[-0.089, -0.004]	0.031
Green land use	-0.900	0.254	[-1.416, -0.385]	0.001
Perceived neighbourhood quality	-2.565	0.818	[-4.222, -0.909]	0.003
Quality * Green land cover	0.054	0.027	[-0.001, 0.110]	0.054
Quality * Green land use	-0.424	0.311	[-1.053, 0.205]	0.180
12 years (*n* = 266)				
Green land cover	-0.003	0.071	[-0.146, 0.139]	0.964
Green land use	0.442	0.931	[-1.423, 2.307]	0.637
Perceived neighbourhood quality	-0.174	2.594	[-5.370, 5.022]	0.947
Quality * Green land cover	-0.079	0.084	[-0.247, 0.088]	0.347
Quality * Green land use	1.037	0.330	[0.374, 1.700]	0.003
11 years (*n* = 203)				
Green land cover	0.051	0.043	[-0.037, 0.139]	0.246
Green land use	-0.042	0.542	[-1.142, 1.057]	0.938
Perceived neighbourhood quality	-4.418	2.044	[-8.563, -0.273]	0.037
Quality * Green land cover	0.036	0.061	[-0.088, 0.159]	0.562
Quality * Green land use	0.780	0.725	[-0.692, 2.251]	0.290
10 years (*n* = 221)				
Green land cover	0.094	0.034	[0.024, 0.164]	0.010
Green land use	0.594	0.672	[-0.778, 1.967]	0.383
Perceived neighbourhood quality	-2.371	0.890	[-4.188, -0.555]	0.012
Quality * Green land cover	-0.008	0.019	[-0.047, 0.031]	0.684
Quality * Green land use	0.790	0.342	[0.092, 1.488]	0.028

Note. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets. Values of 0.000 represent values > 0 AND < 0.001. The green land cover variable is based on raw data [%], whereas the green land use variable is based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should not be compared to the size of the green land use coefficient.

Table 7.14 Regression results for happiness (including interaction terms)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 215)				
Green land cover	-0.002	0.005	[-0.013, 0.009]	0.722
Green land use	-0.027	0.036	[-0.100, 0.047]	0.466
Perceived neighbourhood quality	0.494	0.125	[0.241, 0.747]	0.000
Quality * Green land cover	-0.010	0.003	[-0.017, -0.003]	0.007
Quality * Green land use	0.009	0.041	[-0.075, 0.094]	0.820
14 years (*n* = 227)				
Green land cover	-0.005	0.012	[-0.030, 0.019]	0.669
Green land use	0.127	0.121	[-0.117, 0.372]	0.297
Perceived neighbourhood quality	0.840	0.268	[0.298, 1.383]	0.003
Quality * Green land cover	-0.011	0.007	[-0.024, 0.003]	0.124
Quality * Green land use	-0.128	0.150	[-0.431, 0.176]	0.400
13 years (*n* = 227)				
Green land cover	0.007	0.006	[-0.006, 0.020]	0.306
Green land use	0.043	0.068	[-0.095, 0.180]	0.533
Perceived neighbourhood quality	0.251	0.136	[-0.023, 0.526]	0.072
Quality * Green land cover	-0.005	0.005	[-0.016, 0.006]	0.365
Quality * Green land use	0.033	0.075	[-0.119, 0.185]	0.661
12 years (*n* = 266)				
Green land cover	-0.007	0.010	[-0.027, 0.014]	0.509
Green land use	-0.036	0.162	[-0.361, 0.288]	0.824
Perceived neighbourhood quality	-0.002	0.330	[-0.664, 0.660]	0.995
Quality * Green land cover	0.005	0.005	[-0.004, 0.015]	0.272
Quality * Green land use	-0.023	0.167	[-0.359, 0.313]	0.891
11 years (*n* = 203)				
Green land cover	-0.008	0.005	[-0.018, 0.002]	0.111
Green land use	-0.131	0.073	[-0.280, 0.017]	0.081
Perceived neighbourhood quality	0.427	0.217	[-0.014, 0.868]	0.058
Quality * Green land cover	0.001	0.006	[-0.011, 0.013]	0.843
Quality * Green land use	-0.084	0.062	[-0.210, 0.043]	0.189
10 years (*n* = 221)				
Green land cover	-0.013	0.004	[-0.022, -0.005]	0.004
Green land use	-0.027	0.063	[-0.156, 0.103]	0.678
Perceived neighbourhood quality	-0.054	0.098	[-0.253, 0.146]	0.588
Quality * Green land cover	0.009	0.002	[0.006, 0.013]	0.000
Quality * Green land use	-0.088	0.046	[-0.181, 0.005]	0.064

Note. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets. Values of 0.000 represent values > 0 AND < 0.001. The green land cover variable is based on raw data [%], whereas the green land use variable is based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should not be compared to the size of the green land use coefficient.

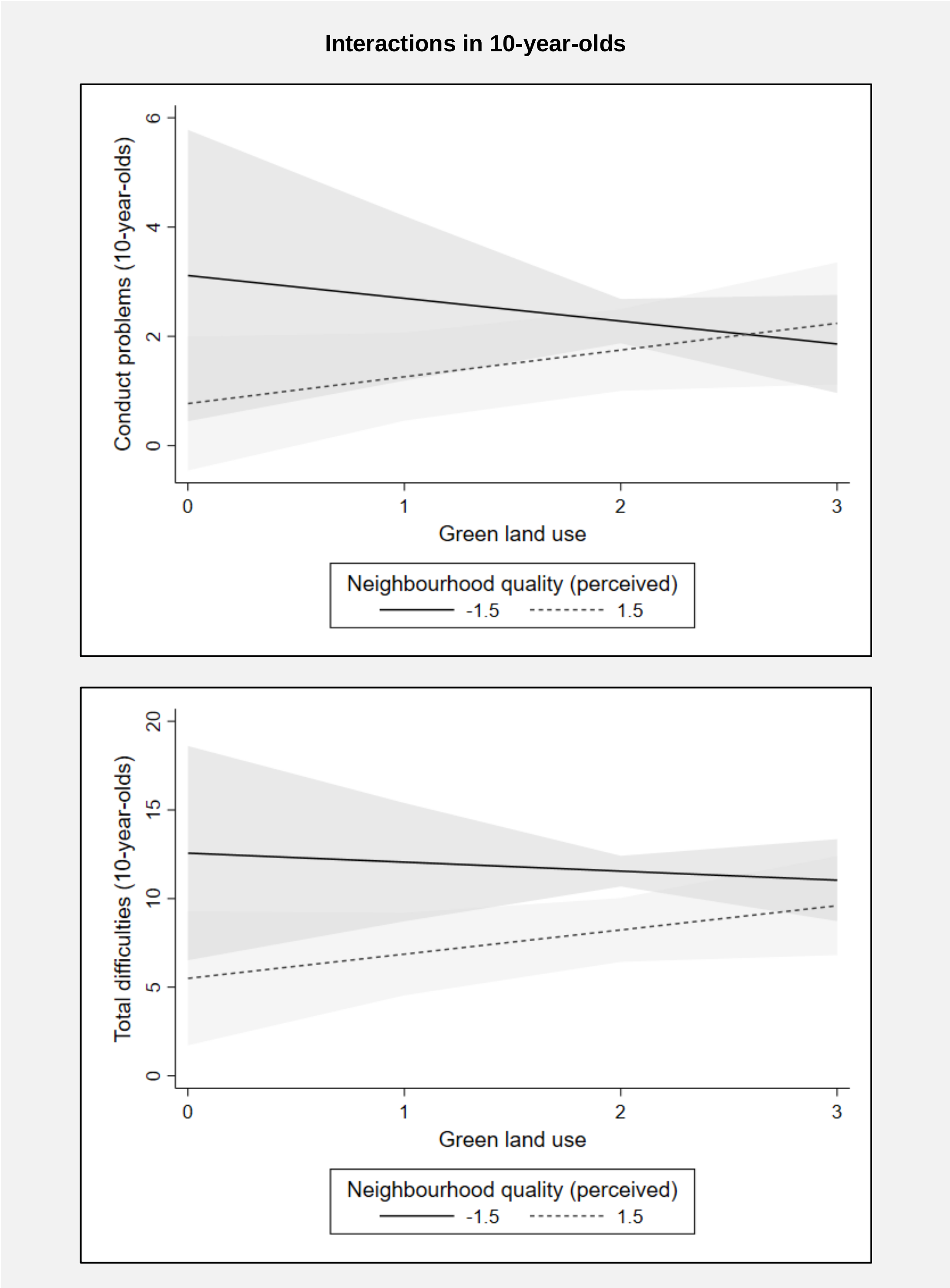

Figure 7.1 Interactions in 10-year-olds. Moderation of the associations of green land use with conduct problems and total difficulties, and the association of green land cover with happiness in 10-year-olds by perceived neighbourhood quality (linear predictions). Plots are based on non-imputed data (*n* = 181) and only serve an illustrative purpose. Shaded areas are 95% confidence intervals.

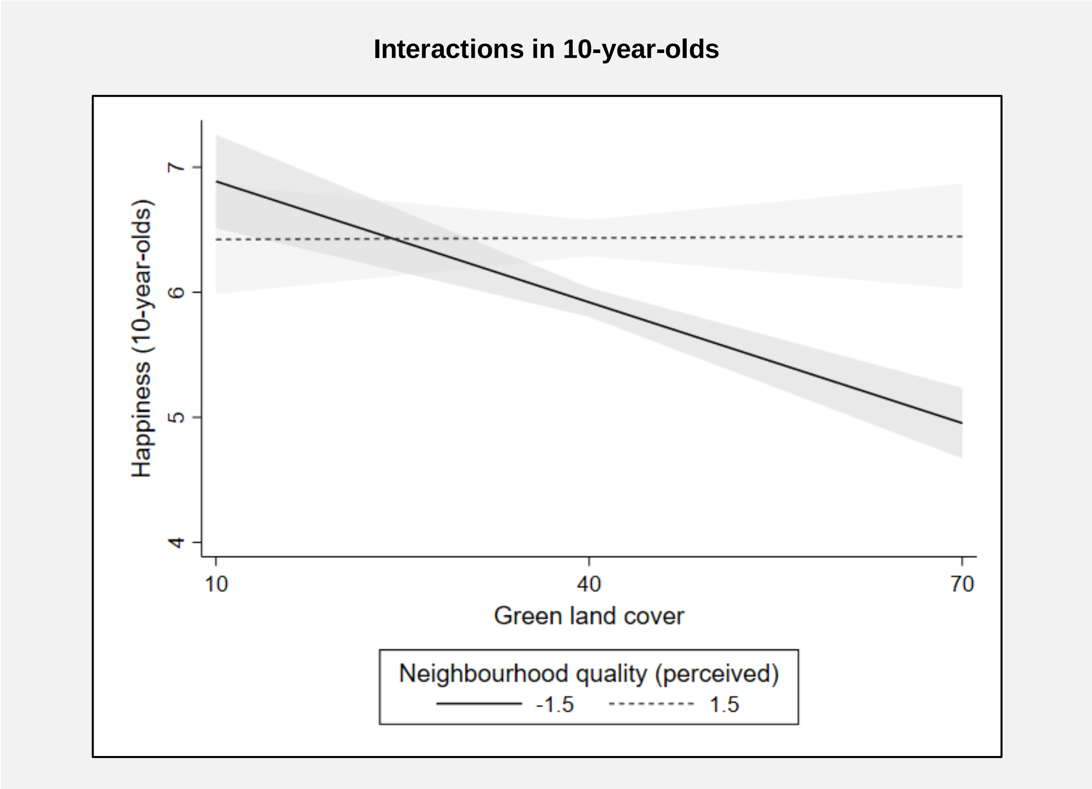

Figure 7.1 (continued) Moderation of the associations of green land use with conduct problems and total difficulties, and the association of green land cover with happiness in 10-year-olds by perceived neighbourhood quality (linear predictions). Plots are based on non-imputed data (*n* = 181) and only serve an illustrative purpose. Shaded areas are 95% confidence intervals.

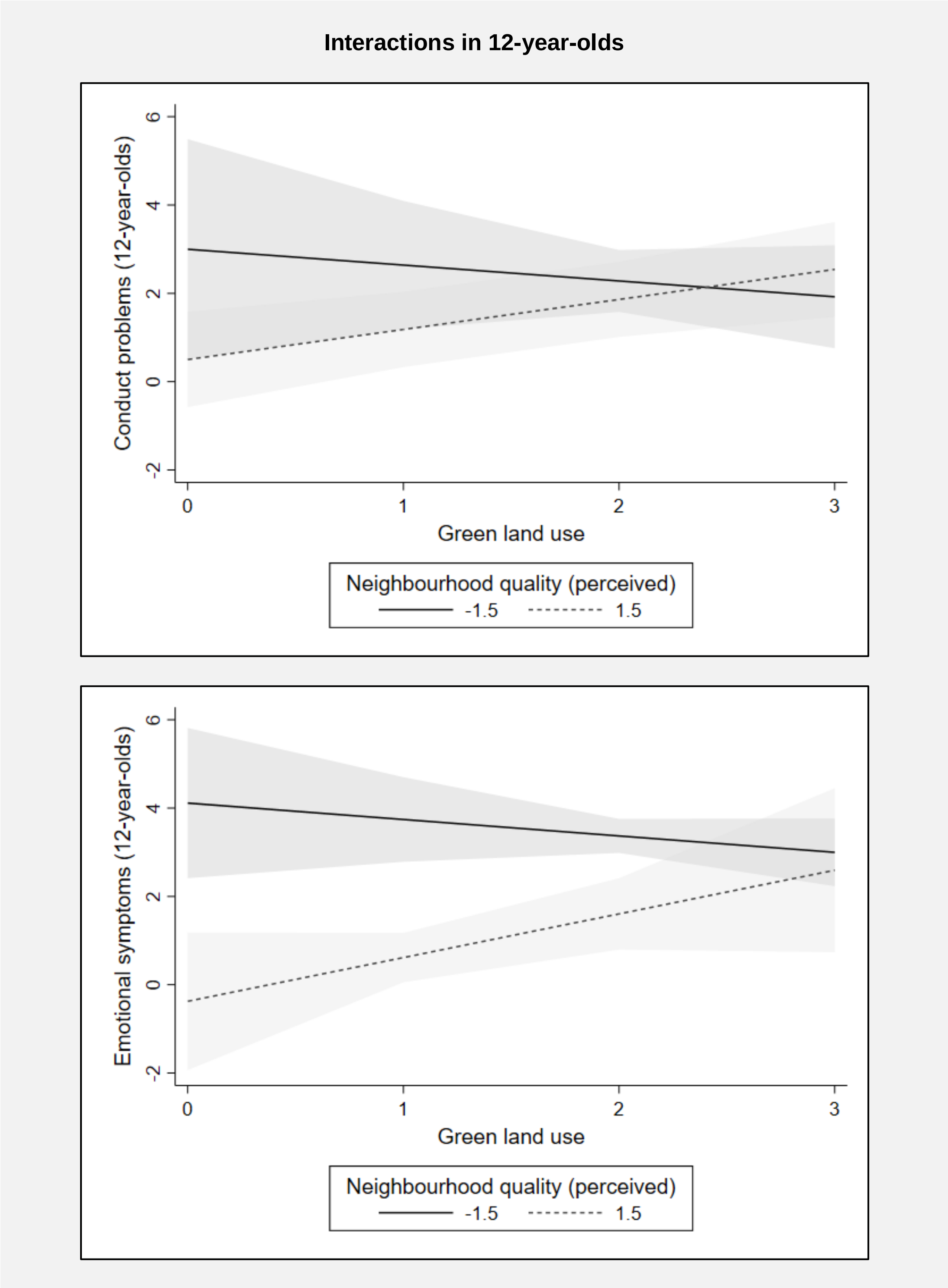

Figure 7.2 Interactions in 12-year-olds. Moderation of the associations of green land use with conduct problems, emotional symptoms, and total difficulties in 12-year-olds by perceived neighbourhood quality (linear predictions). Plots are based on non-imputed data (*n* = 186) and only serve an illustrative purpose. Shaded areas are 95% confidence intervals.

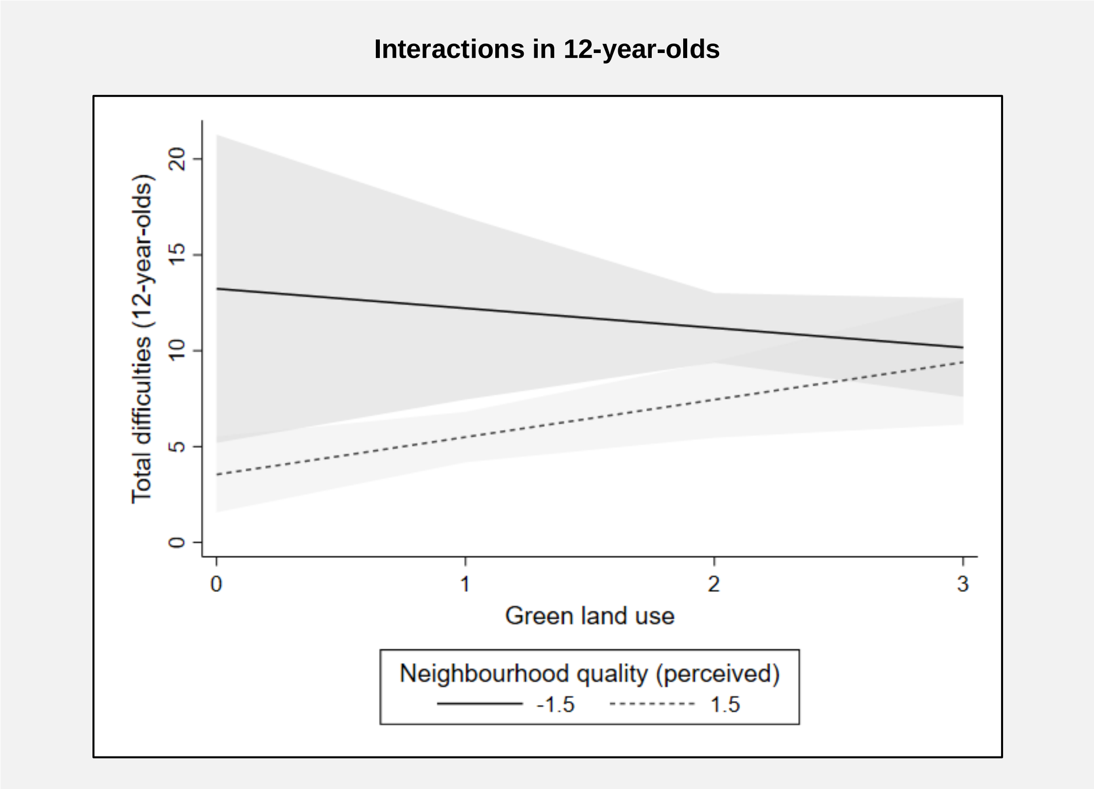

Figure 7.2 (continued) Moderation of the associations of green land use with conduct problems, emotional symptoms, and total difficulties in 12-year-olds by perceived neighbourhood quality (linear predictions). Plots are based on non-imputed data (*n* = 186) and only serve an illustrative purpose. Shaded areas are 95% confidence intervals.

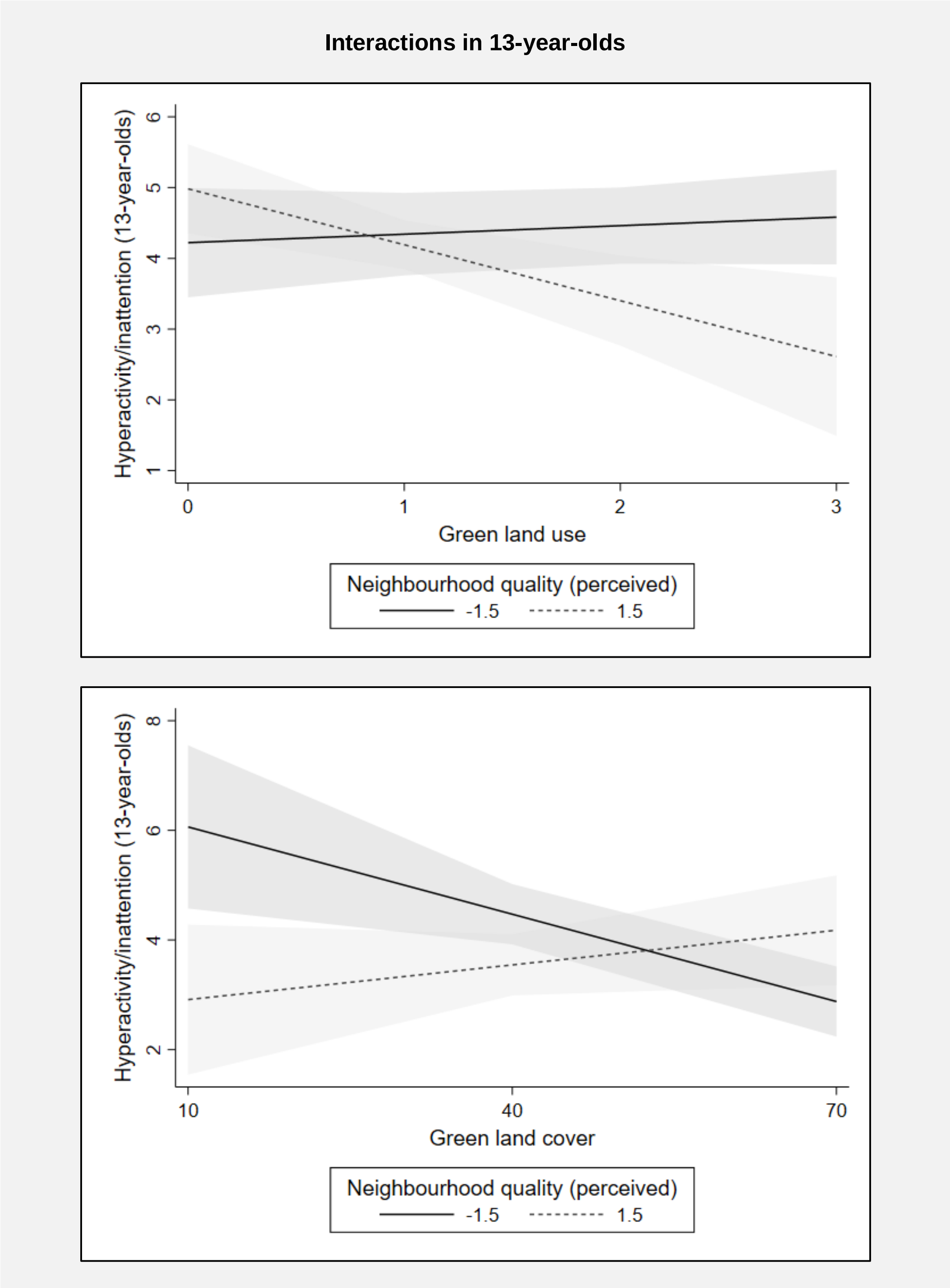

Figure 7.3 Interactions in 13-year-olds. Moderation of the associations of green land use and green land cover with hyperactivity and inattention in 13-year-olds by perceived neighbourhood quality (linear predictions). Plots are based on non-imputed data (*n* = 159) and only serve an illustrative purpose. Shaded areas are 95% confidence intervals.

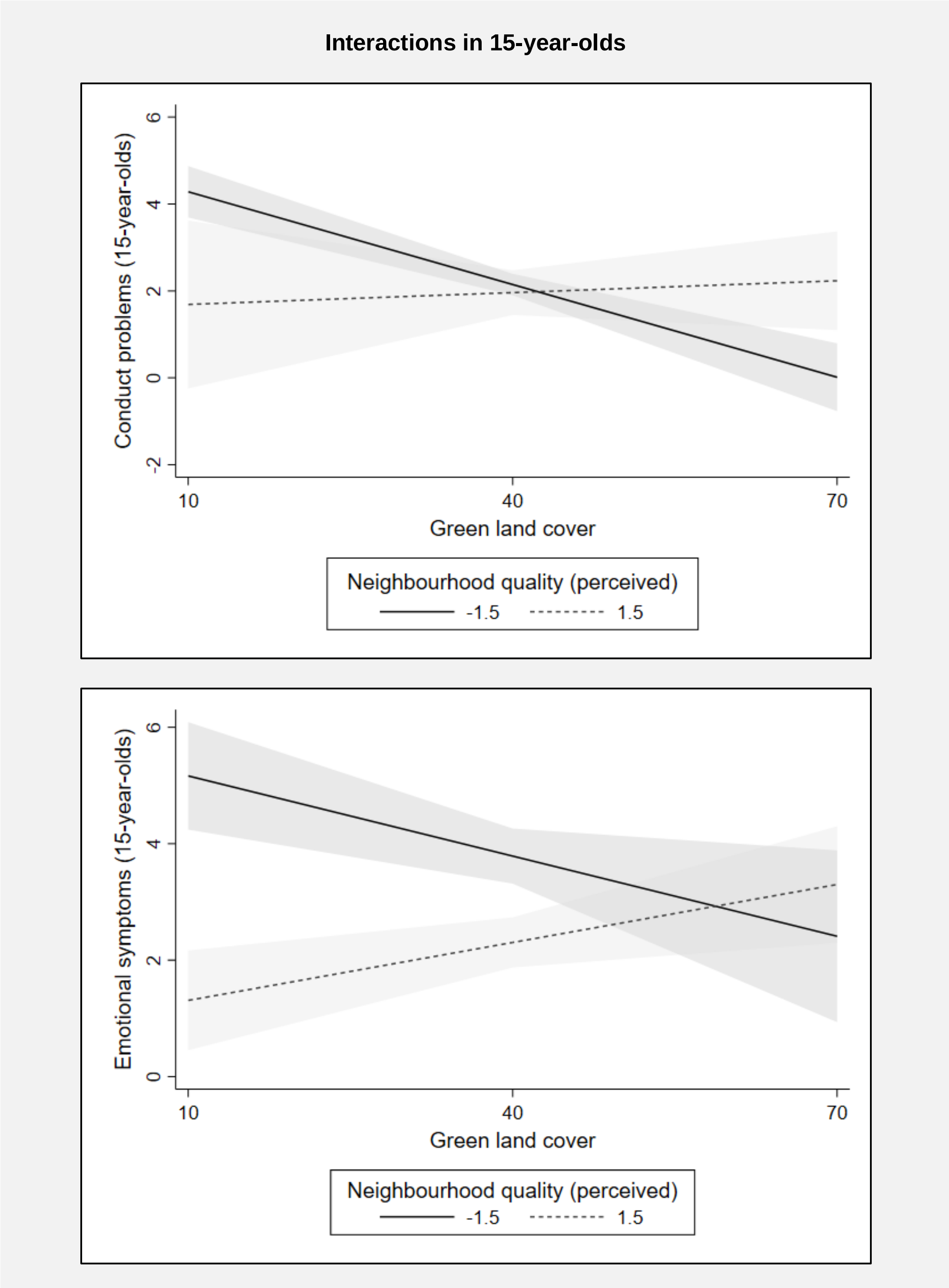

Figure 7.4 Interactions in 15-year-olds. Moderation of the associations of green land cover with conduct problems, emotional symptoms, peer problems, total difficulties, and happiness in 15-year-olds by perceived neighbourhood quality (linear predictions). Plots are based on non-imputed data (*n* = 157) and only serve an illustrative purpose. Shaded areas are 95% confidence intervals.

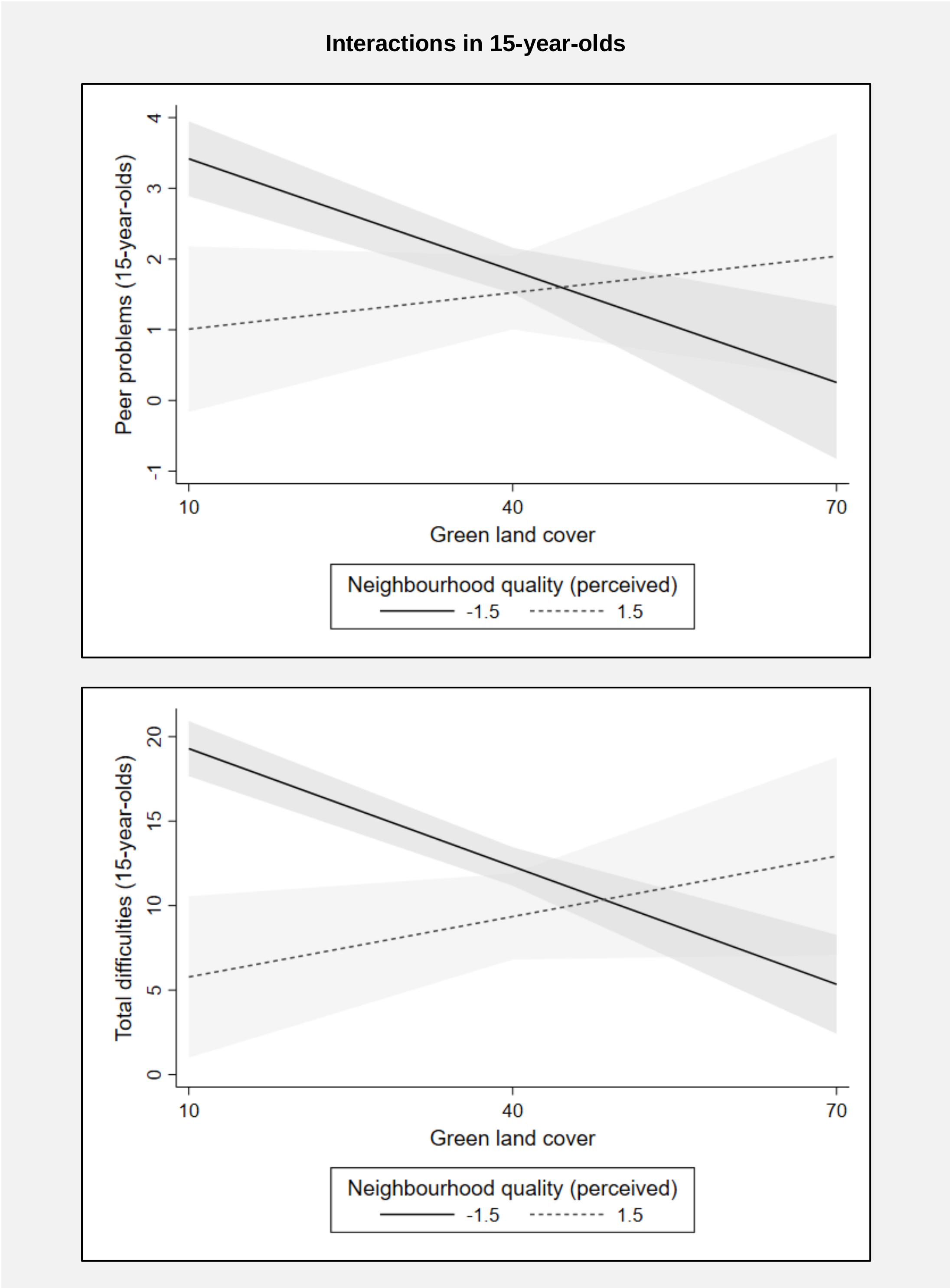

Figure 7.4 (continued) Moderation of the associations of green land cover with conduct problems, emotional symptoms, peer problems, total difficulties, and happiness in 15-year-olds by perceived neighbourhood quality (linear predictions). Plots are based on non-imputed data (*n* = 157) and only serve an illustrative purpose. Shaded areas are 95% confidence intervals.

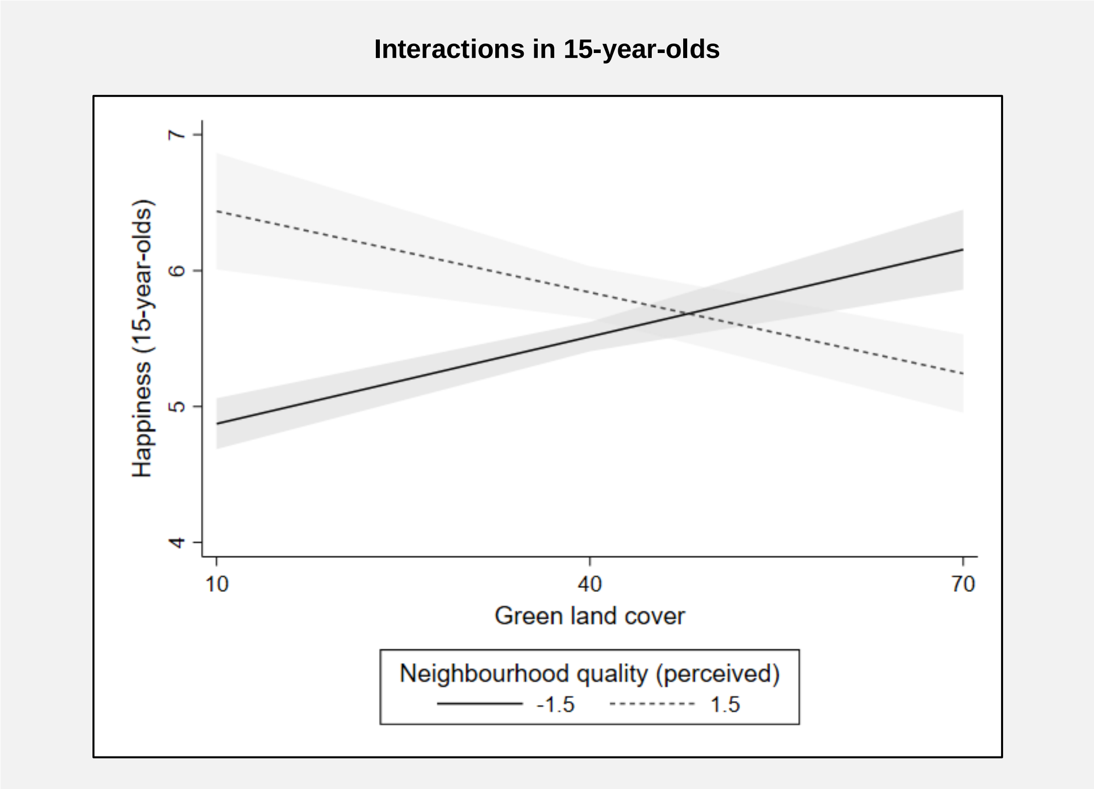

Figure 7.4 (continued) Moderation of the associations of green land cover with conduct problems, emotional symptoms, peer problems, total difficulties, and happiness in 15-year-olds by perceived neighbourhood quality (linear predictions). Plots are based on non-imputed data (*n* = 157) and only serve an illustrative purpose. Shaded areas are 95% confidence intervals.

Table 7.15 Overview of interactions for Study 4 - Part A

	SDQ CP	SDQ ES	SDQ HA	SDQ PP	SDQ TD	Self-esteem	Happiness
15 years							
Quality * Green land cover	[green]	[green]	[yellow]	[green]	[green]	[yellow]	[green]
Quality * Green land use	[yellow]	[yellow]	[yellow]	[yellow]	[yellow]	[yellow]	[yellow]
14 years							
Quality * Green land cover	[yellow]	[yellow]	[yellow]	[yellow]	[yellow]	[yellow]	[yellow]
Quality * Green land use	[yellow]	[yellow]	[yellow]	[yellow]	[yellow]	[yellow]	[yellow]
13 years							
Quality * Green land cover	[yellow]	[yellow]	[green]	[yellow]	[yellow]	[yellow]	[yellow]
Quality * Green land use	[yellow]	[yellow]	[blue]	[yellow]	[yellow]	[yellow]	[yellow]
12 years							
Quality * Green land cover	[yellow]	[yellow]	[yellow]	[yellow]	[yellow]	[yellow]	[yellow]
Quality * Green land use	[green]	[green]	[yellow]	[yellow]	[green]	[yellow]	[yellow]
11 years							
Quality * Green land cover	[yellow]	[yellow]	[yellow]	[yellow]	[yellow]	[yellow]	[yellow]
Quality * Green land use	[yellow]	[yellow]	[yellow]	[yellow]	[yellow]	[yellow]	[yellow]
10 years							
Quality * Green land cover	[yellow]	[yellow]	[yellow]	[yellow]	[yellow]	[yellow]	[orange]
Quality * Green land use	[green]	[yellow]	[yellow]	[yellow]	[green]	[yellow]	[yellow]

Note. This table provides an overview of interactions reported in tables and illustrated in figures above. CP = conduct problems; ES = emotional symptoms; HA = hyperactivity/inattention; PP = peer problems; TD = total difficulties.

X [green] Interaction suggesting that adolescents who perceive their neighbourhoods to be of lower quality 'benefit' more from neighbourhood greenspace than their counterparts.

X [orange] Interaction suggesting that adolescents who perceive their neighbourhoods to be of lower quality 'dis-benefit' more from neighbourhood greenspace than their counterparts.

X [yellow] No interaction.

X [blue] Interaction suggesting that adolescents who perceive their neighbourhoods to be of higher quality 'benefit' more from neighbourhood greenspace than their counterparts.

The Role of Access to Green Spaces with 'High Ecological Quality'

Regression model results for the second part of this study (Part B) are shown in Table 7.16 to Table 7.22. Across age groups and outcomes, I did not find an association of living in an AoD, i.e., of having poor access to green spaces with 'high ecological quality', with mental health and well-being (except for emotional symptoms in 13-year-olds, and peer relationship problems in 10-year-olds). Adjusting for perceived neighbourhood quality did not change results substantially (see Tables A7.2.1 to A7.2.6 in Appendix 2). I also did not find significant associations in children (see Tables A7.3.1 to A7.3.5 in Appendix 2).

Table 7.16 Regression results for conduct problems

	b	*SE*	95% *CI*	*p*
15 years (*n* = 365)				
Lives in an AoD	0.119	0.215	[-0.309, 0.547]	0.582
14 years (*n* = 349)				
Lives in an AoD	0.048	0.294	[-0.537, 0.632]	0.872
13 years (*n* = 378)				
Lives in an AoD	0.114	0.220	[-0.324, 0.553]	0.605
12 years (*n* = 392)				
Lives in an AoD	0.024	0.221	[-0.415, 0.462]	0.915
11 years (*n* = 368)				
Lives in an AoD	-0.074	0.319	[-0.709, 0.560]	0.817
10 years (*n* = 375)				
Lives in an AoD	-0.118	0.295	[-0.706, 0.470]	0.691

Note. AoD = Area of Deficiency. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets.

Table 7.17 Regression results for emotional symptoms

	b	*SE*	95% *CI*	*p*
15 years (*n* = 365)				
Lives in an AoD	-0.518	0.261	[-1.038, 0.002]	0.051
14 years (*n* = 349)				
Lives in an AoD	-0.501	0.463	[-1.423, 0.420]	0.282
13 years (*n* = 378)				
Lives in an AoD	-0.473	0.202	[-0.875, -0.071]	0.022
12 years (*n* = 392)				
Lives in an AoD	-0.109	0.321	[-0.747, 0.528]	0.734
11 years (*n* = 368)				
Lives in an AoD	0.043	0.396	[-0.746, 0.831]	0.914
10 years (*n* = 375)				
Lives in an AoD	-0.466	0.382	[-1.227, 0.295]	0.227

Note. AoD = Area of Deficiency. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets.

Table 7.18 Regression results for hyperactivity and inattention

	b	*SE*	95% *CI*	*p*
15 years (*n* = 365)				
Lives in an AoD	-0.085	0.315	[-0.711, 0.541]	0.788
14 years (*n* = 349)				
Lives in an AoD	-0.495	0.367	[-1.224, 0.235]	0.181
13 years (*n* = 378)				
Lives in an AoD	-0.362	0.268	[-0.895, 0.172]	0.181
12 years (*n* = 392)				
Lives in an AoD	-0.151	0.257	[-0.661, 0.359]	0.559
11 years (*n* = 368)				
Lives in an AoD	-0.111	0.492	[-1.090, 0.868]	0.822
10 years (*n* = 375)				
Lives in an AoD	-0.192	0.281	[-0.752, 0.369]	0.498

Note. AoD = Area of Deficiency. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets.

Table 7.19 Regression results for peer relationship problems

	b	*SE*	95% *CI*	*p*
15 years (*n* = 365)				
Lives in an AoD	-0.062	0.200	[-0.459, 0.336]	0.759
14 years (*n* = 349)				
Lives in an AoD	0.233	0.261	[-0.285, 0.752]	0.374
13 years (*n* = 378)				
Lives in an AoD	-0.150	0.180	[-0.507, 0.208]	0.408
12 years (*n* = 392)				
Lives in an AoD	-0.057	0.230	[-0.515, 0.401]	0.805
11 years (*n* = 368)				
Lives in an AoD	-0.254	0.276	[-0.803, 0.294]	0.359
10 years (*n* = 375)				
Lives in an AoD	-0.436	0.194	[-0.822, -0.049]	0.028

Note. AoD = Area of Deficiency. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets.

Table 7.20 Regression results for total difficulties

	b	*SE*	95% *CI*	*p*
15 years (*n* = 365)				
Lives in an AoD	-0.545	0.632	[-1.802, 0.712]	0.391
14 years (*n* = 349)				
Lives in an AoD	-0.715	1.027	[-2.757, 1.327]	0.488
13 years (*n* = 378)				
Lives in an AoD	-0.870	0.615	[-2.095, 0.356]	0.161
12 years (*n* = 392)				
Lives in an AoD	-0.294	0.735	[-1.754, 1.167]	0.690
11 years (*n* = 368)				
Lives in an AoD	-0.397	0.769	[-1.927, 1.133]	0.607
10 years (*n* = 375)				
Lives in an AoD	-1.211	0.876	[-2.956, 0.534]	0.171

Note. AoD = Area of Deficiency. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets.

Table 7.21 Regression results for self-esteem

	b	*SE*	95% *CI*	*p*
15 years (*n* = 293)				
Lives in an AoD	0.111	0.075	[-0.039, 0.261]	0.144
14 years (*n* = 306)				
Lives in an AoD	0.021	0.048	[-0.074, 0.117]	0.653
13 years (*n* = 338)				
Lives in an AoD	0.063	0.078	[-0.092, 0.218]	0.419
12 years (*n* = 298)				
Lives in an AoD	-0.029	0.085	[-0.200, 0.142]	0.734
11 years (*n* = 336)				
Lives in an AoD	-0.040	0.061	[-0.162, 0.083]	0.520
10 years (*n* = 264)				
Lives in an AoD	-0.022	0.108	[-0.239, 0.194]	0.836

Note. AoD = Area of Deficiency. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets.

Table 7.22 Regression results for happiness

	b	*SE*	95% *CI*	*p*
15 years (*n* = 663)				
Lives in an AoD	0.086	0.105	[-0.121, 0.292]	0.413
14 years (*n* = 663)				
Lives in an AoD	0.065	0.134	[-0.200, 0.330]	0.630
13 years (*n* = 725)				
Lives in an AoD	0.083	0.097	[-0.107, 0.274]	0.391
12 years (*n* = 699)				
Lives in an AoD	-0.018	0.102	[-0.219, 0.183]	0.857
11 years (*n* = 710)				
Lives in an AoD	-0.018	0.085	[-0.187, 0.150]	0.832
10 years (*n* = 644)				
Lives in an AoD	0.131	0.114	[-0.095, 0.356]	0.254

Note. AoD = Area of Deficiency. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets.

7.4. Discussion

In the fourth study of my thesis, I investigated the role of quality in the association between neighbourhood greenspace and adolescent mental health and well-being. I was interested in quality at two levels, neighbourhood level and greenspace level. First, I investigated whether perceived neighbourhood quality moderated the associations of green land use and green land cover with mental health and well-being. Second, I investigated the role of access to green spaces with 'high ecological quality' (defined as living within 1,000 m walking distance from a SINC). Taken together, the results of this study suggest that perceived neighbourhood quality may play a more important role in adolescents' mental health and well-being than living nearby 'high-quality' green spaces. I will now discuss the main findings of this study, separately for Part A and Part B. As in the previous chapters, I will also highlight important limitations that may have contributed to my findings and, therefore, need to be considered in the interpretation of results.

Main Findings

The Role of Perceived Neighbourhood Quality

In the first part of this study (Part A), I investigated whether perceived neighbourhood quality played a moderating role in the association of neighbourhood greenspace with adolescent mental health and well-being. I created a 'perceived neighbourhood quality' variable, based on a PCA on three variables (i.e., whether adolescents liked living in their neighbourhoods, how safe adolescents felt walking in their neighbourhoods in the dark, and how worried adolescents felt to be a victim of crime). The first main finding was that perceived neighbourhood quality was a consistent predictor of adolescent mental health and well-being across age groups and outcomes (except for conduct problems): higher perceived neighbourhood quality was associated with better mental health (i.e., fewer difficulties) and better well-being (i.e., higher levels of happiness). This finding is in line with the literature, suggesting associations of (perceived) neighbourhood safety and (fear of) crime with mental health and well-being (Baranyi et al., 2021; Lorenc et al., 2012; Mueller et al., 2019). It is also in line with the second study of my thesis where I found associations of perceived area safety with adolescent well-being (i.e., self-esteem, happiness, positive mood, negative mood, and antisocial behaviour).

Because the neighbourhood quality variable captured perceived quality, my findings do not have clear implications for neighbourhood policy and design because they do not provide information about what objective factors would improve (perceived) neighbourhood quality. In fact, there was no association between subjective (perceived) neighbourhood quality and objective measures of neighbourhood socio-economic deprivation (i.e., the Carstairs index; $r = -0.05$, $p = .080$), green land cover or green land use (see correlations in Table 7.2), or air pollution ($r = 0.03$, $p = .330$). This suggests that there must be other factors influencing adolescents' perceptions of the quality of their neighbourhoods, which is consistent with the previous literature: for example, it has been shown that subjective fear of crime does not correlate highly with objective crime rates (Prieto Curiel & Bishop, 2018; Reese, 2009).

The main question of this part of the study was whether perceived neighbourhood quality would moderate the associations between green land use and green land cover and adolescent mental health and well-being. Neighbourhood quality, especially the perception of safety, may influence an adolescent's use of their neighbourhood and may also be an indicator of the quality (e.g., maintenance or cleanliness) of green spaces in the neighbourhood, in turn, likely influencing an adolescent's use of these spaces. To test for a potential moderating role, I added two interaction terms to my main models, one for green land cover and one for green land use. The results suggest that perceived neighbourhood quality may, indeed, play a moderating role in the association between greenspace and mental health and well-being. However, interaction effects were not consistent across age groups and outcomes. As for findings in the previous chapter, I will not attempt to interpret single associations but rather look at the pattern of associations. Interestingly, as in the previous chapter, there seems to be a difference between younger adolescents (10- to 12-year-olds) and older adolescents (13- to 15-year-olds).

In younger adolescents, 10- and 12-year-olds in particular, adolescents who perceived their neighbourhoods to be of ‘lower quality’ seemed to benefit from green land use in their neighbourhoods, whereas adolescents who perceived their neighbourhoods to be of ‘higher quality’ showed more problems with increasing levels of green land use. Interestingly, this was not the same for the association of green land cover with happiness: in 10-year-olds who perceived their neighbourhoods to be of ‘lower quality’, higher levels of green land cover were associated with lower levels of happiness. If causal, this suggests a ‘beneficial’ role of green land use, but not green land cover, for young adolescents who perceive their neighbourhoods to be of ‘lower quality’ (e.g., as unsafe).

In older adolescents, 13- and 15-year-olds in particular, I found the opposite pattern. Adolescents who perceived their neighbourhoods to be of ‘lower quality’ seemed to benefit from green land cover in their neighbourhoods, whereas adolescents who perceived their neighbourhoods to be of ‘higher quality’ showed more problems with increasing levels of green land cover. This was most pronounced in 15-year-olds, where I found this pattern for all outcomes (except for hyperactivity and inattention).

My findings suggest that, in adolescents who perceive their neighbourhoods to be of ‘lower quality’, neighbourhood green land cover (i.e., neighbourhood greenness), but not availability of green land use (i.e., availability of free-to-access green spaces), becomes more important with age. Note, however, because I did not run longitudinal analyses assessing associations in the same individuals over time, I could not test this trend formally.

In adolescents who perceived their neighbourhoods to be of ‘lower quality’, why did younger adolescents seem to benefit from green land use and older adolescents seem to benefit from green land cover? One possible explanation would be that younger adolescents in London may not be allowed to move around their neighbourhoods (or beyond) unsupervised (Shaw et al., 2015). So, these adolescents may benefit from green land use in their areas, despite perceiving their neighbourhoods to be of 'lower quality' (e.g., because their parents take them to these spaces). Older adolescents, however, may move around their neighbourhoods, and beyond, unsupervised, either alone or with their friends (Monitor of Engagement with the Natural Environment, 2019). These adolescents may not be tempted to use 'free-to-access' green spaces in their own neighbourhoods but may travel further to visit greenspace outside their neighbourhoods. At the same time, these adolescents may benefit from high levels of greenery (i.e., green land cover) in their neighbourhoods, for example, due to incidental exposure or passive effects, such as breathing cleaner air or viewing nature.

The question remains why effects for green land use and green land cover would be the opposite for adolescents who perceived their neighbourhoods to be of 'higher quality'. It would be plausible to assume that adolescents who like their neighbourhoods and who perceive their neighbourhoods as safe move around more freely, use green spaces more frequently, and may be exposed to 'high-quality' green spaces and greenery. Furthermore, it would be plausible to assume that this would result in better mental health and well-being outcomes. However, this is not what my results suggest: younger adolescents seemed to 'dis-benefit' from green land use, and older adolescents seemed to 'dis-benefit' from green land cover in their neighbourhoods. Noteworthy, there was one interaction that was in the 'expected' direction: there was a negative association of green land use with hyperactivity and inattention in 13-year-olds who perceived their neighbourhoods to be of 'higher quality'. This would fit the explanation above, however, it seemed to be an exception.

In summary, there seem to be complex interactions between perceived neighbourhood quality, exposure, and age, and, overall, findings were unexpected. I hypothesised that adolescents who perceive their neighbourhoods to be of 'higher quality' would benefit more from green spaces than their counterparts. However, my findings suggest the opposite, i.e., a potentially protective role of green spaces for the mental health and well-being of adolescents who perceive their neighbourhoods to be of 'lower quality'. Because findings were not consistent across age groups and exposures, more research is needed into the role of neighbourhood quality in the association between neighbourhood greenspace and adolescent mental health and well-being.

The Role of Access to Green Spaces with 'High Ecological Quality'

In the second part of this study (Part B), I investigated whether there was an association between access to green spaces with 'high ecological quality' and adolescent mental health and well-being. To investigate this, I created a binary variable measuring whether adolescents lived in an Area of Deficiency in Access to a SINC (defined as living beyond 1,000 m walking distance from a SINC). Living in an AoD is an indicator of poor access to green spaces with 'high ecological quality' (where ecological quality is defined as wealth of wildlife). Overall, I did not find an association of living in an AoD with mental health and well-being (except for two associations). This finding was confirmed in a sensitivity analysis adjusted for perceived neighbourhood quality, and in a sensitivity analysis testing for associations in younger children (5- and 8-year-olds). This is interesting considering that Knight et al. (2022) did find an association of the same exposure with life satisfaction in adults living in London.

My findings suggest that living nearby green spaces with 'high ecological quality' may not play a role in adolescents' and children's mental health and well-being. However, this does not mean that the quality of green spaces does not play a role at all. Indeed, there are several possible explanations for why I did not find a significant association. I would like to discuss two, i.e., the definitions of 'quality' and 'exposure'.

In this study, I defined 'high-quality' green spaces as green spaces designated as a SINC, i.e., green spaces with 'high ecological quality'. It is true that green spaces with 'high ecological quality' may be beneficial for mental health and well-being, as suggested by studies on adults, as described in the introduction (Knight et al., 2022; B. W. Wheeler et al., 2015; Wyles et al., 2019). The question is whether ecological quality is as beneficial for adolescents, or whether other dimensions of quality may be more relevant. Passive effects on mental health, due to, for example, viewing nature, hearing birdsong, or breathing cleaner air, are possible. However, for intentional visits of green spaces, other aspects of quality may be more important for adolescents. As described in the introduction, adolescents tend to use green spaces mainly for physical and social activities (Bloemsma et al., 2018) and may be more attracted by well-maintained spaces with playgrounds, trails, and picnic areas (Rivera et al., 2021; Van Hecke et al., 2016). As SINCs are designated for their importance for the local habitat, they may not always be a good fit for adolescents' needs. In other words, adolescents may not perceive or experience them as 'high-quality' green spaces and may not use them much. At individual level, this depends on the characteristics of each SINC, but it may be one explanation for why I did not find significant associations across adolescents.

An additional argument is a dip in nature connectedness in adolescence (Kahn & Kellert, 2002; Krettenauer, 2017; Krettenauer et al., 2020). Adolescents are not as connected (emotionally) with nature as children or adults, which may mean that spaces with 'high ecological quality' are not that appealing to them. I should note, however, that I did not find significant associations in younger children either, although they tend to have higher levels of nature connectedness. This may have to do with the fact that I investigated an urban sample. It has been reported in the literature that urban dwellers have lower levels of nature connectedness due to an 'extinction of experience' (Soga & Gaston, 2016). However, the term has been criticised and the empirical evidence for an 'extinction of experience' is scarce (Gaston & Soga, 2020).

Findings from an experimental study suggest that children prefer pictures of urban spaces over pictures of natural spaces, whereas adults prefer pictures of natural spaces over pictures of urban spaces (Meidenbauer et al., 2019). This may be another explanation for why I did not find an association in young children in my study. Interestingly, this study also suggests that there is a gradual change in preference for natural spaces with age, indicating that adolescents may prefer natural over urban spaces. However, because the study only investigated children until the age of 11 years, it is unclear if there may be a reversal of this trend in adolescence. Furthermore, even if adolescents preferred (pictures of) natural spaces, it is unclear how such a preference relates to actual use of natural spaces or to associations with mental health and well-being. For example, an adolescent may prefer a picture of a natural space over a picture of an urban space, but they may still prefer to spend time with their friends in the city centre rather than in green spaces. Further, a preference for certain types of spaces does not mean that other types of spaces are not important for their mental health and well-being. For example, in the same study, Meidenbauer et al. (2019) found that higher levels of nearby nature were associated with fewer attention problems in children, but this was unrelated to their preferences for urban or natural spaces. In other words, even if children preferred urban spaces, they still seemed to 'benefit' from nearby nature.

Like the definition of 'quality', the definition of 'exposure' may have also contributed to my null findings. Exposure was defined as a binary variable indicating whether an adolescent lived in an AoD (i.e., beyond 1,000 m walking distance from a SINC). Although GiGL used a sophisticated measure to calculate walking distances to SINCs, arguably a more accurate assessment of exposure than Euclidean distances, the question remains whether 1,000 m is a meaningful walking distance for adolescents. Moreover, using a binary variable is associated with a loss in variance and accuracy. First, two adolescents living on the edge of an AoD, one on the inside, the other on the outside, effectively have the same exposure, but their value on the binary exposure variable would be different. Second, two adolescents living outside an AoD may have different exposures: one of them may live right next to a SINC, whereas the other may live further away. However, both would have the same value on the binary exposure variable. Finally, two adolescents living inside an AoD may also have very different exposures: one of them may live just over 1,000 m away from a SINC, whereas the other may live much further away. Again, both would have the same value on the binary exposure variable. Ultimately, a binary variable does not capture the nuanced differences in exposure and, therefore, may add to exposure misclassification bias. Given the relatively small sample size, I may not have had sufficient statistical power to detect potentially small average effects. As mentioned earlier, I will discuss the issues of exposure misclassification bias again in my general discussion in Chapter 8.

Study Limitations

This study had important limitations, most of which I have already described in the previous chapter (please see section 6.4). In addition, measures of perceived neighbourhood quality and access to ‘high-quality’ green spaces also had limitations. The perceived neighbourhood quality variable was a composite measure of three variables that captured some but certainly not all aspects of neighbourhood quality. Indeed, it focused primarily on feelings of safety. Also, it is not clear whether adolescents with a high value on this variable actually perceived their neighbourhoods as ‘high-quality’, and it is likely that there are other factors influencing their perceptions of quality (e.g., cleanliness, social cohesion, or availability of facilities). The ‘perceived neighbourhood quality’ variable must be viewed under these limitations. For the ‘high-quality’ greenspace variable, I have already discussed two key limitations in the previous section, i.e., definitions of ‘quality’ and ‘exposure’.

7.5. Conclusion

I investigated the role of perceived neighbourhood quality and the role of access to ‘high-quality’ green spaces in the mental health and well-being of adolescents living in London, using data from Understanding Society. First, I was interested in whether perceived neighbourhood quality moderated the associations between green land cover and green land use and adolescent mental health and well-being. My findings suggest that adolescents who perceive their neighbourhoods to be of ‘lower quality’ may ‘benefit’ from green spaces in their neighbourhoods (younger adolescents from green land use and older adolescents from green land cover). Adolescents who perceive their neighbourhoods to be of ‘higher quality’, on the other hand, do not seem to ‘benefit’ but to ‘dis-benefit’ from neighbourhood greenspace. Further, I found positive associations between perceived neighbourhood quality and mental health and well-being across age groups and outcomes (except for conduct problems). Second, I was interested in whether access to green spaces with ‘high ecological quality’ was associated with adolescent mental health and well-being. I did not find a significant association, neither in the main analysis nor in supplementary analyses. Taken together, my findings suggest that perceived neighbourhood quality may play a more important role in adolescent mental health and well-being than living nearby ‘high-quality’ green spaces. Importantly, neighbourhood green spaces may have a protective function for the mental health and well-being of adolescents who perceive their neighbourhoods to be of ‘lower quality’. Again, this study had important limitations that need to be considered in the interpretation of findings. In the final chapter (Chapter 8), I will discuss the findings of all my four studies together, highlighting the main challenges and limitations, and making suggestions for future research.

8. General Discussion

The residential neighbourhood is a central environment for children and adolescents, in addition to their homes and schools, where they can play, be active, and spend time with their friends (Villanueva et al., 2016). Even when they do not use them intentionally, children and adolescents are exposed to their neighbourhoods, for example, when they travel to other destinations (e.g., to school) or when they are at home (e.g., when they view nature from their windows). Therefore, even though children and adolescents spend much of their time at home and school, the residential neighbourhood remains an important environment that can influence their development, health, and well-being (Christian et al., 2017; Hooper et al., 2015; Leventhal & Brooks-Gunn, 2000; Minh et al., 2017; Sellström & Bremberg, 2006).

In my thesis, I investigated the association between neighbourhood greenspace and children's and adolescents' mental health and well-being. Greenspace is a modifiable physical environment factor that is thought to be a positive factor for mental health and well-being. It could therefore be a target for large-scale (policy) interventions at the neighbourhood level. However, as I have discussed in my literature review in Chapter 2, the evidence regarding the association between neighbourhood greenspace and children's and adolescents' mental health and well-being is limited and inconclusive. Probably one of the main reasons for this is that most studies have used a relatively crude measure of exposure to greenspace, not distinguishing between different types of green spaces or vegetation, or considering contextual factors. However, it is conceivable that the association between neighbourhood greenspace and children's and adolescents' mental health and well-being is context-specific, and this could have important implications for real-world interventions. Therefore, it is crucial to shed light on the many shades of the association between neighbourhood greenspace and children's and adolescents' mental health and well-being. With my thesis, I aimed to contribute to this effort.

In this final chapter, I will first provide a brief summary of my four studies. I will then discuss the main findings, observations, and limitations in the context of the existing literature. I will also make suggestions for future research. Finally, I will conclude with three main insights that I would like the reader to take away from my thesis.

8.1. Summary of Studies

I ran four empirical studies. In the first study, I investigated the association between neighbourhood greenspace quantity and children's self-regulation. I used data on a large sample of 3- to 7-year-old children from the UK. Self-regulation was measured with two scales, i.e., independence and emotional dysregulation. Neighbourhood greenspace included all vegetated areas larger than 5 m^2 (except for domestic gardens) and was measured at ward level. I did not find a significant association between neighbourhood greenspace quantity and self-regulation. This was confirmed in a sensitivity analysis where I tested for non-linear associations, using a binary (rather than a continuous) greenspace variable.

In the second study, I investigated the association between neighbourhood greenspace quantity and young, urban adolescents' well-being. I used data on a large sample of 11-year-old adolescents living in urban UK who had never changed address throughout their lives. Well-being was measured with five scales, i.e., self-esteem, happiness, positive mood, negative mood, and antisocial behaviour. The neighbourhood greenspace variable was the same as in my first study. I did not find a significant association between neighbourhood greenspace and any of the outcomes. Again, this was confirmed in a sensitivity analysis where I tested for non-linear associations, using a binary greenspace variable. However, I did find that associations were modified and moderated by contextual factors. The most robust modification was by 'access to a private garden': in adolescents who did not have access to a private garden, higher levels of greenspace were associated with lower levels of self-esteem and positive mood. This finding was confirmed in a sensitivity analysis for which I ran the main model (without interaction terms) but only including adolescents who did not have access to a private garden.

In the third study, I investigated the associations between different types of green spaces and children's and adolescents' mental health and well-being. I used data on children (5- and 8-year-olds) and adolescents (10- to 15-year-olds) living in London, UK. Mental health was measured with the Strengths and Difficulties Questionnaire (SDQ). In addition, but only in adolescents, mental well-being was measured with self-esteem and happiness scales. The different types of green spaces were parks & gardens, natural & semi-natural urban greenspaces, and outdoor sports facilities, measured in 500 m around postcode means (in the main analysis). In addition, I included a measure of total green land cover and a measure of total green land use (a composite measure of the three green land use variables above). Overall, I found only few significant associations which were not consistent across exposures, outcomes, and age groups. However, I was able to identify patterns that provide interesting insights (although these should be interpreted with caution). The main observations were that 1) I did not find positive associations between green land cover and mental health and well-being; 2) I found negative associations between greenspace and mental health and well-being in younger adolescents, and positive associations in older adolescents; 3) I found positive associations in older adolescents mainly for parks & gardens and outdoor sports facilities; and 4) I did not find significant associations in children. These observations were generally (but not consistently) confirmed in sensitivity analyses.

In the fourth study, I investigated the potential roles of perceived neighbourhood quality (Part A) and access to green spaces with 'high ecological quality' (Part B). I used data on the same sample as in my third study, but focused my main analysis on adolescents. Mental health and well-being measures were also the same. In Part A, I used the same exposures as in my third study, but I added a measure of perceived neighbourhood quality as a covariate and moderator. In Part B, I used a novel, primary exposure, i.e., access to green spaces with 'high ecological quality'. In Part

A, first, I found significant associations of perceived neighbourhood quality with all outcomes (except for conduct problems) and across all ages: higher perceived neighbourhood quality was associated with fewer problems and more happiness. Second, I found that perceived neighbourhood quality moderated some of the associations between green land cover and green land use and mental health and well-being. I found positive associations only in adolescents who perceived their neighbourhoods to be of ‘lower quality’; however, there was a difference between age groups: younger adolescents (10- and 12-year-olds) seemed to ‘benefit’ from higher levels of green land use in their neighbourhoods, whereas older adolescents (13- and 15-year-olds) seemed to ‘benefit’ from higher levels of green land cover. Adolescents who perceived their neighbourhoods to be of ‘higher quality’ did not seem to ‘benefit’. Rather, younger and older adolescents in this group seemed to ‘dis-benefit’ from higher levels of green land use and green land cover, respectively. In Part B, I did not find a significant association between access to ‘high-quality’ green spaces and adolescent mental health and well-being. I did not find a significant association in children either.

8.2. Discussion of Main Findings and Observations

I have already discussed findings and observations of my four individual studies in Chapters 4 to 7. I will now discuss the three most important findings and observations from my thesis, considering the results of all four studies. First, across studies, I did not find a ‘general association’ between neighbourhood greenspace and children’s and adolescents’ mental health and well-being. This is an important observation because it was unexpected, and it is not in line with most of the existing evidence. Second, I found associations that were modified and moderated by contextual factors, especially ‘access to a private garden’ (in Study 2) and ‘perceived neighbourhood quality’ (in Study 4A). Finally, I observed that not all types of green spaces may be equally relevant for the mental health and well-being of adolescents in London, and that age may also play a role in this. I will now discuss each of these three findings and observations in turn.

No Evidence for a 'General Association'

Overall, I found no evidence for a 'general association' between neighbourhood greenspace and children's and adolescents' mental health and well-being. Although I did find context-specific associations in some of my studies (which I will discuss in the next two sections), considering that I did not find 'main effects' in Studies 1, 2, and 4B (i.e., those studies in which I used only one measure of exposure), it is fair to conclude that I did not find evidence for a 'general association'. Note that with 'general association' I mean finding a 'main effect' of greenspace that is not overly specific (e.g., limited to one study, outcome, or age group). In other words, I would speak of a 'general association' if there was evidence for an association across a range of studies and/or analyses.

In my literature review in Chapter 2, I described that most studies to date used a measure of quantity, assessing either the greenness of an area or the availability of greenspace. Most of these studies found a positive association between neighbourhood greenspace and measures of children's and adolescents' mental health and well-being. Based on these findings and the underlying theory (as described in Chapter 1), I expected to find a positive association too. There are several possible explanations for why this was not the case. For example, there may not be a 'general association'. As mentioned earlier, it is plausible that contextual factors play an important role, which I will discuss in more depth in the next sections. However, even if the association was not 'generic' but context-specific, it would be possible to find a 'main effect' (even if small). That I did not find a 'main effect' may be because there actually is no association in the population. This is possible, especially considering that, in each study, I investigated the association between a certain exposure and a certain outcome in children or adolescents at a certain age. For example, there simply may not be an association between neighbourhood greenspace quantity and self-regulation in 3- to 7-year-old children in the UK. Because I used frequentist statistics, however, I could not test this possibility formally.

Another explanation for why I did not find a ‘main effect’ would be that my measures of exposure may not have captured *true* exposure. Indeed, my studies were prone to exposure misclassification bias. Exposure misclassification bias is systematic measurement error (or information bias) due to a false assignment of individuals to exposure categories or levels of exposure (Blair et al., 2007; Blakely & Woodward, 2000; Delgado-Rodríguez & Llorca, 2004; Nuckols et al., 2004). I have discussed exposure misclassification bias in my empirical chapters, but I would like to revisit it in more depth now because it affects all my studies.

In my first two studies, I used a measure of greenspace quantity at ward level. A ward is a unit of electoral geography in the UK that is not intended to accurately capture an individual’s neighbourhood. Nonetheless, in my first two studies, I was limited to this level of geography, so I used it as a proxy for children’s and adolescents’ neighbourhoods. By defining a neighbourhood as a ward, I used an allocentric neighbourhood definition (Labib et al., 2020), which is associated with exposure misclassification bias, probably more so than an egocentric neighbourhood definition (Chaix et al., 2009). Knowing that a person lives in a particular ward does not tell us much about where exactly they live, especially if the ward is large. For example, they may live in the centre or on the edge of a ward, in a part with dense vegetation or in a part with sparse vegetation, near a park or far from a park, in a ward with low levels of greenery but right next to a ward with high levels of greenery, and so on.

A ward has an average population of 5,000 and can be large and varying in size (i.e., both in population and in geographic area). Therefore, calculating the quantity of greenspace for a given ward and assigning this quantity to everyone living in that ward introduces error because this average exposure will deviate from each individual’s true exposure. This problem is related to the so-called ecological fallacy which describes the error that is introduced by applying an ecological value, based on a group aggregate, to the individual (Idrovo, 2011; Piantadosi et al., 1988). It is also related to the so-called Modifiable Areal Unit Problem (MAUP) which describes that the often arbitrary delineation of a geographic area (i.e., its size and shape) can have a great impact on an areal measure of interest, such as the proportion of greenspace (Buzzelli, 2020; Labib et al., 2020). In a nutshell, the availability of greenspace in a ward may not be an accurate measure of individual exposure.

In addition to measuring exposure at ward level, for disclosure control, neighbourhood greenspace quantity was not measured as raw proportions or percentages but was transformed into deciles. This means that some variation in exposure between individuals was lost. Therefore, taken together, the greenspace quantity measure at ward level may not have captured true differences in exposure, and this would be a possible explanation for my null findings. Note that, given the large sample sizes in Studies 1 and 2, one would have expected to detect even ‘small effects’; however, this was not the case, which is another indication that my exposure variable may not have captured (or approximated) true exposure. Of course, it could also mean that there simply is no association in the population, as discussed earlier.

Two studies that I have already described in my literature review investigated the associations between neighbourhood greenspace quantity and SDQ scores in young children living in urban England (Flouri et al., 2014b) and urban Scotland (Richardson et al., 2017), and they too did not find a robust association. Flouri et al. (2014) used a greenspace quantity measure at LSOA level. The LSOA is a smaller geographic unit than a ward (but can still be large and varying in size). Richardson et al. (2017) used an egocentric neighbourhood definition and measured proportions of total natural space and public parks in 500 m around children’s homes. Further, in a study that is not part of this thesis, I investigated the associations between neighbourhood greenspace quantity at ward level and SDQ scores in 10- to 15-year-old adolescents in the UK, using the same greenspace variable as in Studies 1 and 2 (Mueller et al., 2019). In this study, I also did not find a significant association.

Considering my findings from Studies 1 and 2 together with the three studies described in the previous paragraph, it seems that neighbourhood greenspace quantity, measured as availability of greenspace in the neighbourhood, may not be associated with mental health and well-being in children and adolescents in the UK. The null findings, however, could also be due to exposure misclassification bias, as described earlier. Noteworthy, most studies in the literature that did find a positive association tested multiple levels of aggregation (e.g., different buffer sizes) and often found a significant association only for some but not all of these (as described in my literature review in Chapter 2). Therefore, it is possible that measuring greenspace quantity at different levels of aggregation is needed to detect a significant association. Of course, one should not 'fish' for a significant association, but exploration, to some extent, is necessary, simply because we still do not know how to best measure exposure.

In Study 4B, I aimed to investigate the role of greenspace quality. Some studies found associations between greenspace quality and children's and adolescents' mental health and well-being; however, these studies used a subjective measure of parent-reported quality (Feng et al., 2022; Feng & Astell-Burt, 2017c; Putra et al., 2021a). I used a more objective measure of quality, investigating the association of access to green spaces with 'high ecological quality' and adolescent mental health and well-being. This measure of exposure was different from my first two studies. In particular, I did not use a measure of quantity but a binary indicator of access to 'high-quality' green spaces. Poor access was defined as living beyond a 1,000 m network distance from a Site of Importance for Nature Conservation (SINC). A SINC can be defined as a greenspace with high ecological quality (Knight et al., 2022). Studies on adults using similar site designations found associations between visits to, or availability of, green spaces with 'high ecological quality' and mental health and well-being (Knight et al., 2022; B. W. Wheeler et al., 2015; Wyles et al., 2019). In my study on adolescents in London, I did not find an association between access to SINCs and mental health and well-being.

Again, there are several possible explanations for this null finding, which I have discussed in Chapter 7. Considering this study together with my other studies, especially my null findings in Study 2, in which I investigated associations in adolescents living in urban areas in the UK, it is possible to conclude that there may not be a ‘general association’ between neighbourhood greenspace and adolescent mental health and well-being, even when considering the quality of green spaces. However, this study too was prone to exposure misclassification bias and other limitations, so it is unclear whether there really is no association.

In summary, findings from Studies 1, 2, and 4B do not provide evidence for a ‘general association’ between neighbourhood greenspace and children’s and adolescents’ mental health and well-being in the UK. However, I should emphasise once again that exposure misclassification bias may have been a problem in all of my studies, which may explain my null findings. Furthermore, other limitations (e.g., measurement error in my outcome variables or selective samples) may also have contributed to my null findings. I will discuss these as general limitations later and will now move on to discussing my second main observation, i.e., that there were context-specific associations.

The Role of Context: Modifying and Moderating Factors

The association between neighbourhood greenspace and children’s and adolescents’ mental health and well-being is probably not the same across individuals but depends on contextual factors. These factors could be, for example, at individual level (e.g., sex and age), family level (e.g., parental mental health and socio-economic status [SES]), or neighbourhood level (e.g., social cohesion and safety). Some studies included potential modifying or moderating factors, most often investigating modification by individual sex (Faber Taylor & Kuo, 2011; Feda et al., 2015; Markevych et al., 2014; Piccininni et al., 2018; A. F. Taylor et al., 2002) or moderation by SES (Flouri et al., 2014b; Kuo & Faber Taylor, 2004; D. Li et al., 2018; Poulain et al., 2020; Richardson et al., 2017). Findings of these studies appear to be mixed, with some studies finding evidence for modification/moderation, but, crucially, not always in the same direction, and others not finding evidence for modification/moderation. As described earlier, especially in Study 2, I was interested in potential modification/moderation by contextual factors that may influence children's and adolescents' use of green spaces. Although passive or incidental exposure (e.g., viewing nature through a window, breathing cleaner air, or walking past a greenspace) can be beneficial for mental health and well-being (Mears et al., 2021; A. F. Taylor et al., 2002), intentional exposure may be essential for some functions of green spaces (e.g., for the promotion of physical activity).

In Study 2, I investigated the modifying/moderating roles of private garden access, perceived area safety, and physical activity. In Study 4A, I investigated the role of perceived neighbourhood quality. I will focus my discussion on private garden access and perceived neighbourhood quality because, in Study 2, moderations by perceived neighbourhood safety and physical activity were not robust. For a discussion of these potential moderators, I would refer the reader to Chapter 5.

Private Garden Access

Access to a private garden means access to private, proximal greenspace. Home outdoor areas are probably the most important setting for children's outdoor play. A study on children's play and independent mobility (Dodd et al., 2021) showed that children at the age of 6 to 11 years in Great Britain play most of their time at home (around 500 hours per year on average) and second most of their time outside at home (around 300 hours). Noteworthy, they spend significantly less time playing in public places, such as streets, playgrounds, or parks (around 100 hours each). This suggests that private outdoor space (if available) is an important setting for children's play. This is also suggested by a study on Scottish children that measured use of natural spaces with Global Positioning System (GPS) data (Olsen et al., 2022). This study found that Scottish children at the age of 10 and 11 years spend 15% of their time outdoors in natural spaces, but this number rose to 41% when private gardens were included.

Access to a private garden has been associated positively with mental health outcomes in young children in the UK (Flouri et al., 2014b; Richardson et al., 2017). However, in my first study, I found a negative association between private garden access and young children's independence: children with access to a private garden had lower levels of independence than children without. This could be because young children who have access to a private garden may play under more supervision at home and visit green spaces in their neighbourhoods less often, in turn, limiting their development of independence. Noteworthy, in my second study on urban adolescents, I did not find a significant association between private garden access and any of the mental well-being outcomes considered. This may be because I investigated associations in urban adolescents at the age of 11 years who may already spend more time away from home, or for whom other factors might play a more important role in their well-being (e.g., peer relationships).

The main question that I wanted to answer in my second study (regarding private garden access) was whether having access to a private garden modifies the association between neighbourhood greenspace and young, urban adolescents' mental well-being. As already discussed in Chapter 5, theoretically, access to private greenspace could be associated with both less and more use of public green spaces. Adolescents who have access to a private garden may not need public green spaces as much as their counterparts, i.e., they may visit public green spaces less often (and therefore benefit less from them). On the other hand, they may have a greater connection to nature, i.e., they may visit public green spaces more often (and therefore benefit more from them). However, interestingly, I did not find evidence for either of these possibilities. In fact, I found that, in adolescents who did *not* have access to a private garden, higher levels of neighbourhood greenspace were associated with lower levels of self-esteem and positive mood. This finding was unexpected.

As already mentioned above, it would be plausible that adolescents who do not have access to a private garden benefit disproportionately from public green spaces in their neighbourhoods: they do not have access to *private* greenspace, so they depend on *public* greenspace. Moreover, adolescents without access to a private garden may be socio-economically disadvantaged. On average, disadvantaged groups show more (mental) health problems than advantaged groups, and it has been proposed that neighbourhood greenspace could have the potential to narrow this inequality. This is known as ‘equigenesis’: disadvantaged groups may benefit disproportionately from green spaces in their neighbourhoods, so their (mental) health approaches that of advantaged groups. However, the evidence for this theory is inconsistent (Feng & Astell-Burt, 2017b; McEachan et al., 2016; R. J. Mitchell et al., 2015; Pérez-del-Pulgar et al., 2021; R. Wang et al., 2022).

Indeed, my findings suggest the opposite: adolescents who did not have access to a private garden (who may be disadvantaged) did not ‘benefit’ but ‘dis-benefit’ from greenspace in their neighbourhoods. This could be because disadvantaged neighbourhoods tend to have fewer ‘high-quality’ green spaces than advantaged neighbourhoods (de Vries et al., 2020; R. Wang et al., 2021). Therefore, it is possible that, in my study of young, urban adolescents, neighbourhood greenspace may not have had a protective function for those without access to a private garden because they may have lived in disadvantaged neighbourhoods with ‘low-quality’ greenspace. Higher levels of this ‘low-quality’ greenspace may be associated with lower levels of well-being (i.e., self-esteem and positive mood).

There is another possible explanation that I have already discussed in Chapter 5: adolescents without access to a private garden (probably disadvantaged) who live in neighbourhoods with high levels of greenspace (probably advantaged) may feel ‘relatively deprived’. Feelings of relative deprivation or related concepts, such as perceived socio-economic position, have been linked to lower levels of self-esteem and life satisfaction, and higher levels of mental health problems in adolescents in the UK (Bannink et al., 2016; Quon & McGrath, 2014; Rivenbark et al., 2020). In this explanation, neighbourhood greenspace is an indicator of neigbourhood SES (i.e., higher levels of neighbourhood greenspace could be an indicator of higher neighbourhood SES). Although I have adjusted my statistical models for neighbourhood SES, there may have been residual confounding, and neighbourhood greenspace may have captured variance of neighbourhood SES. Therefore, despite adjusting for neighbourhood SES, feelings of relative deprivation remain a plausible explanation. For a more in-depth discussion of this, I would refer the reader to Chapter 5.

Taken together, under the assumption that private garden access, or the lack of it, is an indicator of individual SES, my findings could be explained by residual confounding (where neighbourhood greenspace is an indicator of neighbourhood SES), or by a negative effect of ‘low-quality’ greenspace on adolescents’ self-esteem and positive mood. Both explanations are plausible, so more research is needed into the associations between private garden access, individual and neighbourhood SES, neighbourhood greenspace, and adolescent mental health and well-being.

Perceived Neighbourhood Quality

In Study 4A, I investigated the moderating role of perceived neighborhood quality in the associations between green land cover and green land use and adolescent mental health and well-being. My ‘perceived neighbourhood quality’ variable was a composite score of three variables (based on a principal components analysis [PCA]), capturing adolescents’ perceptions of the safety of their neighbourhoods, fear of becoming a victim of crime, and feelings towards their neighbourhoods (i.e., whether they liked them). My ‘perceived neighbourhood quality’ variable, therefore, may have primarily captured perceptions of safety. I found that ‘perceived neighbourhood quality’ was associated with all outcomes (except for conduct problems) across all ages (with some exceptions). As discussed earlier, these findings are in line with the previous literature (Lorenc et al., 2012) and with my second study where I found an association between perceived area safety and adolescents’ mental well-being.

With regards to the moderating role of ‘perceived neighbourhood quality’, I have discussed my findings at length in Chapter 7. I will only briefly re-iterate the main points. First, it appeared that there were positive associations between neighbourhood greenspace and mental health and well-being only in adolescents who reported their neighbourhoods to be of ‘lower quality’. There seemed to be negative associations in adolescents who reported their neighbourhoods to be of ‘higher quality’. Second, in adolescents who reported their neighbourhoods to be of ‘lower quality’, younger adolescents seemed to ‘benefit’ from green land use, whereas older adolescents seemed to ‘benefit’ from green land cover.

The first finding may be due to ‘equigenesis’, as described earlier: adolescents who perceived their neighbourhoods to be of ‘lower quality’ may have ‘benefitted’ disproportionately from neighbourhood greenspace. As described above, I found a robust association between ‘perceived neighbourhood quality’ and mental health and well-being, and neighbourhood greenspace may have been a protective factor for those adolescents who perceived their neighbourhoods to be of ‘lower quality’. In other words, under the assumption of causality, perceptions of low neighbourhood quality may have a negative effect on adolescents’ mental health and well-being, but high levels of neighbourhood greenspace may buffer this negative effect.

Looking only at those adolescents who perceived their neighbourhoods to be of ‘lower quality’, younger adolescents seemed to ‘benefit’ from green land use (i.e., parks & gardens, natural & semi-natural urban greenspace, and outdoor sports facilities), whereas older adolescents seemed to ‘benefit’ from green land cover. I have discussed a potential explanation for this in Chapter 7: younger adolescents in London may have limited independent mobility and may therefore depend more on green land use in their neighbourhoods, whereas older adolescents who are more independently mobile may travel further to visit green spaces outside their neighbourhoods (Villanueva et al., 2012). Older adolescents, however, may still benefit from green land cover in their neighbourhoods (e.g., due to passive effects). I should note that it is unclear why younger adolescents did not seem to ‘benefit’ from green land cover. It is also unclear why adolescents who perceived their neighbourhoods to be of ‘higher quality’ seemed to ‘dis-benefit’ from green spaces in their neighbourhoods.

Overall, it should have become clear that the interaction between different types of green spaces, levels of perceived neighbourhood quality, and age is complex. Future research should pay more attention to this complexity. The role of age will also be important in the next section where I will discuss my third main observation: not all types of green spaces may be equally relevant for the mental health and well-being of adolescents living in London.

The Role of Different Types of Green Spaces

There are many different types of spaces and vegetation that fall under the umbrella term 'greenspace' (L. Taylor & Hochuli, 2017), and all of these may play a different role in children's and adolescents' mental health and well-being. However, as discussed in my literature review in Chapter 2, most studies to date used a 'generic' measure of greenspace quantity, not distinguishing between different types of green spaces or vegetation.

To understand better 'what works for whom', in my third study, I investigated the potential roles of different types of green spaces, including measures of parks & gardens, natural & semi-natural urban greenspaces, and outdoor sports facilities. I also included a measure of total green land cover to test whether the general greenness of an area may also be important (e.g., due to passive effects), as suggested by previous studies assessing neighbourhood greenness with the Normalized Difference Vegetation Index (NDVI). As summarised earlier, I did not find a 'positive' association between total green land cover and children's and adolescents' mental health and well-being. Moreover, overall, I found no association in children, negative associations in young adolescents, and positive associations in older adolescents. Positive associations in older adolescents were mainly for parks & gardens and outdoor sports facilities. I have discussed these observations already, so I would refer the reader to Chapter 6 for an in-depth discussion. However, I would like to use the next paragraphs to discuss the implications of my observations more generally.

The findings of studies that investigated different types of green land cover or land use are inconsistent. For example, Maes et al. (2021) found that woodland (rather than grassland) may be particularly ‘beneficial’ for the mental health of adolescents living in London, whereas Markevych et al. (2014) found that urban green spaces (rather than forests) may be particularly ‘beneficial’ for the mental health of adolescents living in Munich, Germany. My findings suggest that, for adolescents in London who have passed the very early stages of adolescence, parks & gardens and outdoor sports facilities (rather than natural & semi-natural urban greenspaces) may be most ‘beneficial’. Other studies found a potential benefit of trees (rather than grass) for outcomes in both adolescents and adults (Donovan et al., 2020; C. Reid et al., 2017). Importantly, all these findings may depend on how exactly exposures and outcomes were measured, and on other, contextual factors, such as the country or city of interest.

The study by Maes et al. (2021) is particularly interesting in the context of my study because it shared important characteristics: they too investigated associations in adolescents at the age of 9 to 15 years in London, also using the SDQ as one of their primary outcomes of interest. They used the Normalized Difference Vegetation Index (NDVI) and Light Detection and Ranging (LiDAR) data, so the data underlying their definitions of grassland and woodland were rather different from the open space data I used in my third study. Essentially, they captured vegetation and vegetation height and used these to define their exposures, focusing on the type of vegetation (low versus high) rather than on the function of a space. Also, they assessed exposure around homes and schools, and day-time weighted their exposure variables. That they found an association for woodland (rather than grassland), and I found associations for parks & gardens and outdoor sports facilities (rather than natural & semi-natural urban greenspaces) seems contrary. However, the great differences in exposure assessments may explain this ‘contradiction’.

One of the advantages of using land cover data is that it not only captures dedicated green spaces but also other bits of vegetation, such as street trees, which may play an important role in children’s and adolescents’ mental health and well-being. This is especially relevant considering incidental (rather than intentional) exposure (Mears et al., 2021). Maes et al.'s (2021) findings, therefore, may not suggest that large areas of woodland are beneficial for adolescents but rather trees in general, including trees in public parks, in private gardens, and along the street. One of the disadvantages of land cover data is that it does not provide information on the use or function of a space. In my study, I focused on designated open spaces that are free to access. Therefore, my focus was on use, i.e., intentional exposure, and this is an important difference between my study and that of Maes et al. (2021).

My observation that older adolescents at the age of 13 to 15 years may ‘benefit’ most from parks & gardens and outdoor sports facilities is in line with adolescents’ usage of green spaces for physical and social activities (Bloemsma et al., 2018), and preferences for certain characteristics of green spaces (Rivera et al., 2021; Van Hecke et al., 2018), as I have discussed earlier. Noteworthy, in a study on the associations between different types of green spaces and mental well-being in adults in London, Houlden et al. (2021) found that natural & semi-natural urban greenspaces seemed to be particularly ‘beneficial’. Availability of these spaces, but not parks & gardens or outdoor sports facilities, in 300 m around the home was associated with higher levels of happiness and life satisfaction. This suggests that age does play a role in the association, and that we should not simply generalise findings from studies on adults to children and adolescents.

Before I conclude this section, I would like to highlight once again the role of perceived neighbourhood quality. In Study 3, where I did not include perceived neighbourhood quality as a covariate and moderator, I could observe that young adolescents did not seem to ‘benefit’ from greenspace in their neighbourhoods, whereas older adolescents did, particularly from parks & gardens and outdoor sports facilities. In Study 4A, when I included perceived neighbourhood quality, I found that, in adolescents who perceived their neighbourhoods to be of ‘lower quality’, younger adolescents seemed to ‘benefit’ from green land use, and older adolescents seemed to ‘benefit’ from green land cover. This illustrates once again how other (environmental) factors may moderate the already complex association between neighbourhood greenspace and children’s and adolescents’ mental health and well-being.

In summary, I observed that older adolescents seemed to ‘benefit’ from green land use, especially parks & gardens and outdoor sports facilities. However, as I have pointed out in Chapter 6, findings need to be taken with caution, also considering the large number of models (and, therefore, tests) conducted. My observation suggests that certain types of green spaces, i.e., those that support physical and social activities, may be particularly relevant for older adolescents. However, it is important to remember that I only included three types of green spaces, and only those that were free to access. Therefore, I focused on intentional rather than incidental exposure. Incidental exposure, however, may be very important on a day-to-day basis (Mears et al., 2021), and future studies should pay more attention to this form of exposure. Furthermore, focusing on only three types of green spaces meant I excluded other smaller, but potentially relevant, green spaces (e.g., allotments and cemeteries). These too should be considered in future studies, as they may provide opportunities for children and adolescents to spend time outdoors and be exposed to greenspace, both supervised and unsupervised.

8.3. General Limitations

There are three main limitations of my thesis that I would like to discuss now, most of which I have already touched on in my four empirical chapters and/or in my discussion of main findings and observations above. First, because I used observational data, I could not make inferences about causality. Second, both ‘mental health and well-being’ and ‘exposure to greenspace’ are complex constructs that are difficult to measure, so my studies were prone to measurement error and information bias. Third, not only the individual constructs but their association too is complex, and I was not able to fully capture this complexity. I will now discuss these three main limitations in turn.

Observational Data and Causality

One major challenge in observational studies is making inferences about causality. Unlike experimental studies, in which a variable X is manipulated to evaluate its effect on an outcome Y, observational studies only allow to observe (but not manipulate) variables X and Y. Therefore, we cannot be sure that an association between X and Y is due to an effect of X *on* Y. There are two issues to consider: reverse causality and confounding bias. Reverse causality means that not X causes Y, but Y causes X. In other words, there is a true association between X and Y, but the direction of causality is reversed. Confounding bias is defined as 'bias of the estimated effect of an exposure on an outcome due to the presence of a common cause of the exposure and the outcome' (Porta, 2014). In other words, the association between X and Y is not true because a common cause (i.e., the confounder) of exposure X and outcome Y explains at least part of their association. Together, reverse causality and confounding bias mean that one cannot be certain about the direction or the strength of a given association. This is problematic because it limits the implications that findings have for the 'real world'.

Reverse causality could have been a problem in my studies; however, it is possible to use common sense, to some extent, to evaluate how likely it is that the direction of an association was, indeed, reversed. For example, in the association between availability of greenspace and child and adolescent mental health and well-being, it is much more likely that the availability of greenspace influences children's and adolescents' mental health and well-being than vice versa. Although it has been shown that health can influence neighbourhood selection (Rolheiser et al., 2022) and, therefore, greenspace availability, this is probably not true for children and adolescents because they typically do not choose where they reside. Note that this would be different if I used 'visits to green spaces' as the main exposure. Then, children's and adolescents' mental health could play a much greater role in the association, and reverse causality could be a much bigger problem. Also note that I did control for health-related neighbourhood selection at family level, by including a measure of maternal mental health in all my four studies.

Confounding bias was probably the greater issue in my studies. However, it was also the one that I could control better. Several factors may be confounders (i.e., a cause of both exposure and outcome), especially factors related to individual and neighbourhood SES. The advantage is that I could control for these factors in my statistical models to minimise confounding bias. The disadvantage is that there may have been residual confounding, for example, because I was not aware of a confounder, I did not have data on a confounder, or I only had data on proxy variables for a confounder. Controlling for a set of main confounders (i.e., neighbourhood SES, maternal mental health, maternal education, housing tenure, family structure, and ethnicity), I attempted to minimise confounding bias as much as possible. Nonetheless, due to the three reasons above, I must accept at least some level of residual confounding and, therefore, bias.

An important additional limitation to note is the possibility of over-adjustment. Causal associations between variables are complex, and it is possible that a variable is both a confounder and a mediator in the association between exposure and outcome. While it is important to adjust for a confounder, one should avoid adjusting for a mediator. This is because a mediator is a variable on the causal pathway between exposure and outcome and, therefore, can 'block' some of the effect of exposure on outcome, reducing the estimated total causal effect of exposure on outcome (Schisterman et al., 2009). Therefore, adjusting for a mediator means over-adjusting, and this could lead to false inferences about the association between exposure and outcome. For example, if a mediator explains a large part of an existing effect of exposure on outcome, one will probably not find this effect when the model is adjusted for the mediator. My four studies included two potential candidates for over-adjustment: neighbourhood air pollution and maternal mental health. I have conceptualised these as confounders in the association between neighbourhood greenspace and children's and adolescents' mental health and well-being; however, they may also be mediators. As I have described in Chapter 1 (in section 1.3), both neighbourhood air pollution and parental mental health could be mechanisms or pathways underlying the association between neighbourhood greenspace and children's and adolescents' mental health and well-being. This means they may be mediators in the association. The possibility of over-adjustment, therefore, should be kept in mind in the interpretation of my findings.

To be able to make valid inferences about causality, the most obvious solution would be to run an experimental study. However, experimental studies are not well suited for investigating neighbourhood effects on health and well-being due to the many factors that are outside the control of the experimenter. More suitable would be a community-based intervention, such as improving an existing greenspace in a neighbourhood and measuring the mental health and well-being of children and adolescents pre- and post-intervention (ideally assessing the same children and adolescents before and after the intervention). Although this approach may also be limited in terms of controllability and generalisability, if planned and conducted well, it would allow for inferences about the effects of an intervention (Pawlowski et al., 2017; van der Laan et al., 2013). However, if one wanted to use large-scale, observational data to study associations at population level, an important step forward would be the optimisation of the variable selection process, for example, by using directed acyclic graphs (DAGs; Chaix et al., 2010; Fleischer & Roux, 2008; Greenland et al., 1999; Pearce & Lawlor, 2016). DAGs are diagrams with which one can illustrate causal relationships between all variables of interest, allowing for a more systematic variable selection process (i.e., what variables to include and what variables not to include in a statistical model). This would also help with the identification of potential over-adjustment. Nevertheless, the problem of residual confounding and bias would not be fully resolved, for the same three reasons already mentioned above. Ultimately, probably the best approach would be a combination of experimental and observational studies, and the integration of results from these studies. In epidemiology, this approach is known as 'triangulation', where the integration of results from two or, ideally, more studies, using different approaches, can help strengthen the confidence in a finding (Lawlor et al., 2017).

Measurement Error

Mental health and well-being are complex, multidimensional constructs, and their assessment is challenging. First, scientists do not agree on definitions of mental health and well-being, or what dimensions these (multi-dimensional) constructs include (Dodge et al., 2012; Galderisi et al., 2015; Manwell et al., 2015; Steptoe, 2019). Second, psychological scales (e.g., surveys and tests) need to be developed that accurately measure dimensions of mental health and well-being. Therefore, researching mental health and well-being is associated with uncertainties about the construct one wants to measure in the first place and whether one can actually measure this construct (or a dimension of it) with a given scale.

The validation of a psychological scale is a crucial step in its development that ensures that it measures the latent construct or dimension that it is intended to measure (Boateng et al., 2018). In psychological research, it is therefore expected to use validated measures of the psychological outcomes of interest. In my first study, I used a validated measure of self-regulation. In my last two studies, I used the SDQ, a validated measure assessing four dimensions of mental health (i.e., emotional symptoms, conduct problems, hyperactivity and inattention, and peer relationship problems). In my second study, however, only self-esteem was measured with the validated Rosenberg self-esteem scale. Therefore, the validity of the other four outcomes (i.e., happiness, positive mood, negative mood, and antisocial behaviour) may have been limited. However, I took steps to ensure that the measures captured at least some aspects of the intended constructs (as described in Chapter 5).

Additional measurement error, systematic and non-systematic, could have occurred at stages of data collection, entry, preparation, and analysis. As I used secondary data, I did not have control over data collection and data entry. However, I did have control over data preparation and analysis. Here, I conducted many iterations of checks, such as going through my syntax and evaluating the plausibility of derived variables, to minimise error. Taken together, however, there were several potential sources of measurement error, and it is likely that my measures of mental health and well-being did only approximate children's and adolescents' true ('real-world') mental health and well-being.

Exposures in my studies were prone to measurement error too, and this is known as 'exposure misclassification bias', as discussed earlier. It can be assumed that some error was introduced in the collection and categorisation of geographic data (i.e., data used in the MEDIx, GiGL, and the London Green and Blue Cover dataset), however, this was out of my control. The most important point for this discussion is the potential introduction of error due to my definitions of exposure. In my literature review in Chapter 2, I have highlighted that there are many ways to assess exposure, for example, with quantity and proximity measures, and that there is great heterogeneity of studies with regards to this. How to best assess exposure remains unknown, and there has been a long-standing discussion about how the assessment of exposure (e.g., the data, scale, and methods used) influences, and potentially biases, results (Davis et al., 2021; Labib et al., 2020; Nordbø et al., 2018).

An important part in the assessment of exposure is defining the exposure area. In neighbourhood and health studies, the exposure area is typically defined as an administrative or census area (allocentric neighbourhood definition), or as a circular or network buffer around the home (egocentric neighbourhood definition). As I have highlighted in my literature review in Chapter 2, there is much variation between studies as to how they define and delineate a neighbourhood. In fact, the question of what a neighbourhood actually is has been asked for a long time and cannot be answered easily (Chaix et al., 2009; Guest & Lee, 1984; Perchoux et al., 2016; Spielman & Yoo, 2009). Formally, we could distinguish three conceptions of neighbourhoods, spatial, social, and institutional (Guest & Lee, 1984); however, ultimately, every individual has their own definition of their own neighbourhood. Because there is no universal definition, the operationalisations of neighbourhoods in the literature tend to be arbitrary (Chaix et al., 2009; Perchoux et al., 2016). In any case, no objective definition will match an individual's subjective definition or accurately capture their true exposure to (neighbourhood) greenspace, and even a self-drawn neighbourhood may not accurately capture the individual's activity space (A. Christensen et al., 2021).

There are ways to minimise exposure misclassification, for example, by using an egocentric rather than an allocentric neighbourhood definition, choosing realistic distances for circular buffers, or using a network rather than a straight-line distance (Nordbø et al., 2018). Ideally, one would have data on all the places that children and adolescents visit throughout the day and on the time they spend in each of these places, as this would allow for the combination of spatial and temporal dimensions of exposure. Some researchers have used Global Positioning System (GPS) data to capture the activity space of an individual, i.e., the space where the individual's daily activities take place (D. Li et al., 2018; Loebach & Gilliland, 2016; Mennis et al., 2018). This would also allow to measure and investigate the role of incidental exposure, arguably the most common type of day-to-day exposure (Mears et al., 2021). However, although the richness of such data is promising, the approach may have limitations regarding the assessment of causal effects of the environment on health (Chaix et al., 2013). Moreover, the data are not readily available and costly to collect, and they typically only cover a short period of time (i.e., days or weeks, not months or years). Therefore, it is a more feasible and still valuable approach to assess more specific exposure areas, such as the residential neighbourhood. However, it would be a good addition to investigate other exposure areas too, such as the neighbourhood around the school, as some studies have already done (Maes et al., 2021; Scott et al., 2018; Srugo et al., 2019).

In addition to defining the exposure area, it is important to define exposure itself. Researchers argue that measuring exposure should move from measuring single factors (e.g., availability, accessibility, and visibility) towards measuring multiple factors, such as frequency, duration, and intensity (Holland et al., 2021). It has also been highlighted that exposure is not static but dynamic, and that it has a spatial and a temporal dimension (Helbich, 2018). Further, in addition to measuring objective exposure more rigorously, one could include subjective factors, such as perceptions, experiences, and quality (Labib et al., 2020), or levels of engagement, such as viewing nature, being in the presence of nearby nature, or active participation in nature (Pretty, 2004). All these are important suggestions that would add more nuance to future studies on the association between neighbourhood greenspace and children's and adolescents' mental health and well-being. There will probably always be some measurement error associated with measuring exposure to greenspace, but moving away from static and towards more dynamic and nuanced exposure assessments will allow for a more thorough understanding of the association and, therefore, for more meaningful implications for real-world interventions. Future studies should investigate the roles of, and interactions between, multiple dimensions of exposure, including spatial dimensions (where/characteristics of space), temporal dimensions (when/how often/how long), activity dimensions (type of activity/with whom), and subjective experience of exposure (perceptions).

Finally, measuring exposure to greenspace, it is, of course, important to define 'greenspace', i.e., what types of land use, land cover, or vegetation are included in a measure of greenspace. I have already touched on this but would like to emphasise once again that the umbrella term 'greenspace' can refer to a wide range of different types of exposures (L. Taylor & Hochuli, 2017). In theory, greenspace may refer to any type of vegetated land, but in practice, researchers tend to use a wide range of different measures, as I have highlighted in my literature review in Chapter 2. It is important that researchers are clear about what types of spaces or vegetation they include in their measure of greenspace, and this has been emphasised by other scholars too (L. Taylor & Hochuli, 2017). In this thesis, I have used a range of different measures (or definitions) of greenspace that included different types of green spaces or vegetation (ranging from very inclusive definitions, including any type of vegetation, to more exclusive definitions, including only specific types of ‘free to access’ green spaces). I aimed to clearly describe these different measures in my four empirical chapters.

Complexity of Associations

I have emphasised throughout that the association between greenspace and health and well-being is complex, even after focusing ‘only’ on the neighbourhood, mental health and well-being, and children and adolescents. Two important factors contributing to the complexity are the constructs of ‘mental health and well-being’ and ‘exposure to greenspace’, as I have discussed above. However, for a comprehensive understanding of the association, it is not only important to accurately measure these two main constructs, but also to investigate interactions between greenspace and other factors, and to understand the pathways underlying the association. Ultimately, we would like to understand what works, for whom, under what conditions, and why. However, because many factors play a role, it is challenging to disentangle the full complexity of associations. There are two additional limitations of my thesis, related to this complexity, that I will now briefly discuss: potential non-linear associations and limited generalisability of findings.

Potential Non-Linear Associations

First, the association between greenspace and health and well-being may not be linear. In my studies, I tested for a linear association, but it is possible that the association is, indeed, non-linear. For example, there may be a benefit of more greenspace only to some extent. This is suggested by Feng and Astell-Burt (2017) longitudinal study on Australian children and adolescents, in which they used a categorical (rather than a continuous) exposure variable and found that the association between neighbourhood greenspace and mental health was strongest for a quantity of 21% to 40% park land (compared to lower and higher percentages). Moreover, it could also be that it is not that more greenspace is associated with better health, but that greenspace deprivation, specifically, is problematic, as suggested by two recent studies on the associations between neighbourhood greenspace quantity and adolescents’ decision-making and risk-taking (Flouri et al., 2022a, 2022b). In other words, one may not benefit from increasing levels of greenspace, but one may ‘dis-benefit’ from greenspace deprivation. Noteworthy, in my Studies 1, 2, and 3, I ran sensitivity analyses and tested for non-linear associations, but they were non-significant. However, as there are several ways to test for non-linear associations, these findings may be explained by how I created binary and categorical exposure variables. Future studies should test for non-linear associations, as this could provide insights about the ‘dose’ of neighbourhood greenspace that is essential, and sufficient, to support children’s and adolescents’ mental health and well-being.

Limited Generalisability of Findings

Second, the association between greenspace and health may not generalise across contexts, and this is because of the many factors that play a role in it. Indeed, it is likely that every individual comes with their own set of conditions, so findings may never truly generalise across all individuals. However, even if we accept that an average ‘effect’ may never truly apply to the individual, there are also differences between groups of individuals, e.g., between countries, between rural areas and urban areas, and between age groups. Generalisability, however, is an important concept in both psychology and epidemiology because it means that findings can be applied not only to a specific context (or sample) but to a broader context (or target population).

There are several reasons for why my findings may not generalise to other contexts. First, with my focus on the UK, my findings may not generalise to other areas in the world. This may be due to cultural factors (e.g., children and adolescents in other countries may have a generally different relationship with the natural environment than children and adolescents in the UK), or physical factors (e.g., other regions of the world may have a different dominant type of nature, such as desert land, as opposed to green [vegetated] space). Although the focus of my thesis was on children and adolescents in the UK, and generalisability to other countries in the world was not the aim of this thesis, it is important to remember that cultural and physical factors likely play a role in the association, so studies in other parts of the world are needed to identify similarities and differences between contexts.

Second, in the context of the generalisability of my findings to UK children and adolescents, my focus on London in Studies 3 and 4, in particular, must be kept in mind because it made my sample selective and unlikely to be representative of the general UK population of children and adolescents. Therefore, even if we limit the concept of generalisability to making inferences about a target population (rather than, for example, across countries), probably only findings of my first study were generalisable (because the sample in my second study was selective too, including only ‘urban stayers’ at the age of 11 years).

Third, relatedly, with my focus on urban areas, at least in Studies 2, 3, and 4, my findings may not generalise to rural areas in the UK (or elsewhere). This is indicated by supplementary analyses in Studies 1 and 2 where I ran separate analyses for rural and urban children. I found that higher levels of greenspace were associated with lower levels of emotional dysregulation (Study 1) and lower levels of happiness (Study 2), but only in rural children. Therefore, rurality and urbanicity are important to consider in future research.

Fourth, with my focus on young children and adolescents in the UK (3 to 15 years), my findings may not generalise to older children and adolescents. Considering further rapid developments after the age of 15 years, such as gains in independence and changing interests, it is possible that findings based on young children and adolescents do not generalise to older adolescents. This is important to remember because policy and planning should consider all people at all ages.

Limitations regarding generalisability are important to remember, and, for a comprehensive understanding of associations, more research is needed that investigates associations in other countries, in rural areas, and across a broader range of age groups. It is important to remember, however, that due to the many potential factors influencing the relationship between greenspace and health, a generalisable finding across all children and adolescents in the UK (and beyond) may not be realistic, and contextual factors should be considered and investigated to be able to inform effective real-world decision-making. Ultimately, a combination of studies is needed to disentangle the association between neighbourhood greenspace and children’s and adolescents’ mental health and well-being at global, national, community, and individual levels.

There would be many other open questions to think about and to investigate (e.g., regarding mediation and moderation). There would also be questions about aspects beyond the scope of this thesis, such as the relevance of other exposure areas (e.g., kindergartens and schools) or other types of nature (e.g., blue spaces and deserts). This section was intended to highlight that there are many open questions to explore. However, it would be out of scope to discuss all these open questions in depth. In the next section, I will make three suggestions for future research. Thereafter, I will discuss potential implications for policy and planning. Finally, I will conclude with three messages I would like the reader to take away from my thesis.

8.4. Suggestions for Future Research

Throughout this discussion, I have made suggestions for future research related to specific points discussed. In this section, I will describe three more general suggestions for future research: first, running more large-scale, cross-country observational studies, investigating the roles of different types of green spaces and context; second, investigating exposure areas beyond the residential neighbourhood; and third, complementing observational studies with experimental studies, asking questions about causality and mechanisms underlying the association between greenspace and children’s and adolescents’ mental health and well-being.

First, to investigate associations at population level, more large-scale, observational studies are needed, ideally assessing associations across countries. White et al. (2021) investigated associations between green and blue spaces and adult mental health and well-being, using data on individuals from 18 countries. They found differences between countries regarding the associations between availability of green and blue spaces, frequency of recreational visits, and mental health and well-being. They highlight the need for cross-country research and emphasise that their results suggest that one must be careful with the generalisation of findings across countries (as I have also mentioned earlier).

In addition to running large-scale, observational, cross-country studies, I would suggest future research to include exposures that go beyond mere quantity, for example, investigating the roles of different types of green spaces. This could involve not only distinguishing relatively broad categories (e.g., parks versus woods) but investigating more specific characteristics (e.g., presence of playgrounds) or the composition of green spaces (e.g., proportions of horizontal and vertical vegetation, and human-built structures). Furthermore, I would suggest a systematic investigation of interactions with contextual factors (beyond SES and sex), potentially also including more than two variables (although such three-way interactions could be difficult to interpret). Finally, to be able to make causal inferences from observational studies, researchers should clearly define their assumptions about underlying causal relationships. Large-scale, observational, cross-country studies, investigating different types of green spaces and contextual factors would allow for a more nuanced understanding of the association between neighbourhood greenspace and child and adolescent mental health and well-being at the population level. This, in turn, could have implications for large-scale, real-world interventions within and across countries.

Second, related to my first point, I suggest that future research also investigates the role of greenspace in other exposure areas, such as important settings like the kindergarten and school. Children and adolescents spend much of their time in these settings, and it would be important to understand both the independent associations and the interactions between exposure at home, in the neighbourhood, and in childcare or educational settings. Some studies have already investigated exposure at kindergartens or schools (Brons et al., 2022; Liao et al., 2020; Maes et al., 2021; Mygind et al., 2022; Scott et al., 2018; Srugo et al., 2019), and including exposure beyond the residential neighbourhood would be feasible in the context of large-scale, longitudinal studies. However, physical environment factors for areas around homes, kindergartens, and schools would need to be collected in large-scale, longitudinal studies. Alternatively, spatial identifiers would need to be provided for the linkage of external physical environment data (which would allow data users more flexibility in the definition of their primary exposures of interest). As physical environment factors have not been a priority in large-scale, longitudinal studies in the past, more attention should be paid in the future to include data on the physical environment in these studies, or to make it more straightforward for the data users to link their own physical environment variables.

Finally, in addition to observational studies, it would be valuable to run experimental studies. Experimental studies can provide important insight into the mechanisms underlying the association between neighbourhood greenspace and children's and adolescents' mental health and well-being. However, as I have mentioned earlier, experimental studies are difficult to run in a real-world neighbourhood due to the many factors that are outside the experimenter's control. Moreover, it would be difficult to 'manipulate' the main exposure variable of interest (i.e., greenspace). It would be possible, however, to create a neighbourhood in a virtual environment (Browning et al., 2020; Hackman et al., 2019; Shin et al., 2022), or in a research facility that allows for the creation of actual, physical environments, such as the Person Environment Activity Research Laboratory (PEARL) at University College London (UCL, 2021). The great advantage of an experimental approach is the possibility for the manipulation of a specific aspect of the exposure to see its effect on children's and adolescents' mental health and well-being. Together with large-scale, observational studies, experimental studies could advance our understanding of the association between neighbourhood greenspace and children's and adolescents' mental health and well-being.

8.5. Potential Implications for Policy and Planning

In the previous sections, I have summarised and discussed main observations and important limitations of my thesis, and made suggestions for future research. With this, I have focused primarily on the impact that my studies have inside academia: they are a contribution to the literature and can inform future research. However, my studies also have a potential impact outside academia: my findings become part of the evidence base and can inform evidence-based decision-making in the ‘real world’. I would like to use this section to briefly describe the implications that my thesis, as part of the wider evidence base, may have for policy and planning in the UK.

At national level, several departments may be interested in my work, due to the interdisciplinary and multifaceted nature of my studies: the Department for Education; the Department for Environment, Food and Rural Affairs; the Department for Levelling Up, Housing and Communities; and the Department of Health and Social Care (*Departments, Agencies and Public Bodies*, n.d.). These departments make policies at national level within the scope of their responsibilities (e.g., ensuring high-quality education, improving and protecting the environment, supporting local areas and communities, and ensuring good health for all people). They need to consider and weigh evidence from a wide range of scientific disciplines and research areas in order to decide how to distribute (limited) resources effectively.

Research into the role of neighbourhood greenspace in children’s and adolescents’ mental health and well-being generally, and nuanced observations like those from my thesis, should be considered in national policies, but also in the policies and actions of local authorities. For example, the 2021 National Planning Policy Framework, a policy paper by the former Ministry of Housing, Communities and Local Government (now the Department for Levelling Up, Housing and Communities), sets out policies for a range of objectives, including ‘promoting healthy and safe communities’, ‘making effective use of land’, and ‘conserving and enhancing the natural environment’ (*National Planning Policy Framework*, 2021). This national framework should be used by local authorities, but planning decisions will be affected by local contexts and circumstances. This is important to note because, while the wider evidence base may inform policies at national level, more specific or nuanced findings may be interesting at local (e.g., city, borough, or neighbourhood) levels. For example, The London Plan is a framework that sets out policies for the spatial development of London specifically. It also informs the Local Plans of all Greater London boroughs. This means that local authorities need to make decisions in 'general conformity' with the London Plan, but decisions can be adjusted to specific contexts, if justified (*The London Plan 2021*, n.d.). Moreover, communities within districts can impact local planning decisions by developing a Neighbourhood Plan (*Neighbourhood Planning*, 2020).

As suggested by the previous paragraph, the maintenance, development, and provision of green spaces in the UK happens at multiple (national and local) levels. The local level, in particular, may benefit from nuanced observations like those provided by my thesis. My null findings and conditional findings, together, suggest that there may not be a 'universal' association between neighbourhood greenspace and mental health and well-being in children and adolescents. Merely maintaining and providing more greenspace may not improve children's and adolescents' mental health and well-being. The type of greenspace, and factors at individual and neighbourhood levels may play an important role and should be considered in neighbourhood planning and design. Therefore, a potential implication for policy is to consider the local neighbourhood context (i.e., spatial configuration and social composition) in the planning and development of neighbourhood green spaces. As the evidence does not allow clear conclusions about 'what works best for whom', a community-led planning approach may be most effective, and this should include children and adolescents representing their peers in their neighbourhoods.

My findings may also have implications beyond neighbourhood policy and planning. Although the focus of my thesis was on the residential neighbourhood, it may also be interesting for preschools and schools where children and adolescents spend much of their time. The greening of school grounds, and the potential implication for children’s and adolescents’ well-being are not new ideas. For example, an interesting project by the Department for Education, the Department for Environment, Food and Rural Affairs, and Natural England, called *Nature Friendly Schools,* aims to connect children with nature by providing education about, and encouraging contact with, nature in schools (*Nature Friendly Schools*, n.d.). Although my thesis did not directly address the role of greenspace in or around schools, it is plausible that individual and neighbourhood factors play a similar role, so the configuration and composition of a school should be considered in the development of green school grounds, and children and adolescents should be consulted about their needs and preferences. Based on the findings of my thesis, however, I cannot make more specific policy recommendations.

8.6. Conclusion

In my doctoral thesis, I have investigated the association between neighbourhood greenspace and children’s and adolescents’ mental health and well-being in the UK. I have looked at associations for a range of outcomes and ages, and, importantly, I have explored exposures beyond mere greenspace quantity, and contextual factors. My four studies varied in several aspects, so it is difficult to draw general conclusions. Nonetheless, I would like the reader to take away three main messages.

First, there does not seem to be a ‘general association’ between neighbourhood greenspace and children’s and adolescents’ mental health and well-being. The type of greenspace, the outcome of interest, the age group under study, and contextual factors, such as perceived neighbourhood quality, may all play a role in the association. To inform effective interventions, these complex relationships need to be further disentangled in future research. Second, exposure misclassification bias (due to the types of green spaces and vegetation included in a measure, and the definition of the exposure area) is a general problem in ‘greenspace and health’ studies that needs to be considered and addressed in future research. Even if it may be impossible to eliminate exposure misclassification bias, researchers must acknowledge and aim to at least minimise it. Again, this is important to be able to inform effective, real-world interventions. Finally, I would like to highlight that greenspace is a modifiable physical environment factor that has great potential for real-world interventions. Even if effects may be small, or at least smaller than those of more proximal factors, large-scale neighbourhood interventions may have an accumulated effect on population health and well-being, as long as we understand the nuances of the association between (neighbourhood) greenspace and (mental) health and well-being (in children and adolescents).

This should be the aim for future research: rather than simply accepting our studies' limitations, international, interdisciplinary teams should seek to overcome these limitations in a collaborative effort to unravel the complexity of the relationship between greenspace and child and adolescent mental health and well-being, and to translate the resulting understanding into actions that can have a real impact in the real world.

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Appendices

Appendix 1

Appendix 1 contains supplementary materials for Chapter 6.

Tables A6.1.1 to A6.4.7 show regression results for LSOA, 1,000-m-buffer, 300-m-buffer, and distance analyses. Table A6.5 shows ‘positive’ and ‘negative’ associations for two groups, i.e., younger adolescents (10- to 12-year-olds) and older adolescents (13- to 15-year-olds), separately for Waves 1, 3, 5, and 7. For reasons of parsimony, the table shows results for SDQ outcomes and significant associations only. All results are taken from fully adjusted models.

Table A6.1.1

Regression results for conduct problems (LSOA analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 370)				
Green land cover	-0.004	0.009	[-0.022, 0.015]	0.706
Green land use	0.189	0.067	[0.057, 0.322]	0.006
Parks/gardens	0.254	0.059	[0.137, 0.372]	0.000
Natural/semi-natural spaces	-0.055	0.101	[-0.255, 0.145]	0.585
Outdoor sports facilities	0.051	0.086	[-0.119, 0.222]	0.552
14 years (*n* = 356)				
Green land cover	-0.003	0.011	[-0.025, 0.019]	0.800
Green land use	0.062	0.099	[-0.135, 0.259]	0.531
Parks/gardens	0.099	0.108	[-0.116, 0.314]	0.363
Natural/semi-natural spaces	0.106	0.201	[-0.293, 0.505]	0.598
Outdoor sports facilities	-0.252	0.173	[-0.596, 0.092]	0.149
13 years (*n* = 386)				
Green land cover	-0.012	0.012	[-0.036, 0.012]	0.314
Green land use	-0.150	0.099	[-0.346, 0.047]	0.133
Parks/gardens	-0.082	0.091	[-0.263, 0.099]	0.369
Natural/semi-natural spaces	0.015	0.180	[-0.343, 0.373]	0.935
Outdoor sports facilities	-0.337	0.153	[-0.643, -0.032]	0.031
12 years (*n* = 402)				
Green land cover	0.011	0.008	[-0.004, 0.027]	0.149
Green land use	0.219	0.090	[0.042, 0.397]	0.016
Parks/gardens	0.100	0.096	[-0.089, 0.290]	0.297
Natural/semi-natural spaces	0.266	0.161	[-0.054, 0.586]	0.102
Outdoor sports facilities	0.013	0.175	[-0.335, 0.362]	0.939
11 years (*n* = 378)				
Green land cover	-0.005	0.008	[-0.021, 0.012]	0.584
Green land use	-0.112	0.131	[-0.373, 0.148]	0.394
Parks/gardens	-0.055	0.112	[-0.277, 0.167]	0.624
Natural/semi-natural spaces	-0.187	0.230	[-0.645, 0.271]	0.419
Outdoor sports facilities	-0.109	0.130	[-0.366, 0.149]	0.405
10 years (*n* = 383)				
Green land cover	-0.000	0.007	[-0.013, 0.013]	0.999
Green land use	0.038	0.093	[-0.146, 0.222]	0.682
Parks/gardens	0.083	0.093	[-0.102, 0.267]	0.374
Natural/semi-natural spaces	-0.002	0.133	[-0.267, 0.263]	0.986
Outdoor sports facilities	-0.067	0.217	[-0.500, 0.366]	0.760
8 years (*n* = 457)				
Green land cover	-0.009	0.009	[-0.028, 0.009]	0.324
Green land use	0.051	0.079	[-0.105, 0.207]	0.515
Parks/gardens	0.286	0.080	[0.128, 0.444]	0.001
Natural/semi-natural spaces	-0.226	0.092	[-0.409, -0.043]	0.016
Outdoor sports facilities	-0.051	0.086	[-0.222, 0.121]	0.559
5 years (*n* = 438)				
Green land cover	0.004	0.007	[-0.011, 0.019]	0.586
Green land use	0.050	0.098	[-0.144, 0.245]	0.608
Parks/gardens	0.054	0.108	[-0.160, 0.269]	0.616
Natural/semi-natural spaces	0.017	0.162	[-0.305, 0.339]	0.918
Outdoor sports facilities	-0.004	0.108	[-0.219, 0.210]	0.968

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. Values of 0.000 represent values > 0 AND < 0.001; values of -0.000 represent values < 0 AND > -0.001. The green land cover variable is based on raw data [%], whereas the green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should therefore not be compared to the size of a green land use coefficient.

Table A6.1.2

Regression results for emotional symptoms (LSOA analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 370)				
Green land cover	0.012	0.009	[-0.007, 0.030]	0.228
Green land use	0.065	0.091	[-0.116, 0.246]	0.477
Parks/gardens	-0.037	0.093	[-0.223, 0.148]	0.690
Natural/semi-natural spaces	0.244	0.194	[-0.141, 0.630]	0.211
Outdoor sports facilities	-0.086	0.167	[-0.418, 0.257]	0.610
14 years (*n* = 356)				
Green land cover	-0.007	0.009	[-0.026, 0.012]	0.459
Green land use	-0.196	0.116	[-0.427, 0.036]	0.096
Parks/gardens	0.032	0.141	[-0.249, 0.313]	0.821
Natural/semi-natural spaces	-0.321	0.251	[-0.820, 0.178]	0.204
Outdoor sports facilities	-0.325	0.199	[-0.720, 0.070]	0.105
13 years (*n* = 386)				
Green land cover	-0.009	0.012	[-0.032, 0.015]	0.464
Green land use	-0.181	0.098	[-0.377, 0.014]	0.069
Parks/gardens	-0.209	0.112	[-0.433, 0.015]	0.067
Natural/semi-natural spaces	-0.004	0.146	[-0.294, 0.286]	0.978
Outdoor sports facilities	-0.112	0.190	[-0.490, 0.266]	0.557
12 years (*n* = 402)				
Green land cover	-0.003	0.009	[-0.020, 0.015]	0.757
Green land use	0.032	0.106	[-0.178, 0.242]	0.763
Parks/gardens	-0.087	0.114	[-0.315, 0.140]	0.447
Natural/semi-natural spaces	0.102	0.202	[-0.299, 0.502]	0.615
Outdoor sports facilities	0.131	0.135	[-0.138, 0.399]	0.336
11 years (*n* = 378)				
Green land cover	-0.004	0.010	[-0.025, 0.016]	0.673
Green land use	-0.124	0.150	[-0.422, 0.175]	0.412
Parks/gardens	-0.078	0.105	[-0.288, 0.131]	0.459
Natural/semi-natural spaces	-0.068	0.323	[-0.710, 0.575]	0.835
Outdoor sports facilities	-0.212	0.105	[-0.421, -0.002]	0.048
10 years (*n* = 383)				
Green land cover	0.008	0.014	[-0.019, 0.035]	0.574
Green land use	0.136	0.148	[-0.158, 0.430]	0.361
Parks/gardens	0.023	0.167	[-0.309, 0.355]	0.890
Natural/semi-natural spaces	0.239	0.220	[-0.199, 0.677]	0.281
Outdoor sports facilities	-0.059	0.156	[-0.370, 0.251]	0.704
8 years (*n* = 457)				
Green land cover	-0.004	0.018	[-0.040, 0.031]	0.810
Green land use	-0.062	0.137	[-0.335, 0.210]	0.650
Parks/gardens	-0.026	0.169	[-0,362. 0.310]	0.879
Natural/semi-natural spaces	-0.125	0.241	[-0.603, 0.354]	0.606
Outdoor sports facilities	-0.078	0.229	[-0.532, 0.376]	0.733
5 years (*n* = 438)				
Green land cover	-0.000	0.014	[-0.029, 0.029]	0.999
Green land use	-0.062	0.149	[-0.359, 0.235]	0.679
Parks/gardens	-0.080	0.164	[-0.405, 0.245]	0.625
Natural/semi-natural spaces	0.146	0.187	[-0.226, 0.518]	0.438
Outdoor sports facilities	-0.288	0.185	[-0.656, 0.080]	0.123

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. Values of -0.000 represent values < 0 AND > -0.001. The green land cover variable is based on raw data [%], whereas the green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should therefore not be compared to the size of a green land use coefficient.

Table A6.1.3

Regression results for hyperactivity and inattention (LSOA analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 370)				
Green land cover	-0.000	0.012	[-0.023, 0.023]	0.973
Green land use	-0.075	0.075	[-0.225, 0.075]	0.326
Parks/gardens	-0.112	0.097	[-0.305, 0.082]	0.254
Natural/semi-natural spaces	0.062	0.125	[-0.186, 0.311]	0.620
Outdoor sports facilities	-0.116	0.121	[-0.356, 0.124]	0.340
14 years (*n* = 356)				
Green land cover	-0.000	0.013	[-0.025, 0.025]	0.986
Green land use	0.078	0.121	[-0.164, 0.319]	0.524
Parks/gardens	0.232	0.157	[-0.081, 0.544]	0.144
Natural/semi-natural spaces	-0.123	0.357	[-0.832, 0.587]	0.732
Outdoor sports facilities	-0.542	0.205	[-0.949, -0.134]	0.010
13 years (*n* = 386)				
Green land cover	-0.005	0.013	[-0.030, 0.021]	0.721
Green land use	-0.224	0.099	[-0.421, -0.028]	0.026
Parks/gardens	-0.180	0.087	[-0.353, -0.007]	0.042
Natural/semi-natural spaces	-0.107	0.208	[-0.521, 0.307]	0.608
Outdoor sports facilities	-0.124	0.155	[-0.433, 0.184]	0.425
12 years (*n* = 402)				
Green land cover	0.003	0.007	[-0.012, 0.017]	0.699
Green land use	0.202	0.088	[0.028, 0.376]	0.024
Parks/gardens	0.146	0.100	[-0.053, 0.346]	0.149
Natural/semi-natural spaces	0.059	0.140	[-0.219, 0.337]	0.675
Outdoor sports facilities	0.148	0.163	[-0.176, 0.471]	0.367
11 years (*n* = 378)				
Green land cover	0.012	0.011	[-0.009, 0.034]	0.249
Green land use	-0.047	0.147	[-0.339, 0.244]	0.748
Parks/gardens	-0.141	0.109	[-0.357, 0.074]	0.196
Natural/semi-natural spaces	0.192	0.268	[-0.342, 0.725]	0.476
Outdoor sports facilities	-0.107	0.122	[-0.350, 0.136]	0.384
10 years (*n* = 383)				
Green land cover	0.010	0.013	[-0.015, 0.036]	0.422
Green land use	0.186	0.119	[-0.050, 0.423]	0.121
Parks/gardens	0.211	0.108	[-0.004, 0.426]	0.054
Natural/semi-natural spaces	0.033	0.206	[-0.378, 0.444]	0.873
Outdoor sports facilities	0.067	0.160	[-0.252, 0.386]	0.676
8 years (*n* = 457)				
Green land cover	0.010	0.016	[-0.021, 0.041]	0.539
Green land use	0.063	0.138	[-0.211, 0.337]	0.648
Parks/gardens	0.148	0.191	[-0.232, 0.529]	0.441
Natural/semi-natural spaces	-0.070	0.196	[-0.459, 0.319]	0.720
Outdoor sports facilities	0.002	0.231	[-0.458, 0.462]	0.992
5 years (*n* = 438)				
Green land cover	0.009	0.020	[-0.030, 0.048]	0.657
Green land use	0.037	0.147	[-0.255, 0.328]	0.803
Parks/gardens	-0.131	0.163	[-0.455, 0.192]	0.421
Natural/semi-natural spaces	0.332	0.263	[-0.190, 0.854]	0.210
Outdoor sports facilities	0.034	0.279	[-0.520, 0.589]	0.902

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. Values of -0.000 represent values < 0 AND > -0.001. The green land cover variable is based on raw data [%], whereas the green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should therefore not be compared to the size of a green land use coefficient.

Table A6.1.4

Regression results for peer relationship problems (LSOA analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 370)				
Green land cover	-0.003	0.005	[-0.012, 0.007]	0.551
Green land use	0.041	0.054	[-0.066, 0.148]	0.449
Parks/gardens	0.068	0.064	[-0.060, 0.196]	0.291
Natural/semi-natural spaces	-0.146	0.077	[-0.299, 0.007]	0.061
Outdoor sports facilities	0.029	0.099	[-0.169, 0.226]	0.773
14 years (*n* = 356)				
Green land cover	-0.004	0.008	[-0.020, 0.012]	0.652
Green land use	-0.041	0.109	[-0.258, 0.176]	0.709
Parks/gardens	-0.014	0.082	[-0.178, 0.150]	0.867
Natural/semi-natural spaces	0.012	0.234	[-0.453, 0.477]	0.959
Outdoor sports facilities	-0.102	0.156	[-0.411, 0.208]	0.516
13 years (*n* = 386)				
Green land cover	-0.005	0.009	[-0.022, 0.012]	0.587
Green land use	0.044	0.088	[-0.130, 0.219]	0.615
Parks/gardens	-0.010	0.056	[-0.121, 0.101]	0.859
Natural/semi-natural spaces	0.018	0.217	[-0.415, 0.450]	0.936
Outdoor sports facilities	0.057	0.119	[-0.180, 0.293]	0.634
12 years (*n* = 402)				
Green land cover	-0.002	0.007	[-0.016, 0.011]	0.749
Green land use	0.021	0.076	[-0.130, 0.173]	0.780
Parks/gardens	-0.074	0.068	[-0.208, 0.061]	0.281
Natural/semi-natural spaces	0.042	0.142	[-0.240, 0.323]	0.770
Outdoor sports facilities	0.284	0.086	[0.113, 0.456]	0.001
11 years (*n* = 378)				
Green land cover	-0.004	0.008	[-0.020, 0.013]	0.653
Green land use	0.089	0.132	[-0.173, 0.351]	0.501
Parks/gardens	0.037	0.114	[-0.189, 0.263]	0.744
Natural/semi-natural spaces	0.050	0.287	[-0.522, 0.621]	0.863
Outdoor sports facilities	-0.022	0.105	[-0.230, 0.186]	0.833
10 years (*n* = 383)				
Green land cover	0.006	0.011	[-0.015, 0.027]	0.553
Green land use	0.159	0.071	[0.018, 0.300]	0.028
Parks/gardens	0.066	0.086	[-0.106, 0.239]	0.444
Natural/semi-natural spaces	0.148	0.137	[-0.125, 0.420]	0.284
Outdoor sports facilities	0.143	0.128	[-0.113, 0.398]	0.270
8 years (*n* = 457)				
Green land cover	0.009	0.015	[-0.021, 0.038]	0.564
Green land use	0.124	0.089	[-0.054, 0.301]	0.169
Parks/gardens	0.123	0.130	[-0.134, 0.381]	0.344
Natural/semi-natural spaces	0.024	0.193	[-0.360, 0.407]	0.903
Outdoor sports facilities	0.013	0.159	[-0.302, 0.329]	0.933
5 years (*n* = 438)				
Green land cover	0.008	0.017	[-0.027, 0.043]	0.656
Green land use	0.033	0.111	[-0.188, 0.253]	0.770
Parks/gardens	-0.022	0.129	[-0.279, 0.235]	0.867
Natural/semi-natural spaces	0.138	0.246	[-0.351, 0.627]	0.577
Outdoor sports facilities	-0.102	0.128	[-0.356, 0.152]	0.427

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. The green land cover variable is based on raw data [%], whereas the green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should therefore not be compared to the size of a green land use coefficient.

Table A6.1.5

Regression results for total difficulties (LSOA analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 370)				
Green land cover	0.005	0.027	[-0.049, 0.059]	0.860
Green land use	0.221	0.196	[-0.169, 0.611]	0.263
Parks/gardens	0.174	0.151	[-0.126, 0.474]	0.252
Natural/semi-natural spaces	0.105	0.350	[-0.591, 0.802]	0.764
Outdoor sports facilities	-0.122	0.341	[-0.800, 0.556]	0.722
14 years (*n* = 356)				
Green land cover	-0.014	0.027	[-0.067, 0.040]	0.611
Green land use	-0.097	0.247	[-0.588, 0.394]	0.696
Parks/gardens	0.349	0.332	[-0.312, 1.010]	0.297
Natural/semi-natural spaces	-0.325	0.706	[-1.729, 1.078]	0.646
Outdoor sports facilities	-1.221	0.513	[-2.240, -0.201]	0.020
13 years (*n* = 386)				
Green land cover	-0.030	0.037	[-0.105, 0.045]	0.426
Green land use	-0.511	0.273	[-1.056, 0.034]	0.066
Parks/gardens	-0.480	0.235	[-0.949, -0.012]	0.045
Natural/semi-natural spaces	-0.079	0.540	[-1.155, 0.998]	0.884
Outdoor sports facilities	-0.517	0.459	[-1.431, 0.397]	0.264
12 years (*n* = 402)				
Green land cover	0.009	0.020	[-0.030, 0.048]	0.637
Green land use	0.475	0.209	[0.059, 0.890]	0.026
Parks/gardens	0.085	0.282	[-0.475, 0.646]	0.763
Natural/semi-natural spaces	0.468	0.415	[-0.355, 1.292]	0.262
Outdoor sports facilities	0.576	0.448	[-0.313, 1.465]	0.202
11 years (*n* = 378)				
Green land cover	-0.000	0.024	[-0.049, 0.048]	0.992
Green land use	-0.194	0.424	[-1.038, 0.649]	0.648
Parks/gardens	-0.237	0.292	[-0.817, 0.343]	0.418
Natural/semi-natural spaces	-0.013	0.920	[-1.842, 1.816]	0.989
Outdoor sports facilities	-0.449	0.305	[-1.055, 0.157]	0.144
10 years (*n* = 383)				
Green land cover	0.024	0.030	[-0.035, 0.083]	0.414
Green land use	0.519	0.277	[-0.033, 1.071]	0.065
Parks/gardens	0.383	0.309	[-0.232, 0.999]	0.219
Natural/semi-natural spaces	0.417	0.380	[-0.339, 1.173]	0.275
Outdoor sports facilities	0.084	0.419	[-0.751, 0.918]	0.842
8 years (*n* = 457)				
Green land cover	0.005	0.045	[-0.084, 0.094]	0.916
Green land use	0.176	0.317	[-0.455, 0.806]	0.581
Parks/gardens	0.532	0.413	[-0.288, 1.351]	0.201
Natural/semi-natural spaces	-0.398	0.581	[-1.553, 0.757]	0.495
Outdoor sports facilities	-0.113	0.493	[-1.092, 0.866]	0.819
5 years (*n* = 438)				
Green land cover	0.021	0.049	[-0.077, 0.118]	0.675
Green land use	0.058	0.400	[-0.736, 0.851]	0.885
Parks/gardens	-0.179	0.413	[-0.998, 0.640]	0.665
Natural/semi-natural spaces	0.632	0.646	[-0.651, 1.915]	0.330
Outdoor sports facilities	-0.360	0.418	[-1.190, 0.470]	0.391

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. Values of -0.000 represent values < 0 AND > -0.001. The green land cover variable is based on raw data [%], whereas the green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should therefore not be compared to the size of a green land use coefficient.

Table A6.1.6

Regression results for self-esteem (LSOA analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 298)				
Green land cover	-0.001	0.003	[-0.006, 0.004]	0.738
Green land use	0.030	0.036	[-0.043, 0.103]	0.412
Parks/gardens	-0.020	0.033	[-0.086, 0.045]	0.538
Natural/semi-natural spaces	0.140	0.036	[0.069, 0.211]	0.000
Outdoor sports facilities	-0.006	0.040	[-0.085, 0.073]	0.885
14 years (*n* = 313)				
Green land cover	-0.002	0.002	[-0.005, 0.002]	0.289
Green land use	0.037	0.017	[0.003, 0.070]	0.031
Parks/gardens	0.022	0.015	[-0.009, 0.052]	0.155
Natural/semi-natural spaces	0.021	0.030	[-0.039, 0.081]	0.490
Outdoor sports facilities	-0.009	0.033	[-0.076, 0.057]	0.777
13 years (*n* = 347)				
Green land cover	0.001	0.002	[-0.003, 0.005]	0.711
Green land use	-0.035	0.026	[-0.086, 0.016]	0.180
Parks/gardens	-0.026	0.040	[-0.106, 0.053]	0.507
Natural/semi-natural spaces	-0.019	0.044	[-0.106, 0.068]	0.670
Outdoor sports facilities	-0.003	0.027	[-0.058, 0.051]	0.899
12 years (*n* = 307)				
Green land cover	-0.003	0.003	[-0.010, 0.003]	0.307
Green land use	-0.019	0.024	[-0.067, 0.028]	0.414
Parks/gardens	0.002	0.027	[-0.052, 0.056]	0.933
Natural/semi-natural spaces	-0.051	0.044	[-0.138, 0.036]	0.246
Outdoor sports facilities	0.008	0.047	[-0.087, 0.103]	0.870
11 years (*n* = 343)				
Green land cover	0.001	0.001	[-0.002, 0.003]	0.537
Green land use	0.007	0.017	[-0.027, 0.040]	0.701
Parks/gardens	0.003	0.017	[-0.030, 0.037]	0.846
Natural/semi-natural spaces	0.025	0.019	[-0.013, 0.063]	0.190
Outdoor sports facilities	0.014	0.053	[-0.091, 0.120]	0.790
10 years (*n* = 269)				
Green land cover	-0.001	0.004	[-0.008, 0.006]	0.791
Green land use	0.010	0.038	[-0.065, 0.086]	0.788
Parks/gardens	0.019	0.040	[-0.060, 0.099]	0.626
Natural/semi-natural spaces	-0.027	0.045	[-0.117, 0.064]	0.557
Outdoor sports facilities	0.030	0.052	[-0.073, 0.133]	0.564

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. Values of 0.000 represent values > 0 AND < 0.001. The green land cover variable is based on raw data [%], whereas the green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should therefore not be compared to the size of a green land use coefficient.

Table A6.1.7

Regression results for happiness (LSOA analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 674)				
Green land cover	-0.000	0.003	[-0.007, 0.006]	0.920
Green land use	0.042	0.032	[-0.022, 0.105]	0.198
Parks/gardens	0.021	0.040	[-0.058, 0.100]	0.608
Natural/semi-natural spaces	0.068	0.072	[-0.074, 0.209]	0.347
Outdoor sports facilities	0.051	0.041	[-0.029, 0.131]	0.213
14 years (*n* = 678)				
Green land cover	0.002	0.003	[-0.004, 0.009]	0.473
Green land use	0.053	0.026	[0.002, 0.103]	0.041
Parks/gardens	-0.002	0.036	[-0.072, 0.069]	0.964
Natural/semi-natural spaces	0.057	0.062	[-0.065, 0.180]	0.356
Outdoor sports facilities	0.094	0.049	[-0.003, 0.191]	0.057
13 years (*n* = 742)				
Green land cover	0.005	0.004	[-0.003, 0.014]	0.224
Green land use	-0.014	0.035	[-0.082, 0.054]	0.686
Parks/gardens	-0.023	0.038	[-0.098, 0.052]	0.541
Natural/semi-natural spaces	-0.063	0.058	[-0.178, 0.052]	0.282
Outdoor sports facilities	0.138	0.053	[0.033, 0.243]	0.010
12 years (*n* = 719)				
Green land cover	-0.007	0.003	[-0.014, -0.000]	0.041
Green land use	-0.050	0.039	[-0.127, 0.026]	0.196
Parks/gardens	-0.048	0.045	[-0.136, 0.040]	0.285
Natural/semi-natural spaces	-0.033	0.060	[-0.152, 0.086]	0.589
Outdoor sports facilities	-0.008	0.066	[-0.139, 0.122]	0.900
11 years (*n* = 727)				
Green land cover	-0.004	0.003	[-0.009, 0.001]	0.158
Green land use	-0.020	0.028	[-0.075, 0.035]	0.468
Parks/gardens	-0.018	0.031	[-0.080, 0.044]	0.563
Natural/semi-natural spaces	-0.017	0.043	[-0.102, 0.067]	0.685
Outdoor sports facilities	0.032	0.035	[-0.036, 0.101]	0.350
10 years (*n* = 657)				
Green land cover	-0.003	0.003	[-0.008, 0.003]	0.351
Green land use	-0.023	0.035	[-0.092, 0.045]	0.504
Parks/gardens	-0.055	0.040	[-0.134, 0.023]	0.167
Natural/semi-natural spaces	-0.034	0.042	[-0.116, 0.049]	0.422
Outdoor sports facilities	0.076	0.046	[-0.015, 0.168]	0.102

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. Values of -0.000 represent values < 0 AND > -0.001. The green land cover variable is based on raw data [%], whereas the green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should therefore not be compared to the size of a green land use coefficient.

Table A6.2.1

Regression results for conduct problems (1,000-m-buffer analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 360)				
Green land cover	-0.024	0.014	[-0.052, 0.003]	0.081
Green land use	-0.163	0.209	[-0.578, 0.252]	0.437
Parks/gardens	0.008	0.221	[-0.432, 0.449]	0.970
Natural/semi-natural spaces	-0.176	0.142	[-0.460, 0.107]	0.220
Outdoor sports facilities	0.011	0.163	[-0.313, 0.336]	0.945
14 years (*n* = 341)				
Green land cover	0.004	0.015	[-0.027, 0.034]	0.809
Green land use	-0.141	0.268	[-0.674, 0.392]	0.600
Parks/gardens	0.041	0.203	[-0.362, 0.445]	0.839
Natural/semi-natural spaces	-0.056	0.202	[-0.457, 0.345]	0.781
Outdoor sports facilities	0.069	0.282	[-0.491, 0.629]	0.808
13 years (*n* = 372)				
Green land cover	-0.021	0.017	[-0.055, 0.014]	0.233
Green land use	-0.513	0.179	[-0.869, -0.157]	0.005
Parks/gardens	-0.080	0.202	[-0.483, 0.322]	0.692
Natural/semi-natural spaces	-0.193	0.138	[-0.467, 0.081]	0.165
Outdoor sports facilities	-0.190	0.180	[-0.549, 0.169]	0.296
12 years (*n* = 383)				
Green land cover	-0.001	0.008	[-0.016, 0.015]	0.941
Green land use	0.275	0.159	[-0.041, 0.591]	0.087
Parks/gardens	0.136	0.103	[-0.070, 0.341]	0.192
Natural/semi-natural spaces	-0.100	0.095	[-0.288, 0.089]	0.296
Outdoor sports facilities	0.007	0.121	[-0.234, 0.248]	0.956
11 years (*n* = 362)				
Green land cover	-0.004	0.013	[-0.030, 0.021]	0.734
Green land use	-0.036	0.196	[-0.426, 0.354]	0.855
Parks/gardens	0.113	0.296	[-0.476, 0.702]	0.703
Natural/semi-natural spaces	-0.155	0.216	[-0.584, 0.275]	0.476
Outdoor sports facilities	-0.002	0.293	[-0.585, 0.582]	0.996
10 years (*n* = 369)				
Green land cover	-0.013	0.008	[-0.028, 0.002]	0.087
Green land use	-0.135	0.408	[-0.949, 0.679]	0.741
Parks/gardens	-0.124	0.250	[-0.623, 0.375]	0.622
Natural/semi-natural spaces	-0.117	0.098	[-0.313, 0.079]	0.237
Outdoor sports facilities	0.256	0.175	[-0.092, 0.605]	0.147
8 years (*n* = 439)				
Green land cover	0.007	0.011	[-0.015, 0.029]	0.541
Green land use	0.086	0.266	[-0.443, 0.615]	0.747
Parks/gardens	0.416	0.205	[0.008, 0.824]	0.046
Natural/semi-natural spaces	-0.077	0.136	[-0.348, 0.193]	0.571
Outdoor sports facilities	-0.063	0.157	[-0.376, 0.250]	0.689
5 years (*n* = 419)				
Green land cover	-0.004	0.009	[-0.023, 0.014]	0.656
Green land use	-0.080	0.219	[-0.515, 0.356]	0.718
Parks/gardens	-0.023	0.197	[-0.414, 0.369]	0.908
Natural/semi-natural spaces	0.010	0.149	[-0.285, 0.306]	0.945
Outdoor sports facilities	0.079	0.141	[-0.201, 0.360]	0.576

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. The green land cover variable is based on raw data [%], whereas the green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should therefore not be compared to the size of a green land use coefficient.

Table A6.2.2

Regression results for emotional symptoms (1,000-m-buffer analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 360)				
Green land cover	0.011	0.017	[-0.024, 0.045]	0.540
Green land use	0.249	0.204	[-0.157, 0.654]	0.226
Parks/gardens	-0.007	0.156	[-0.318, 0.304]	0.966
Natural/semi-natural spaces	0.178	0.155	[-0.131, 0.486]	0.255
Outdoor sports facilities	-0.312	0.213	[-0.736, 0.111]	0.146
14 years (*n* = 341)				
Green land cover	0.048	0.015	[0.019, 0.077]	0.002
Green land use	0.427	0.409	[-0.387, 1.241]	0.300
Parks/gardens	0.319	0.267	[-0.212, 0.850]	0.235
Natural/semi-natural spaces	0.172	0.332	[-0.489, 0.833]	0.606
Outdoor sports facilities	0.236	0.352	[-0.464, 0.937]	0.504
13 years (*n* = 372)				
Green land cover	-0.021	0.016	[-0.053, 0.011]	0.189
Green land use	-0.249	0.209	[-0.665, 0.167]	0.236
Parks/gardens	-0.273	0.269	[-0.809, 0.263]	0.313
Natural/semi-natural spaces	-0.034	0.170	[-0.372, 0.304]	0.841
Outdoor sports facilities	0.153	0.241	[-0.327, 0.633]	0.526
12 years (*n* = 383)				
Green land cover	-0.006	0.013	[-0.033, 0.021]	0.651
Green land use	-0.107	0.305	[-0.713, 0.498]	0.725
Parks/gardens	-0.025	0.221	[-0.463, 0.413]	0.909
Natural/semi-natural spaces	0.062	0.159	[-0.254, 0.379]	0.697
Outdoor sports facilities	-0.033	0.189	[-0.408, 0.342]	0.862
11 years (*n* = 362)				
Green land cover	0.002	0.015	[-0.028, 0.031]	0.917
Green land use	-0.420	0.263	[-0.942, 0.102]	0.114
Parks/gardens	-0.195	0.174	[-0.542, 0.152]	0.267
Natural/semi-natural spaces	-0.173	0.213	[-0.597, 0.251]	0.419
Outdoor sports facilities	-0.141	0.269	[-0.676, 0.394]	0.601
10 years (*n* = 369)				
Green land cover	0.021	0.019	[-0.017, 0.060]	0.274
Green land use	0.325	0.524	[-0.719, 1.368]	0.537
Parks/gardens	0.022	0.382	[-0.740, 0.784]	0.954
Natural/semi-natural spaces	0.021	0.244	[-0.466, 0.507]	0.933
Outdoor sports facilities	-0.164	0.271	[-0.704, 0.376]	0.546
8 years (*n* = 439)				
Green land cover	0.012	0.027	[-0.042, 0.067]	0.661
Green land use	0.352	0.339	[-0.322, 1.027]	0.302
Parks/gardens	0.320	0.373	[-0.421, 1.061]	0.393
Natural/semi-natural spaces	0.050	0.223	[-0.395, 0.494]	0.825
Outdoor sports facilities	-0.063	0.393	[-0.845, 0.719]	0.874
5 years (*n* = 419)				
Green land cover	0.009	0.018	[-0.026, 0.044]	0.621
Green land use	0.061	0.392	[-0.717, 0.839]	0.877
Parks/gardens	-0.063	0.324	[-0.707, 0.581]	0.847
Natural/semi-natural spaces	0.130	0.204	[-0.274, 0.535]	0.524
Outdoor sports facilities	-0.106	0.195	[-0.494, 0.282]	0.589

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. The green land cover variable is based on raw data [%], whereas the green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should therefore not be compared to the size of a green land use coefficient.

Table A6.2.3

Regression results for hyperactivity and inattention (1,000-m-buffer analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 360)				
Green land cover	-0.002	0.014	[-0.030, 0.025]	0.874
Green land use	-0.194	0.266	[-0.724, 0.336]	0.468
Parks/gardens	-0.034	0.247	[-0.526, 0.458]	0.891
Natural/semi-natural spaces	-0.181	0.160	[-0.500, 0.137]	0.261
Outdoor sports facilities	-0.269	0.193	[-0.653, 0.114]	0.166
14 years (*n* = 341)				
Green land cover	0.005	0.015	[-0.025, 0.034]	0.750
Green land use	-0.046	0.386	[-0.814, 0.722]	0.905
Parks/gardens	0.566	0.243	[0.082, 1.050]	0.022
Natural/semi-natural spaces	-0.337	0.234	[-0.802, 0.127]	0.152
Outdoor sports facilities	-0.374	0.342	[-1.055, 0.306]	0.277
13 years (*n* = 372)				
Green land cover	-0.015	0.020	[-0.055, 0.026]	0.479
Green land use	-0.317	0.281	[-0.876, 0.243]	0.263
Parks/gardens	-0.227	0.198	[-0.622, 0.167]	0.255
Natural/semi-natural spaces	-0.071	0.147	[-0.365, 0.222]	0.629
Outdoor sports facilities	0.159	0.212	[-0.264, 0.582]	0.456
12 years (*n* = 383)				
Green land cover	-0.008	0.011	[-0.030, 0.014]	0.493
Green land use	0.446	0.277	[-0.105, 0.997]	0.111
Parks/gardens	0.365	0.166	[0.036, 0.695]	0.030
Natural/semi-natural spaces	-0.159	0.128	[-0.413, 0.095]	0.216
Outdoor sports facilities	0.186	0.186	[-0.183, 0.555]	0.320
11 years (*n* = 362)				
Green land cover	0.034	0.012	[0.010, 0.058]	0.006
Green land use	0.053	0.251	[-0.446, 0.552]	0.833
Parks/gardens	-0.108	0.223	[-0.553, 0.336]	0.629
Natural/semi-natural spaces	0.099	0.218	[-0.335, 0.534]	0.650
Outdoor sports facilities	0.213	0.245	[-0.274, 0.700]	0.387
10 years (*n* = 369)				
Green land cover	0.016	0.019	[-0.022, 0.054]	0.416
Green land use	0.158	0.295	[-0.430, 0.745]	0.594
Parks/gardens	0.061	0.245	[-0.426, 0.549]	0.803
Natural/semi-natural spaces	-0.182	0.175	[-0.532, 0.167]	0.302
Outdoor sports facilities	-0.002	0.209	[-0.418, 0.414]	0.992
8 years (*n* = 439)				
Green land cover	0.011	0.025	[-0.039, 0.061]	0.671
Green land use	-0.164	0.423	[-1.004, 0.676]	0.699
Parks/gardens	0.254	0.405	[-0.551, 1.059]	0.532
Natural/semi-natural spaces	-0.179	0.219	[-0.615, 0.256]	0.415
Outdoor sports facilities	-0.239	0.320	[-0.875, 0.397]	0.457
5 years (*n* = 419)				
Green land cover	0.009	0.033	[-0.056, 0.075]	0.776
Green land use	-0.139	0.301	[-0.738, 0.460]	0.646
Parks/gardens	-0.276	0.352	[-0.975, 0.424]	0.436
Natural/semi-natural spaces	0.191	0.261	[-0.327, 0.709]	0.466
Outdoor sports facilities	-0.076	0.325	[-0.722, 0.571]	0.816

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. The green land cover variable is based on raw data [%], whereas the green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should therefore not be compared to the size of a green land use coefficient.

Table A6.2.4

Regression results for peer relationship problems (1,000-m-buffer analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 360)				
Green land cover	-0.007	0.010	[-0.026, 0.013]	0.495
Green land use	0.101	0.144	[-0.186, 0.388]	0.486
Parks/gardens	0.149	0.116	[-0.082, 0.381]	0.202
Natural/semi-natural spaces	0.071	0.102	[-0.132, 0.274]	0.489
Outdoor sports facilities	-0.240	0.152	[-0.543, 0.062]	0.118
14 years (*n* = 341)				
Green land cover	-0.008	0.010	[-0.028, 0.015]	0.415
Green land use	-0.268	0.227	[-0.721, 0.184]	0.242
Parks/gardens	-0.238	0.135	[-0.506, 0.029]	0.080
Natural/semi-natural spaces	0.001	0.133	[-0.264, 0.267]	0.992
Outdoor sports facilities	0.018	0.154	[-0.288, 0.325]	0.905
13 years (*n* = 372)				
Green land cover	-0.004	0.010	[-0.025, 0.017]	0.698
Green land use	0.059	0.195	[-0.329, 0.447]	0.762
Parks/gardens	-0.098	0.140	[-0.377, 0.180]	0.483
Natural/semi-natural spaces	0.197	0.117	[-0.035, 0.430]	0.095
Outdoor sports facilities	0.137	0.141	[-0.143, 0.418]	0.333
12 years (*n* = 383)				
Green land cover	0.003	0.007	[-0.011, 0.018]	0.638
Green land use	0.132	0.136	[-0.138, 0.401]	0.335
Parks/gardens	-0.154	0.117	[-0.385, 0.078]	0.191
Natural/semi-natural spaces	0.285	0.113	[0.059, 0.510]	0.014
Outdoor sports facilities	0.021	0.134	[-0.245, 0.287]	0.877
11 years (*n* = 362)				
Green land cover	-0.008	0.011	[-0.029, 0.014]	0.486
Green land use	0.086	0.274	[-0.460, 0.631]	0.755
Parks/gardens	0.064	0.227	[-0.388, 0.516]	0.779
Natural/semi-natural spaces	-0.059	0.179	[-0.415, 0.297]	0.743
Outdoor sports facilities	-0.028	0.222	[-0.469, 0.414]	0.901
10 years (*n* = 369)				
Green land cover	0.009	0.019	[-0.028, 0.047]	0.618
Green land use	0.448	0.218	[0.015, 0.882]	0.043
Parks/gardens	-0.078	0.147	[-0.370, 0.214]	0.596
Natural/semi-natural spaces	0.325	0.128	[0.069, 0.581]	0.013
Outdoor sports facilities	-0.048	0.138	[-0.323, 0.226]	0.727
8 years (*n* = 439)				
Green land cover	0.019	0.026	[-0.032, 0.070]	0.459
Green land use	0.169	0.298	[-0.423, 0.761]	0.571
Parks/gardens	-0.028	0.287	[-0.599, 0.542]	0.922
Natural/semi-natural spaces	0.211	0.183	[-0.153, 0.575]	0.252
Outdoor sports facilities	-0.093	0.323	[-0.735, 0.549]	0.774
5 years (*n* = 419)				
Green land cover	0.006	0.025	[-0.043, 0.055]	0.798
Green land use	0.137	0.256	[-0.372, 0.646]	0.595
Parks/gardens	0.092	0.222	[-0.350, 0.533]	0.680
Natural/semi-natural spaces	0.099	0.192	[-0.283, 0.480]	0.609
Outdoor sports facilities	-0.009	0.196	[-0.399, 0.381]	0.963

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. The green land cover variable is based on raw data [%], whereas the green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should therefore not be compared to the size of a green land use coefficient.

Table A6.2.5

Regression results for total difficulties (1,000-m-buffer analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 360)				
Green land cover	-0.023	0.043	[-0.108, 0.063]	0.600
Green land use	-0.008	0.661	[-1.323, 1.308]	0.991
Parks/gardens	0.117	0.610	[-1.098, 1.332]	0.848
Natural/semi-natural spaces	-0.109	0.415	[-0.935, 0.717]	0.794
Outdoor sports facilities	-0.810	0.527	[-1.860, 0.239]	0.128
14 years (*n* = 341)				
Green land cover	0.049	0.032	[-0.014, 0.111]	0.128
Green land use	-0.028	0.791	[-1.602, 1.546]	0.972
Parks/gardens	0.688	0.641	[-0.587, 1.963]	0.286
Natural/semi-natural spaces	-0.220	0.678	[-1.569, 1.129]	0.746
Outdoor sports facilities	-0.051	0.849	[-1.740, 1.639]	0.952
13 years (*n* = 372)				
Green land cover	-0.061	0.049	[-0.159, 0.038]	0.224
Green land use	-1.020	0.646	[-2.308, 0.268]	0.119
Parks/gardens	-0.679	0.644	[-1.963, 0.605]	0.295
Natural/semi-natural spaces	-0.101	0.421	[-0.941, 0.738]	0.811
Outdoor sports facilities	0.260	0.550	[-0.836, 1.356]	0.638
12 years (*n* = 383)				
Green land cover	-0.011	0.027	[-0.064, 0.042]	0.685
Green land use	0.746	0.570	[-0.388, 1.879]	0.194
Parks/gardens	0.322	0.480	[-0.632, 1.276]	0.504
Natural/semi-natural spaces	0.088	0.351	[-0.609, 0.786]	0.802
Outdoor sports facilities	0.180	0.413	[-0.641, 1.002]	0.663
11 years (*n* = 362)				
Green land cover	0.024	0.034	[-0.043, 0.091]	0.486
Green land use	-0.317	0.569	[-1.449, 0.815]	0.579
Parks/gardens	-0.126	0.563	[-1.246, 0.994]	0.823
Natural/semi-natural spaces	-0.287	0.578	[-1.438, 0.863]	0.621
Outdoor sports facilities	0.042	0.736	[-1.422, 1.507]	0.954
10 years (*n* = 369)				
Green land cover	0.033	0.038	[-0.042, 0.108]	0.382
Green land use	0.795	0.970	[-1.139, 2.730]	0.415
Parks/gardens	-0.119	0.616	[-1.347, 1.109]	0.848
Natural/semi-natural spaces	0.046	0.453	[-0.857, 0.949]	0.919
Outdoor sports facilities	0.041	0.588	[-1.130, 1.213]	0.944
8 years (*n* = 439)				
Green land cover	0.049	0.071	[-0.093, 0.191]	0.496
Green land use	0.444	0.848	[-1.242, 2.130]	0.602
Parks/gardens	0.914	0.966	[-0.959, 2.882]	0.322
Natural/semi-natural spaces	0.004	0.539	[-1.067, 1.075]	0.994
Outdoor sports facilities	-0.458	0.905	[-2.256, 1.340]	0.614
5 years (*n* = 419)				
Green land cover	0.020	0.067	[-0.112, 0.153]	0.759
Green land use	-0.021	0.819	[-1.648, 1.607]	0.980
Parks/gardens	-0.269	0.863	[-1.983, 1.446]	0.756
Natural/semi-natural spaces	0.430	0.605	[-0.772, 1.632]	0.479
Outdoor sports facilities	-0.112	0.650	[-1.403, 1.180]	0.864

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. The green land cover variable is based on raw data [%], whereas the green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should therefore not be compared to the size of a green land use coefficient.

Table A6.2.6

Regression results for self-esteem (1,000-m-buffer analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 288)				
Green land cover	-0.004	0.007	[-0.017, 0.009]	0.528
Green land use	0.070	0.079	[-0.088, 0.228]	0.379
Parks/gardens	0.035	0.103	[-0.172, 0.242]	0.736
Natural/semi-natural spaces	0.018	0.050	[-0.082, 0.119]	0.715
Outdoor sports facilities	0.037	0.047	[-0.056, 0.130]	0.433
14 years (*n* = 303)				
Green land cover	-0.001	0.002	[-0.005, 0.002]	0.448
Green land use	0.027	0.031	[-0.035, 0.089]	0.389
Parks/gardens	-0.004	0.030	[-0.064, 0.056]	0.897
Natural/semi-natural spaces	0.010	0.028	[-0.045, 0.065]	0.728
Outdoor sports facilities	0.049	0.032	[-0.015, 0.114]	0.130
13 years (*n* = 330)				
Green land cover	-0.004	0.002	[-0.008, 0.000]	0.077
Green land use	-0.100	0.061	[-0.222, 0.022]	0.105
Parks/gardens	-0.019	0.050	[-0.118, 0.081]	0.711
Natural/semi-natural spaces	-0.020	0.052	[-0.124, 0.084]	0.707
Outdoor sports facilities	-0.048	0.064	[-0.175, 0.080]	0.458
12 years (*n* = 292)				
Green land cover	-0.000	0.004	[-0.009, 0.009]	0.993
Green land use	-0.004	0.096	[-0.196, 0.188]	0.964
Parks/gardens	0.020	0.063	[-0.105, 0.145]	0.748
Natural/semi-natural spaces	-0.002	0.045	[-0.092, 0.087]	0.961
Outdoor sports facilities	0.060	0.032	[-0.005, 0.125]	0.070
11 years (*n* = 327)				
Green land cover	-0.000	0.002	[-0.005, 0.004]	0.851
Green land use	-0.012	0.047	[-0.106, 0.082]	0.793
Parks/gardens	-0.031	0.025	[-0.080, 0.018]	0.211
Natural/semi-natural spaces	-0.013	0.030	[-0.072, 0.047]	0.672
Outdoor sports facilities	0.009	0.026	[-0.044, 0.061]	0.742
10 years (*n* = 258)				
Green land cover	-0.001	0.004	[-0.009, 0.007]	0.835
Green land use	0.159	0.086	[-0.013, 0.332]	0.070
Parks/gardens	0.073	0.071	[-0.070, 0.216]	0.310
Natural/semi-natural spaces	0.033	0.073	[-0.113, 0.180]	0.651
Outdoor sports facilities	0.061	0.073	[-0.085, 0.207]	0.404

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. Values of 0.000 represent values > 0 AND < 0.001; values of -0.000 represent values < 0 AND > -0.001. The green land cover variable is based on raw data [%], whereas the green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should therefore not be compared to the size of a green land use coefficient.

Table A6.2.7

Regression results for happiness (1,000-m-buffer analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 653)				
Green land cover	0.005	0.006	[-0.006, 0.016]	0.394
Green land use	0.159	0.089	[-0.017, 0.335]	0.076
Parks/gardens	-0.013	0.083	[-0.177, 0.151]	0.877
Natural/semi-natural spaces	0.051	0.070	[-0.087, 0.189]	0.467
Outdoor sports facilities	0.075	0.084	[-0.091, 0.240]	0.375
14 years (*n* = 652)				
Green land cover	-0.002	0.005	[-0.009, 0.009]	0.974
Green land use	0.102	0.096	[-0.088, 0.292]	0.292
Parks/gardens	-0.024	0.092	[-0.205, 0.157]	0.798
Natural/semi-natural spaces	0.041	0.070	[-0.097, 0.179]	0.559
Outdoor sports facilities	0.029	0.080	[-0.128, 0.186]	0.716
13 years (*n* = 711)				
Green land cover	0.005	0.004	[-0.003, 0.013]	0.244
Green land use	0.022	0.079	[-0.133, 0.178]	0.777
Parks/gardens	0.010	0.085	[-0.159, 0.178]	0.909
Natural/semi-natural spaces	0.007	0.063	[-0.117, 0.131]	0.912
Outdoor sports facilities	-0.029	0.097	[-0.201, 0.143]	0.742
12 years (*n* = 684)				
Green land cover	-0.005	0.007	[-0.019, 0.009]	0.505
Green land use	-0.016	0.124	[-0.260, 0.228]	0.899
Parks/gardens	-0.003	0.082	[-0.164, 0.159]	0.975
Natural/semi-natural spaces	-0.001	0.063	[-0.126, 0.124]	0.983
Outdoor sports facilities	-0.049	0.059	[-0.166, 0.067]	0.403
11 years (*n* = 695)				
Green land cover	0.000	0.004	[-0.009, 0.009]	0.991
Green land use	0.034	0.078	[-0.120, 0.189]	0.661
Parks/gardens	0.010	0.062	[-0.112, 0.132]	0.874
Natural/semi-natural spaces	0.041	0.056	[-0.069, 0.150]	0.464
Outdoor sports facilities	0.038	0.055	[-0.071, 0.147]	0.494
10 years (*n* = 631)				
Green land cover	0.001	0.005	[-0.009, 0.012]	0.822
Green land use	0.018	0.090	[-0.160, 0.197]	0.840
Parks/gardens	0.050	0.072	[-0.092, 0.191]	0.490
Natural/semi-natural spaces	-0.027	0.055	[-0.139, 0.079]	0.592
Outdoor sports facilities	0.002	0.073	[-0.142, 0.146]	0.982

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. Values of 0.000 represent values > 0 AND < 0.001. The green land cover variable is based on raw data [%], whereas the green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should therefore not be compared to the size of a green land use coefficient.

Table A6.3.1

Regression results for conduct problems (300-m-buffer analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 366)				
Green land cover	-0.013	0.012	[-0.036, 0.010]	0.268
Green land use	0.069	0.085	[-0.101, 0.238]	0.424
Parks/gardens	0.158	0.075	[0.009, 0.308]	0.038
Natural/semi-natural spaces	-0.040	0.116	[-0.272, 0.191]	0.731
Outdoor sports facilities	-0.042	0.142	[-0.324, 0.240]	0.766
14 years (*n* = 352)				
Green land cover	-0.022	0.014	[-0.050, 0.006]	0.128
Green land use	-0.025	0.113	[-0.248, 0.199]	0.827
Parks/gardens	-0.009	0.133	[-0.274, 0.256]	0.945
Natural/semi-natural spaces	-0.054	0.202	[-0.454, 0.346]	0.789
Outdoor sports facilities	-0.260	0.121	[-0.500, -0.020]	0.034
13 years (*n* = 379)				
Green land cover	-0.016	0.015	[-0.047, 0.015]	0.304
Green land use	-0.203	0.101	[-0.404, -0.002]	0.048
Parks/gardens	-0.108	0.104	[-0.317, 0.100]	0.303
Natural/semi-natural spaces	-0.021	0.132	[-0.283, 0.242]	0.875
Outdoor sports facilities	-0.367	0.154	[-0.675, -0.060]	0.020
12 years (*n* = 394)				
Green land cover	0.001	0.011	[-0.020, 0.022]	0.923
Green land use	0.131	0.147	[-0.161, 0.424]	0.376
Parks/gardens	0.112	0.079	[-0.046, 0.270]	0.163
Natural/semi-natural spaces	0.074	0.285	[-0.493, 0.641]	0.796
Outdoor sports facilities	-0.041	0.116	[-0.271, 0.190]	0.728
11 years (*n* = 368)				
Green land cover	-0.014	0.011	[-0.035, 0.008]	0.209
Green land use	-0.163	0.155	[-0.471, 0.146]	0.298
Parks/gardens	-0.013	0.153	[-0.318, 0.291]	0.930
Natural/semi-natural spaces	-0.309	0.174	[-0.655, 0.037]	0.079
Outdoor sports facilities	-0.204	0.159	[-0.520, 0.112]	0.202
10 years (*n* = 377)				
Green land cover	0.002	0.012	[-0.022, 0.026]	0.867
Green land use	0.119	0.117	[-0.113, 0.351]	0.310
Parks/gardens	-0.013	0.157	[-0.326, 0.301]	0.936
Natural/semi-natural spaces	0.038	0.165	[-0.290, 0.366]	0.819
Outdoor sports facilities	0.175	0.203	[-0.229, 0.580]	0.390
8 years (*n* = 451)				
Green land cover	-0.008	0.007	[-0.023, 0.007]	0.285
Green land use	-0.013	0.099	[-0.210, 0.184]	0.894
Parks/gardens	0.169	0.095	[-0.020, 0.357]	0.079
Natural/semi-natural spaces	-0.250	0.226	[-0.698, 0.198]	0.271
Outdoor sports facilities	-0.218	0.154	[-0.524, 0.087]	0.159
5 years (*n* = 435)				
Green land cover	0.001	0.007	[-0.014, 0.015]	0.918
Green land use	0.091	0.097	[-0.101, 0.284]	0.349
Parks/gardens	-0.000	0.091	[-0.181, 0.181]	0.997
Natural/semi-natural spaces	0.098	0.151	[-0.202, 0.398]	0.519
Outdoor sports facilities	0.220	0.138	[-0.054, 0.493]	0.114

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. Values of -0.000 represent values < 0 AND > -0.001. The green land cover variable is based on raw data [%], whereas the green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should therefore not be compared to the size of a green land use coefficient.

Table A6.3.2

Regression results for emotional symptoms (300-m-buffer analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 366)				
Green land cover	0.018	0.009	[-0.001, 0.036]	0.060
Green land use	0.216	0.101	[0.015, 0.418]	0.035
Parks/gardens	0.150	0.097	[-0.044, 0.344]	0.127
Natural/semi-natural spaces	0.495	0.290	[-0.082, 1.072]	0.092
Outdoor sports facilities	-0.228	0.166	[-0.558, 0.101]	0.172
14 years (*n* = 352)				
Green land cover	-0.008	0.014	[-0.036, 0.020]	0.568
Green land use	-0.285	0.171	[-0.624, 0.053]	0.098
Parks/gardens	-0.115	0.169	[-0.450, 0.220]	0.497
Natural/semi-natural spaces	-0.434	0.336	[-1.102, 0.235]	0.201
Outdoor sports facilities	-0.188	0.209	[-0.602, 0.227]	0.371
13 years (*n* = 379)				
Green land cover	-0.019	0.018	[-0.054, 0.016]	0.276
Green land use	-0.224	0.112	[-0.447, -0.002]	0.048
Parks/gardens	-0.288	0.134	[-0.555, -0.020]	0.035
Natural/semi-natural spaces	-0.050	0.117	[-0.282, 0.183]	0.672
Outdoor sports facilities	0.049	0.135	[-0.220, 0.319]	0.716
12 years (*n* = 394)				
Green land cover	-0.013	0.014	[-0.040, 0.014]	0.343
Green land use	0.033	0.120	[-0.205, 0.272]	0.781
Parks/gardens	0.080	0.123	[-0.165, 0.324]	0.518
Natural/semi-natural spaces	-0.096	0.324	[-0.739, 0.546]	0.766
Outdoor sports facilities	0.062	0.132	[-0.200, 0.323]	0.640
11 years (*n* = 368)				
Green land cover	-0.001	0.011	[-0.023, 0.020]	0.892
Green land use	0.107	0.120	[-0.132, 0.347]	0.374
Parks/gardens	0.062	0.127	[-0.190, 0.314]	0.624
Natural/semi-natural spaces	0.220	0.192	[-0.161, 0.602]	0.254
Outdoor sports facilities	-0.015	0.119	[-0.252, 0.222]	0.899
10 years (*n* = 377)				
Green land cover	0.026	0.020	[-0.013, 0.066]	0.185
Green land use	0.377	0.141	[0.097, 0.658]	0.009
Parks/gardens	0.218	0.188	[-0.156, 0.592]	0.250
Natural/semi-natural spaces	0.543	0.452	[-0.357, 1.444]	0.233
Outdoor sports facilities	0.119	0.199	[-0.277, 0.516]	0.551
8 years (*n* = 451)				
Green land cover	0.004	0.026	[-0.047, 0.054]	0.885
Green land use	-0.125	0.159	[-0.440, 0.190]	0.432
Parks/gardens	0.094	0.259	[-0.420, 0.608]	0.716
Natural/semi-natural spaces	-0.281	0.200	[-0.679, 0.116]	0.163
Outdoor sports facilities	-0.087	0.255	[-0.595, 0.420]	0.733
5 years (*n* = 435)				
Green land cover	0.007	0.012	[-0.017, 0.032]	0.567
Green land use	0.128	0.121	[-0.114, 0.369]	0.296
Parks/gardens	0.076	0.173	[-0.268, 0.419]	0.663
Natural/semi-natural spaces	0.260	0.171	[-0.079, 0.600]	0.131
Outdoor sports facilities	-0.064	0.159	[-0.380, 0.252]	0.689

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. The green land cover variable is based on raw data [%], whereas the green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should therefore not be compared to the size of a green land use coefficient.

Table A6.3.3

Regression results for hyperactivity and inattention (300-m-buffer analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 366)				
Green land cover	0.004	0.010	[-0.016, 0.025]	0.674
Green land use	0.140	0.109	[-0.076, 0.357]	0.201
Parks/gardens	0.039	0.116	[-0.193, 0.270]	0.739
Natural/semi-natural spaces	0.300	0.172	[-0.042, 0.642]	0.085
Outdoor sports facilities	-0.134	0.223	[-0.577, 0.310]	0.551
14 years (*n* = 352)				
Green land cover	-0.008	0.018	[-0.044, 0.027]	0.645
Green land use	-0.011	0.153	[-0.011, 0.153]	0.941
Parks/gardens	0.146	0.195	[-0.242, 0.534]	0.456
Natural/semi-natural spaces	-0.295	0.513	[-1.314, 0.724]	0.567
Outdoor sports facilities	-0.408	0.211	[-0.828, 0.012]	0.057
13 years (*n* = 379)				
Green land cover	-0.014	0.015	[-0.044, 0.017]	0.373
Green land use	-0.277	0.114	[-0.505, -0.049]	0.018
Parks/gardens	-0.294	0.117	[-0.528, -0.061]	0.014
Natural/semi-natural spaces	-0.148	0.192	[-0.529, 0.234]	0.443
Outdoor sports facilities	0.135	0.149	[-0.163, 0.433]	0.369
12 years (*n* = 394)				
Green land cover	0.005	0.013	[-0.019, 0.030]	0.663
Green land use	0.168	0.139	[-0.109, 0.444]	0.232
Parks/gardens	0.142	0.123	[-0.102, 0.385]	0.250
Natural/semi-natural spaces	0.017	0.237	[-0.455, 0.489]	0.943
Outdoor sports facilities	0.162	0.123	[-0.081, 0.406]	0.189
11 years (*n* = 368)				
Green land cover	0.019	0.011	[-0.002, 0.041]	0.075
Green land use	0.128	0.147	[-0.165, 0.422]	0.386
Parks/gardens	0.002	0.150	[-0.296, 0.300]	0.990
Natural/semi-natural spaces	0.321	0.178	[-0.034, 0.676]	0.076
Outdoor sports facilities	0.154	0.171	[-0.186, 0.494]	0.371
10 years (*n* = 377)				
Green land cover	0.027	0.012	[0.003, 0.050]	0.029
Green land use	0.211	0.155	[-0.098, 0.520]	0.178
Parks/gardens	0.114	0.139	[-0.162, 0.390]	0.412
Natural/semi-natural spaces	-0.042	0.319	[-0.679, 0.594]	0.895
Outdoor sports facilities	0.283	0.185	[-0.085, 0.651]	0.130
8 years (*n* = 451)				
Green land cover	0.011	0.022	[-0.032, 0.054]	0.616
Green land use	-0.059	0.171	[-0.399, 0.281]	0.731
Parks/gardens	-0.164	0.224	[-0.609, 0.280]	0.464
Natural/semi-natural spaces	-0.071	0.188	[-0.443, 0.302]	0.707
Outdoor sports facilities	0.172	0.245	[-0.314, 0.658]	0.484
5 years (*n* = 435)				
Green land cover	0.016	0.025	[-0.034, 0.067]	0.525
Green land use	0.271	0.161	[-0.049, 0.591]	0.095
Parks/gardens	0.068	0.260	[-0.449, 0.584]	0.795
Natural/semi-natural spaces	0.538	0.240	[0.062, 1.015]	0.027
Outdoor sports facilities	-0.064	0.286	[-0.632, 0.504]	0.823

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. The green land cover variable is based on raw data [%], whereas the green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should therefore not be compared to the size of a green land use coefficient.

Table A6.3.4

Regression results for peer relationship problems (300-m-buffer analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 366)				
Green land cover	-0.009	0.006	[-0.020, 0.002]	0.106
Green land use	0.042	0.062	[-0.082, 0.167]	0.499
Parks/gardens	0.007	0.077	[-0.146, 0.161]	0.924
Natural/semi-natural spaces	0.213	0.096	[0.022, 0.404]	0.029
Outdoor sports facilities	-0.060	0.118	[-0.295, 0.176]	0.614
14 years (*n* = 352)				
Green land cover	0.002	0.008	[-0.014, 0.018]	0.818
Green land use	-0.031	0.118	[-0.267, 0.204]	0.791
Parks/gardens	-0.132	0.086	[-0.303, 0.039]	0.130
Natural/semi-natural spaces	0.162	0.205	[-0.245, 0.570]	0.430
Outdoor sports facilities	-0.115	0.106	[-0.326, 0.095]	0.280
13 years (*n* = 379)				
Green land cover	-0.005	0.007	[-0.020, 0.010]	0.518
Green land use	0.035	0.085	[-0.134, 0.205]	0.680
Parks/gardens	-0.095	0.066	[-0.227, 0.036]	0.151
Natural/semi-natural spaces	0.099	0.182	[-0.265, 0.462]	0.590
Outdoor sports facilities	0.209	0.092	[0.027, 0.392]	0.025
12 years (*n* = 394)				
Green land cover	0.008	0.009	[-0.010, 0.025]	0.394
Green land use	0.079	0.071	[-0.062, 0.220]	0.269
Parks/gardens	-0.010	0.073	[-0.156, 0.134]	0.889
Natural/semi-natural spaces	0.029	0.140	[-0.248, 0.307]	0.834
Outdoor sports facilities	0.195	0.084	[0.028, 0.361]	0.022
11 years (*n* = 368)				
Green land cover	-0.008	0.011	[-0.030, 0.014]	0.454
Green land use	0.155	0.101	[-0.046, 0.356]	0.128
Parks/gardens	0.080	0.116	[-0.151, 0.310]	0.493
Natural/semi-natural spaces	0.095	0.191	[-0.285, 0.475]	0.620
Outdoor sports facilities	0.133	0.144	[-0.154, 0.421]	0.358
10 years (*n* = 377)				
Green land cover	0.010	0.009	[-0.008, 0.028]	0.273
Green land use	0.154	0.106	[-0.057, 0.364]	0.150
Parks/gardens	-0.010	0.085	[-0.178, 0.159]	0.911
Natural/semi-natural spaces	0.316	0.173	[-0.029, 0.661]	0.072
Outdoor sports facilities	0.129	0.156	[-0.182, 0.440]	0.412
8 years (*n* = 451)				
Green land cover	0.015	0.022	[-0.029, 0.059]	0.494
Green land use	-0.063	0.135	[-0.331, 0.204]	0.639
Parks/gardens	-0.015	0.213	[-0.438, 0.408]	0.945
Natural/semi-natural spaces	0.000	0.167	[-0.332, 0.332]	1.000
Outdoor sports facilities	-0.081	0.208	[-0.495, 0.332]	0.697
5 years (*n* = 435)				
Green land cover	0.010	0.020	[-0.029, 0.049]	0.615
Green land use	0.096	0.090	[-0.083, 0.275]	0.291
Parks/gardens	0.068	0.173	[-0.277, 0.412]	0.697
Natural/semi-natural spaces	0.164	0.156	[-0.146, 0.475]	0.296
Outdoor sports facilities	0.022	0.128	[-0.233, 0.276]	0.865

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. Values of 0.000 represent values > 0 AND < 0.001. The green land cover variable is based on raw data [%], whereas the green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should therefore not be compared to the size of a green land use coefficient.

Table A6.3.5

Regression results for total difficulties (300-m-buffer analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 366)				
Green land cover	0.000	0.026	[-0.052, 0.052]	0.990
Green land use	0.468	0.256	[-0.041, 0.976]	0.071
Parks/gardens	0.355	0.237	[-0.118, 0.827]	0.139
Natural/semi-natural spaces	0.968	0.533	[-0.094, 2.030]	0.074
Outdoor sports facilities	-0.464	0.522	[-1.502, 0.574]	0.376
14 years (*n* = 352)				
Green land cover	-0.036	0.037	[-0.110, 0.037]	0.327
Green land use	-0.353	0.323	[-0.995, 0.289]	0.277
Parks/gardens	-0.110	0.413	[-0.931, 0.712]	0.791
Natural/semi-natural spaces	-0.620	0.930	[-2.469, 1.228]	0.507
Outdoor sports facilities	-0.971	0.385	[-1.737, -0.204]	0.014
13 years (*n* = 379)				
Green land cover	-0.054	0.048	[-0.149, 0.042]	0.266
Green land use	-0.669	0.262	[-1.191, -0.148]	0.013
Parks/gardens	-0.786	0.303	[-1.390, -0.182]	0.011
Natural/semi-natural spaces	-0.119	0.451	[-1.019, 0.780]	0.792
Outdoor sports facilities	0.026	0.339	[-0.649, 0.702]	0.938
12 years (*n* = 394)				
Green land cover	0.001	0.035	[-0.068, 0.071]	0.972
Green land use	0.411	0.403	[-0.390, 1.212]	0.311
Parks/gardens	0.323	0.298	[-0.269, 0.915]	0.281
Natural/semi-natural spaces	0.024	0.826	[-1.617, 1.665]	0.977
Outdoor sports facilities	0.378	0.282	[-0.182, 0.938]	0.183
11 years (*n* = 368)				
Green land cover	-0.004	0.033	[-0.070, 0.062]	0.902
Green land use	0.228	0.349	[-0.465, 0.922]	0.514
Parks/gardens	0.130	0.376	[-0.618, 0.879]	0.730
Natural/semi-natural spaces	0.327	0.558	[-0.783, 1.438]	0.559
Outdoor sports facilities	0.068	0.413	[-0.754, 0.890]	0.870
10 years (*n* = 377)				
Green land cover	0.065	0.033	[-0.002, 0.131]	0.056
Green land use	0.861	0.371	[0.122, 1.600]	0.023
Parks/gardens	0.310	0.374	[-0.436, 1.056]	0.411
Natural/semi-natural spaces	0.855	0.799	[-0.737, 2.447]	0.288
Outdoor sports facilities	0.706	0.410	[-0.109, 1.522]	0.089
8 years (*n* = 451)				
Green land cover	0.022	0.063	[-0.103, 0.147]	0.729
Green land use	-0.261	0.421	[-1.097, 0.575]	0.537
Parks/gardens	0.084	0.628	[-1.164, 1.331]	0.894
Natural/semi-natural spaces	-0.602	0.587	[-1.768, 0.565]	0.308
Outdoor sports facilities	-0.215	0.558	[-1.324, 0.894]	0.701
5 years (*n* = 435)				
Green land cover	0.034	0.053	[-0.072, 0.140]	0.525
Green land use	0.586	0.343	[-0.096, 1.268]	0.091
Parks/gardens	0.211	0.543	[-0.868, 1.289]	0.699
Natural/semi-natural spaces	1.061	0.527	[0.015, 2.107]	0.047
Outdoor sports facilities	0.113	0.446	[-0.771, 0.998]	0.800

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. Values of 0.000 represent values > 0 AND < 0.001. The green land cover variable is based on raw data [%], whereas the green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should therefore not be compared to the size of a green land use coefficient.

Table A6.3.6

Regression results for self-esteem (300-m-buffer analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 294)				
Green land cover	0.004	0.003	[-0.002, 0.011]	0.216
Green land use	0.037	0.039	[-0.040, 0.114]	0.342
Parks/gardens	-0.015	0.040	[-0.095, 0.064]	0.701
Natural/semi-natural spaces	0.104	0.034	[0.035, 0.173]	0.004
Outdoor sports facilities	0.022	0.045	[-0.068, 0.111]	0.631
14 years (*n* = 308)				
Green land cover	0.002	0.002	[-0.002, 0.007]	0.266
Green land use	0.058	0.022	[0.015, 0.101]	0.009
Parks/gardens	0.047	0.020	[0.007, 0.087]	0.021
Natural/semi-natural spaces	0.033	0.041	[-0.049, 0.115]	0.428
Outdoor sports facilities	0.006	0.030	[-0.053, 0.066]	0.827
13 years (*n* = 340)				
Green land cover	0.000	0.003	[-0.005, 0.006]	0.871
Green land use	-0.040	0.029	[-0.098, 0.019]	0.180
Parks/gardens	-0.056	0.036	[-0.128, 0.016]	0.128
Natural/semi-natural spaces	0.035	0.088	[-0.140, 0.210]	0.688
Outdoor sports facilities	-0.040	0.031	[-0.103, 0.023]	0.211
12 years (*n* = 298)				
Green land cover	-0.003	0.003	[-0.008, 0.002]	0.244
Green land use	-0.028	0.034	[-0.097, 0.040]	0.405
Parks/gardens	-0.003	0.028	[-0.058, 0.053]	0.917
Natural/semi-natural spaces	-0.083	0.067	[-0.216, 0.051]	0.219
Outdoor sports facilities	-0.040	0.083	[-0.206, 0.125]	0.627
11 years (*n* = 338)				
Green land cover	-0.001	0.002	[-0.005, 0.003]	0.611
Green land use	-0.016	0.019	[-0.054, 0.023]	0.424
Parks/gardens	-0.041	0.021	[-0.083, 0.002]	0.059
Natural/semi-natural spaces	0.033	0.024	[-0.015, 0.081]	0.171
Outdoor sports facilities	0.021	0.040	[-0.059, 0.101]	0.605
10 years (*n* = 264)				
Green land cover	-0.000	0.003	[-0.007, 0.007]	0.972
Green land use	-0.006	0.029	[-0.065, 0.052]	0.833
Parks/gardens	0.001	0.027	[-0.053, 0.056]	0.963
Natural/semi-natural spaces	-0.014	0.038	[-0.091, 0.063]	0.718
Outdoor sports facilities	-0.009	0.053	[-0.115, 0.097]	0.871

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. Values of 0.000 represent values > 0 AND < 0.001; values of -0.000 represent values < 0 AND > -0.001. The green land cover variable is based on raw data [%], whereas the green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should therefore not be compared to the size of a green land use coefficient.

Table A6.3.7

Regression results for happiness (300-m-buffer analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 665)				
Green land cover	0.005	0.004	[-0.002, 0.012]	0.195
Green land use	0.053	0.034	[-0.015, 0.121]	0.125
Parks/gardens	0.029	0.050	[-0.069, 0.127]	0.560
Natural/semi-natural spaces	0.047	0.087	[-0.123, 0.218]	0.588
Outdoor sports facilities	0.036	0.051	[-0.065, 0.138]	0.483
14 years (*n* = 668)				
Green land cover	0.008	0.006	[-0.003, 0.020]	0.169
Green land use	0.085	0.033	[0.021, 0.150]	0.010
Parks/gardens	0.036	0.044	[-0.050, 0.123]	0.408
Natural/semi-natural spaces	0.094	0.069	[-0.043, 0.230]	0.177
Outdoor sports facilities	0.074	0.044	[-0.013, 0.160]	0.096
13 years (*n* = 728)				
Green land cover	0.006	0.004	[-0.002, 0.014]	0.120
Green land use	0.011	0.040	[-0.067, 0.089]	0.779
Parks/gardens	-0.009	0.041	[-0.090, 0.071]	0.817
Natural/semi-natural spaces	-0.008	0.082	[-0.170, 0.155]	0.927
Outdoor sports facilities	0.036	0.069	[-0.100, 0.171]	0.603
12 years (*n* = 701)				
Green land cover	-0.007	0.005	[-0.017, 0.003]	0.148
Green land use	-0.022	0.039	[-0.098, 0.054]	0.574
Parks/gardens	-0.054	0.041	[-0.135, 0.027]	0.190
Natural/semi-natural spaces	0.011	0.087	[-0.160, 0.183]	0.896
Outdoor sports facilities	0.042	0.052	[-0.060, 0.144]	0.421
11 years (*n* = 712)				
Green land cover	-0.006	0.004	[-0.013, 0.001]	0.099
Green land use	-0.086	0.027	[-0.140, -0.032]	0.002
Parks/gardens	-0.071	0.035	[-0.141, -0.001]	0.046
Natural/semi-natural spaces	-0.094	0.073	[-0.239, 0.051]	0.202
Outdoor sports facilities	0.044	0.047	[-0.049, 0.137]	0.354
10 years (*n* = 646)				
Green land cover	-0.006	0.003	[-0.013, 0.000]	0.060
Green land use	-0.082	0.030	[-0.142, -0.022]	0.007
Parks/gardens	-0.081	0.033	[-0.145, -0.016]	0.015
Natural/semi-natural spaces	-0.106	0.048	[-0.201, -0.010]	0.030
Outdoor sports facilities	0.027	0.048	[-0.067, 0.122]	0.571

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. Values of 0.000 represent values > 0 AND < 0.001. The green land cover variable is based on raw data [%], whereas the green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$]. The size of the green land cover coefficient should therefore not be compared to the size of a green land use coefficient.

Table A6.4.1

Regression results for conduct problems (distance analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 365)				
Green land use	-0.073	0.091	[-0.255, 0.108]	0.424
Parks/gardens	-0.192	0.082	[-0.354, -0.030]	0.021
Natural/semi-natural spaces	0.146	0.123	[-0.098, 0.390]	0.237
Outdoor sports facilities	-0.030	0.100	[-0.229, 0.170]	0.767
14 years (*n* = 349)				
Green land use	0.074	0.136	[-0.196, 0.345]	0.586
Parks/gardens	-0.016	0.124	[-0.262, 0.231]	0.899
Natural/semi-natural spaces	0.068	0.178	[-0.285, 0.421]	0.704
Outdoor sports facilities	0.221	0.157	[-0.092, 0.533]	0.164
13 years (*n* = 378)				
Green land use	0.157	0.135	[-0.112, 0.426]	0.249
Parks/gardens	0.082	0.123	[-0.163, 0.327]	0.506
Natural/semi-natural spaces	0.146	0.128	[-0.110, 0.401]	0.261
Outdoor sports facilities	0.103	0.122	[-0.141, 0.347]	0.402
12 years (*n* = 392)				
Green land use	-0.065	0.133	[-0.329, 0.199]	0.625
Parks/gardens	-0.069	0.089	[-0.247, 0.108]	0.439
Natural/semi-natural spaces	0.069	0.106	[-0.142, 0.280]	0.515
Outdoor sports facilities	0.130	0.106	[-0.080, 0.340]	0.223
11 years (*n* = 368)				
Green land use	0.144	0.175	[-0.205, 0.493]	0.413
Parks/gardens	-0.023	0.189	[-0.398, 0.353]	0.904
Natural/semi-natural spaces	0.278	0.202	[-0.124, 0.680]	0.173
Outdoor sports facilities	0.148	0.163	[-0.176, 0.473]	0.366
10 years (*n* = 375)				
Green land use	-0.099	0.152	[-0.402, 0.204]	0.516
Parks/gardens	0.029	0.141	[-0.253, 0.311]	0.839
Natural/semi-natural spaces	-0.059	0.096	[-0.250, 0.132]	0.541
Outdoor sports facilities	-0.120	0.210	[-0.539, 0.299]	0.570
8 years (*n* = 451)				
Green land use	0.078	0.105	[-0.132, 0.288]	0.462
Parks/gardens	-0.211	0.099	[-0.408, -0.013]	0.037
Natural/semi-natural spaces	0.249	0.205	[-0.159, 0.658]	0.228
Outdoor sports facilities	0.219	0.106	[0.008, 0.430]	0.042
5 years (*n* = 430)				
Green land use	-0.152	0.146	[-0.441, 0.137]	0.300
Parks/gardens	-0.038	0.107	[-0.250, 0.174]	0.724
Natural/semi-natural spaces	-0.104	0.109	[-0.321, 0.113]	0.344
Outdoor sports facilities	-0.186	0.122	[-0.429, 0.057]	0.132

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. Distances (in metres) were log-transformed.

Table A6.4.2

Regression results for emotional symptoms (distance analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 365)				
Green land use	-0.160	0.156	[-0.471, 0.152]	0.311
Parks/gardens	-0.048	0.151	[-0.348, 0.252]	0.750
Natural/semi-natural spaces	-0.181	0.186	[-0.552, 0.190]	0.334
Outdoor sports facilities	0.178	0.129	[-0.078, 0.434]	0.170
14 years (*n* = 349)				
Green land use	0.351	0.170	[0.012, 0.690]	0.043
Parks/gardens	0.083	0.146	[-0.208, 0.374]	0.573
Natural/semi-natural spaces	0.191	0.307	[-0.420, 0.801]	0.536
Outdoor sports facilities	0.073	0.173	[-0.270, 0.417]	0.672
13 years (*n* = 378)				
Green land use	0.268	0.190	[-0.110, 0.647]	0.162
Parks/gardens	0.347	0.186	[-0.027, 0.715]	0.069
Natural/semi-natural spaces	0.136	0.148	[-0.158, 0.430]	0.361
Outdoor sports facilities	-0.091	0.169	[-0.428, 0.247]	0.594
12 years (*n* = 392)				
Green land use	0.004	0.143	[-0.280, 0.287]	0.979
Parks/gardens	-0.109	0.128	[-0.363, 0.145]	0.396
Natural/semi-natural spaces	0.072	0.161	[-0.247, 0.391]	0.654
Outdoor sports facilities	-0.089	0.162	[-0.410, 0.233]	0.585
11 years (*n* = 368)				
Green land use	-0.010	0.154	[-0.317, 0.296]	0.947
Parks/gardens	0.065	0.129	[-0.192, 0.322]	0.617
Natural/semi-natural spaces	0.103	0.204	[-0.302, 0.508]	0.614
Outdoor sports facilities	-0.019	0.124	[-0.265, 0.227]	0.878
10 years (*n* = 375)				
Green land use	-0.269	0.234	[-0.735, 0.197]	0.253
Parks/gardens	-0.105	0.152	[-0.407, 0.197]	0.490
Natural/semi-natural spaces	-0.075	0.382	[-0.836, 0.686]	0.844
Outdoor sports facilities	0.076	0.169	[-0.261, 0.414]	0.654
8 years (*n* = 451)				
Green land use	0.061	0.278	[-0.493, 0.614]	0.827
Parks/gardens	-0.142	0.245	[-0.629, 0.344]	0.563
Natural/semi-natural spaces	0.146	0.273	[-0.396, 0.688]	0.593
Outdoor sports facilities	0.222	0.277	[-0.328, 0.773]	0.424
5 years (*n* = 430)				
Green land use	-0.150	0.164	[-0.476, 0.176]	0.363
Parks/gardens	-0.118	0.179	[-0.474, 0.238]	0.512
Natural/semi-natural spaces	-0.198	0.138	[-0.473, 0.076]	0.155
Outdoor sports facilities	0.131	0.108	[-0.084, 0.346]	0.228

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. Distances (in metres) were log-transformed.

Table A6.4.3

Regression results for hyperactivity and inattention (distance analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 365)				
Green land use	-0.155	0.131	[-0.415, 0.105]	0.239
Parks/gardens	-0.099	0.139	[-0.374, 0.177]	0.478
Natural/semi-natural spaces	0.082	0.143	[-0.203, 0.367]	0.568
Outdoor sports facilities	0.178	0.136	[-0.093, 0.449]	0.195
14 years (*n* = 349)				
Green land use	0.108	0.181	[-0.253, 0.468]	0.554
Parks/gardens	-0.184	0.203	[-0.587, 0.291]	0.367
Natural/semi-natural spaces	0.309	0.275	[-0.237, 0.855]	0.263
Outdoor sports facilities	0.453	0.184	[0.087, 0.819]	0.016
13 years (*n* = 378)				
Green land use	0.113	0.146	[-0.179, 0.404]	0.443
Parks/gardens	0.179	0.146	[-0.113, 0.470]	0.225
Natural/semi-natural spaces	0.251	0.149	[-0.047, 0.548]	0.097
Outdoor sports facilities	-0.206	0.129	[-0.464, 0.052]	0.115
12 years (*n* = 392)				
Green land use	-0.115	0.162	[-0.437, 0.207]	0.481
Parks/gardens	-0.133	0.116	[-0.363, 0.097]	0.254
Natural/semi-natural spaces	0.089	0.123	[-0.155, 0.333]	0.471
Outdoor sports facilities	-0.149	0.177	[-0.501, 0.203]	0.403
11 years (*n* = 368)				
Green land use	-0.083	0.161	[-0.403, 0.236]	0.605
Parks/gardens	0.102	0.148	[-0.193, 0.398]	0.493
Natural/semi-natural spaces	-0.057	0.191	[-0.437, 0.324]	0.768
Outdoor sports facilities	-0.161	0.127	[-0.412, 0.091]	0.208
10 years (*n* = 375)				
Green land use	-0.188	0.195	[-0.577, 0.200]	0.338
Parks/gardens	-0.134	0.127	[-0.387, 0.120]	0.296
Natural/semi-natural spaces	0.102	0.210	[-0.318, 0.521]	0.630
Outdoor sports facilities	-0.037	0.154	[-0.344, 0.270]	0.810
8 years (*n* = 451)				
Green land use	0.054	0.247	[-0.436, 0.545]	0.827
Parks/gardens	0.120	0.230	[-0.336, 0.576]	0.602
Natural/semi-natural spaces	0.027	0.240	[-0.450, 0.505]	0.910
Outdoor sports facilities	0.075	0.291	[-0.504, 0.654]	0.797
5 years (*n* = 430)				
Green land use	-0.433	0.218	[-0.865, -0.000]	0.050
Parks/gardens	-0.144	0.235	[-0.611, 0.323]	0.543
Natural/semi-natural spaces	-0.472	0.216	[-0.900, -0.043]	0.031
Outdoor sports facilities	0.045	0.291	[-0.534, 0.623]	0.879

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. Values of -0.000 represent values < 0 AND > -0.001. Distances (in metres) were log-transformed.

Table A6.4.4

Regression results for peer relationship problems (distance analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 365)				
Green land use	-0.008	0.073	[-0.153, 0.138]	0.917
Parks/gardens	0.017	0.077	[-0.135, 0.170]	0.821
Natural/semi-natural spaces	-0.093	0.082	[-0.255, 0.070]	0.259
Outdoor sports facilities	0.081	0.088	[-0.094, 0.255]	0.359
14 years (*n* = 349)				
Green land use	0.055	0.085	[-0.114, 0.225]	0.516
Parks/gardens	0.151	0.074	[0.003, 0.299]	0.045
Natural/semi-natural spaces	-0.117	0.122	[-0.360, 0.126]	0.341
Outdoor sports facilities	0.058	0.072	[-0.085, 0.202]	0.423
13 years (*n* = 378)				
Green land use	0.004	0.100	[-0.196, 0.204]	0.965
Parks/gardens	0.109	0.076	[-0.043, 0.261]	0.157
Natural/semi-natural spaces	-0.101	0.097	[-0.294, 0.092]	0.301
Outdoor sports facilities	-0.134	0.088	[-0.308, 0.041]	0.132
12 years (*n* = 392)				
Green land use	-0.104	0.095	[-0.292, 0.085]	0.278
Parks/gardens	-0.059	0.075	[-0.208, 0.089]	0.429
Natural/semi-natural spaces	-0.112	0.095	[-0.301, 0.078]	0.244
Outdoor sports facilities	-0.045	0.101	[-0.246, 0.156]	0.658
11 years (*n* = 368)				
Green land use	-0.123	0.132	[-0.387, 0.140]	0.354
Parks/gardens	-0.042	0.131	[-0.302, 0.218]	0.747
Natural/semi-natural spaces	0.087	0.187	[-0.285, 0.459]	0.643
Outdoor sports facilities	-0.109	0.131	[-0.370, 0.152]	0.409
10 years (*n* = 375)				
Green land use	-0.102	0.137	[-0.376, 0.171]	0.459
Parks/gardens	0.044	0.091	[-0.138, 0.226]	0.634
Natural/semi-natural spaces	-0.219	0.143	[-0.504, 0.067]	0.131
Outdoor sports facilities	-0.056	0.130	[-0.315, 0.202]	0.666
8 years (*n* = 451)				
Green land use	0.064	0.174	[-0.282, 0.410]	0.714
Parks/gardens	0.024	0.157	[-0.288, 0.336]	0.877
Natural/semi-natural spaces	-0.051	0.238	[-0.525, 0.422]	0.830
Outdoor sports facilities	0.088	0.234	[-0.377, 0.553]	0.707
5 years (*n* = 430)				
Green land use	-0.131	0.132	[-0.393, 0.131]	0.324
Parks/gardens	-0.108	0.163	[-0.431, 0.214]	0.507
Natural/semi-natural spaces	-0.132	0.186	[-0.501, 0.236]	0.478
Outdoor sports facilities	-0.005	0.144	[-0.290, 0.281]	0.974

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. Distances (in metres) were log-transformed.

Table A6.4.5

Regression results for total difficulties (distance analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 365)				
Green land use	-0.395	0.304	[-1.000, 0.209]	0.197
Parks/gardens	-0.321	0.291	[-0.900, 0.257]	0.272
Natural/semi-natural spaces	-0.046	0.397	[-0.837, 0.745]	0.908
Outdoor sports facilities	0.407	0.346	[-0.282, 1.096]	0.243
14 years (*n* = 349)				
Green land use	0.588	0.390	[-0.187, 1.364]	0.135
Parks/gardens	0.034	0.337	[-0.636, 0.704]	0.920
Natural/semi-natural spaces	0.451	0.740	[-1.020, 1.922]	0.544
Outdoor sports facilities	0.806	0.423	[-0.035, 1.646]	0.060
13 years (*n* = 378)				
Green land use	0.542	0.378	[-0.210, 1.295]	0.155
Parks/gardens	0.714	0.385	[-0.054, 1.482]	0.068
Natural/semi-natural spaces	0.431	0.368	[-0.302, 1.164]	0.245
Outdoor sports facilities	-0.328	0.345	[-1.015, 0.360]	0.345
12 years (*n* = 392)				
Green land use	-0.280	0.412	[-1.098, 0.539]	0.499
Parks/gardens	-0.371	0.292	[-0.950, 0.209]	0.207
Natural/semi-natural spaces	0.119	0.395	[-0.667, 0.904]	0.765
Outdoor sports facilities	-0.153	0.383	[-0.913, 0.608]	0.691
11 years (*n* = 368)				
Green land use	-0.073	0.448	[-0.964, 0.818]	0.871
Parks/gardens	0.102	0.435	[-0.763, 0.967]	0.815
Natural/semi-natural spaces	0.411	0.620	[-0.822, 1.644]	0.509
Outdoor sports facilities	-0.140	0.419	[-0.974, 0.694]	0.739
10 years (*n* = 375)				
Green land use	-0.659	0.536	[-1.727, 0.410]	0.223
Parks/gardens	-0.166	0.362	[-0.888, 0.555]	0.647
Natural/semi-natural spaces	-0.251	0.704	[-1.654, 1.152]	0.722
Outdoor sports facilities	-0.137	0.434	[-1.002, 0.728]	0.753
8 years (*n* = 451)				
Green land use	0.257	0.580	[-0.896, 1.411]	0.659
Parks/gardens	-0.208	0.566	[-1.334, 0.917]	0.714
Natural/semi-natural spaces	0.371	0.743	[-1.106, 1.848]	0.619
Outdoor sports facilities	0.605	0.626	[-0.639, 1.849]	0.337
5 years (*n* = 430)				
Green land use	-0.866	0.446	[-1.751, 0.020]	0.055
Parks/gardens	-0.408	0.477	[-1.355, 0.539]	0.394
Natural/semi-natural spaces	-0.906	0.506	[-1.910, 0.098]	0.076
Outdoor sports facilities	-0.015	0.518	[-1.043, 1.014]	0.977

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. Distances (in metres) were log-transformed.

Table A6.4.6

Regression results for self-esteem (distance analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 293)				
Green land use	-0.101	0.044	[-0.189, -0.013]	0.025
Parks/gardens	-0.011	0.050	[-0.110, 0.088]	0.821
Natural/semi-natural spaces	-0.058	0.023	[-0.105, -0.011]	0.016
Outdoor sports facilities	-0.048	0.035	[-0.117, 0.021]	0.169
14 years (*n* = 306)				
Green land use	-0.038	0.040	[-0.118, 0.042]	0.344
Parks/gardens	-0.029	0.031	[-0.092, 0.033]	0.349
Natural/semi-natural spaces	-0.020	0.033	[-0.086, 0.046]	0.543
Outdoor sports facilities	-0.016	0.025	[-0.066, 0.034]	0.528
13 years (*n* = 338)				
Green land use	0.033	0.042	[-0.050, 0.116]	0.435
Parks/gardens	0.055	0.027	[0.001, 0.110]	0.047
Natural/semi-natural spaces	-0.026	0.066	[-0.158, 0.105]	0.690
Outdoor sports facilities	0.021	0.038	[-0.055, 0.096]	0.591
12 years (*n* = 298)				
Green land use	0.012	0.040	[-0.068, 0.091]	0.767
Parks/gardens	-0.032	0.037	[-0.106, 0.042]	0.394
Natural/semi-natural spaces	0.020	0.038	[-0.056, 0.097]	0.594
Outdoor sports facilities	0.005	0.040	[-0.075, 0.085]	0.899
11 years (*n* = 336)				
Green land use	0.003	0.020	[-0.037, 0.044]	0.864
Parks/gardens	0.026	0.019	[-0.012, 0.064]	0.173
Natural/semi-natural spaces	-0.008	0.013	[-0.033, 0.017]	0.526
Outdoor sports facilities	-0.008	0.028	[-0.063, 0.047]	0.761
10 years (*n* = 264)				
Green land use	0.012	0.044	[-0.076, 0.100]	0.785
Parks/gardens	-0.012	0.039	[-0.091, 0.067]	0.758
Natural/semi-natural spaces	0.006	0.046	[-0.087, 0.098]	0.905
Outdoor sports facilities	-0.015	0.044	[-0.103, 0.073]	0.734

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. Distances (in metres) were log-transformed.

Table A6.4.7

Regression results for happiness (distance analysis)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 663)				
Green land use	-0.123	0.052	[-0.226, -0.021]	0.019
Parks/gardens	-0.056	0.047	[-0.149, 0.038]	0.244
Natural/semi-natural spaces	-0.052	0.092	[-0.233, 0.129]	0.572
Outdoor sports facilities	-0.030	0.051	[-0.131, 0.071]	0.555
14 years (*n* = 663)				
Green land use	-0.066	0.055	[-0.175, 0.043]	0.236
Parks/gardens	-0.006	0.047	[-0.100, 0.087]	0.892
Natural/semi-natural spaces	-0.078	0.081	[-0.238, 0.083]	0.341
Outdoor sports facilities	-0.029	0.051	[-0.130, 0.071]	0.566
13 years (*n* = 725)				
Green land use	-0.036	0.048	[-0.131, 0.058]	0.448
Parks/gardens	0.012	0.041	[-0.068, 0.093]	0.765
Natural/semi-natural spaces	-0.030	0.082	[-0.192, 0.133]	0.719
Outdoor sports facilities	-0.033	0.052	[-0.136, 0.069]	0.522
12 years (*n* = 699)				
Green land use	-0.021	0.049	[-0.117, 0.075]	0.671
Parks/gardens	0.028	0.053	[-0.076, 0.133]	0.591
Natural/semi-natural spaces	-0.023	0.055	[-0.131, 0.085]	0.680
Outdoor sports facilities	-0.032	0.048	[-0.127, 0.062]	0.496
11 years (*n* = 710)				
Green land use	0.067	0.044	[-0.021, 0.155]	0.133
Parks/gardens	0.021	0.037	[-0.052, 0.095]	0.565
Natural/semi-natural spaces	0.002	0.063	[-0.121, 0.126]	0.969
Outdoor sports facilities	-0.062	0.035	[-0.131, 0.008]	0.081
10 years (*n* = 644)				
Green land use	0.090	0.048	[-0.004, 0.184]	0.060
Parks/gardens	0.061	0.037	[-0.011, 0.133]	0.098
Natural/semi-natural spaces	0.050	0.049	[-0.048, 0.147]	0.314
Outdoor sports facilities	-0.015	0.046	[-0.107, 0.077]	0.751

Note. Estimates are taken from separate models (i.e., one model for each age-exposure combination). Estimates are pooled estimates of 25 imputed datasets. Distances (in metres) were log-transformed.

Table A6.5

Significant associations from an analysis stratified by age group (10- to 12-year-olds and 13- to 15-year-olds)

	10- to 12-year-olds	13- to 15-year-olds
Wave 1	*n* = 422	*n* = 411
'Positive'	-	SDQ HA N/SN UG: *b* = -0.464, *SE* = 0.117, $p < .001$ SDQ TD GLU: *b* = -0.641, *SE* = 0.307, *p* = .040 N/SN UG: *b* = -0.718, *SE* = 0.339, *p* = .037
'Negative'	-	-
Wave 3	*n* = 267	*n* = 267
'Positive'	-	SDQ CP GLC: *b* = -0.026, *SE* = 0.008, *p* = .003 GLU: *b* = -0.160, *SE* = 0.068, *p* = .025 N/SN UG: *b* = -0.305, *SE* = 0.121, *p* = .016 SDQ ES GLC: *b* = -0.027, *SE* = 0.009, *p* = .006 SDQ HA P/G: *b* = -0.378, *SE* = 0.155, *p* = .020 SDQ PP GLC: *b* = -0.024, *SE* = 0.011, *p* = .033 P/G: *b* = -0.298, *SE* = 0.062, $p < .001$ SDQ TD GLC: *b* = -0.106, *SE* = 0.035, *p* = .004
'Negative'	-	-
Wave 5	*n* = 191	*n* = 185
'Positive'	SDQ HA N/SN UG: *b* = -0.406, *SE* = 0.166, *p* = .023	-
'Negative'	-	SDQ PP N/SN UG: *b* = 0.222, *SE* = 0.101, *p* = .040
Wave 7	*n* = 255	*n* = 229
'Positive'	-	SDQ HA OSF: *b* = -0.517, *SE* = 0.198, *p* = .012
'Negative'	SDQ ES GLC: *b* = 0.042, *SE* = 0.017, *p* = .013 GLU: *b* = 0.639, *SE* = 0.152, $p < .001$ N/SN UG: *b* = 0.524, *SE* = 0.212, *p* = .016 SDQ HA GLC: *b* = 0.069, *SE* = 0.016, $p < .001$ SDQ PP GLU: *b* = 0.481, *SE* = 0.187, *p* = .012 SDQ TD GLC: *b* = 0.166, *SE* = 0.038, $p < .001$ GLU: *b* = 1.772, *SE* = 0.423, $p < .001$ N/SN UG: *b* = 1.359, *SE* = 0.464, *p* = .005	-

Note. CP = conduct problems; ES = emotional symptoms; HA = hyperactivity/inattention; PP = peer problems; TD = total difficulties; GLC = green land cover; GLU = green land use; P/G = parks/gardens; N/SN UG = natural/semi-natural urban greenspaces; OSF = outdoor sports facilities. 'Positive' and 'Negative' do not refer to the sign of a given association; 'Positive' refers to 'a positive association of greenspace with mental health', and 'Negative' refers to 'a negative association of greenspace with mental health'.

Appendix 2

Appendix 2 contains supplementary materials for Chapter 7.

<u>Part A: The Role of Perceived Neighbourhood Quality</u>

Tables A7.1.1 to A7.1.5 show regression results for models testing the moderating role of perceived neighbourhood quality in the associations of parks & gardens, natural & semi-natural urban greenspaces, and outdoor sports facilities with adolescent mental health and well-being. For reasons of parsimony, tables include models with significant interaction terms only. All results are taken from fully adjusted models.

<u>Part B: The Role of Access to Green Spaces with ‘High Ecological Quality’</u>

Tables A7.2.1 to A7.2.6 show regression results for models adjusted for perceived neighbourhood quality. Tables A7.3.1 to A7.3.5 show regression results for children (5- and 8-year-olds). All results are taken from fully adjusted models.

Table A7.1.1

Regression results for conduct problems (including interaction terms)

	b	*SE*	95% *CI*	*p*
14 years (*n* = 227)				
Parks/gardens	-0.097	0.199	[-0.499, 0.304]	0.627
Natural/semi-natural spaces	0.028	0.131	[-0.236, 0.293]	0.829
Outdoor sports facilities	-0.056	0.190	[-0.440, 0.328]	0.769
Perceived neighbourhood quality	-0.037	0.118	[-0.275, 0.201]	0.754
Quality * Parks/gardens	-0.177	0.096	[-0.371, 0.017]	0.072
Quality * Natural/semi-natural spaces	-0.133	0.126	[-0.387, 0.121]	0.297
Quality * Outdoor sports facilities	0.301	0.076	[0.148, 0.454]	0.000
13 years (*n* = 227)				
Parks/gardens	-0.193	0.116	[-0.427, 0.041]	0.103
Natural/semi-natural spaces	-0.203	0.153	[-0.513, 0.108]	0.194
Outdoor sports facilities	-0.455	0.148	[-0.755, -0.154]	0.004
Perceived neighbourhood quality	-0.206	0.188	[-0.587, 0.175]	0.280
Quality * Parks/gardens	-0.007	0.093	[-0.195, 0.182]	0.942
Quality * Natural/semi-natural spaces	0.374	0.110	[0.152, 0.596]	0.002
Quality * Outdoor sports facilities	-0.062	0.110	[-0.285, 0.161]	0.578

Note. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets. Values of 0.000 represent values > 0 AND < 0.001. Green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$].

Table A7.1.2

Regression results for emotional symptoms (including interaction terms)

	b	*SE*	95% *CI*	*p*
13 years (*n* = 227)				
Parks/gardens	-0.471	0.125	[-0.724, -0.219]	0.001
Natural/semi-natural spaces	-0.033	0.119	[-0.275, 0.209]	0.784
Outdoor sports facilities	-0.019	0.180	[-0.384, 0.346]	0.917
Perceived neighbourhood quality	-0.217	0.164	[-0.550, 0.115]	0.194
Quality * Parks/gardens	-0.142	0.064	[-0.272, -0.013]	0.032
Quality * Natural/semi-natural spaces	0.029	0.183	[-0.342, 0.400]	0.874
Quality * Outdoor sports facilities	-0.008	0.173	[-0.357, 0.341]	0.963

Note. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets. Green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$].

Table A7.1.3

Regression results for peer relationship problems (including interaction terms)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 215)				
Parks/gardens	0.165	0.104	[-0.047, 0.376]	0.123
Natural/semi-natural spaces	0.182	0.087	[0.006, 0.357]	0.043
Outdoor sports facilities	-0.097	0.116	[-0.332, 0.138]	0.408
Perceived neighbourhood quality	-0.418	0.140	[-0.702, -0.135]	0.005
Quality * Parks/gardens	0.243	0.084	[0.074, 0.413]	0.006
Quality * Natural/semi-natural spaces	-0.013	0.075	[-0.164, 0.138]	0.863
Quality * Outdoor sports facilities	0.013	0.088	[-0.164, 0.191]	0.880
13 years (*n* = 227)				
Parks/gardens	-0.165	0.087	[-0.342, 0.011]	0.066
Natural/semi-natural spaces	0.009	0.120	[-0.234, 0.253]	0.938
Outdoor sports facilities	0.112	0.099	[-0.090, 0.313]	0.268
Perceived neighbourhood quality	-0.612	0.151	[-0.918, -0.307]	0.000
Quality * Parks/gardens	0.169	0.064	[0.039, 0.299]	0.012
Quality * Natural/semi-natural spaces	0.121	0.119	[-0.119, 0.362]	0.314
Quality * Outdoor sports facilities	0.106	0.112	[-0.120, 0.332]	0.348
12 years (*n* = 266)				
Parks/gardens	0.057	0.065	[-0.073, 0.188]	0.385
Natural/semi-natural spaces	0.230	0.106	[0.018, 0.442]	0.034
Outdoor sports facilities	0.121	0.125	[-0.130, 0.372]	0.338
Perceived neighbourhood quality	-0.043	0.173	[-0.390, 0.304]	0.806
Quality * Parks/gardens	-0.097	0.082	[-0.261, 0.068]	0.246
Quality * Natural/semi-natural spaces	-0.218	0.101	[-0.419, -0.016]	0.035
Quality * Outdoor sports facilities	-0.087	0.095	[-0.277, 0.103]	0.361
10 years (*n* = 221)				
Parks/gardens	0.370	0.133	[0.098, 0.643]	0.009
Natural/semi-natural spaces	0.569	0.186	[0.189, 0.949]	0.005
Outdoor sports facilities	0.265	0.224	[-0.192, 0.722]	0.245
Perceived neighbourhood quality	-0.612	0.162	[-0.942, -0.282]	0.001
Quality * Parks/gardens	0.156	0.066	[0.022, 0.290]	0.024
Quality * Natural/semi-natural spaces	-0.017	0.163	[-0.349, 0.315]	0.916
Quality * Outdoor sports facilities	0.140	0.118	[-0.102, 0.382]	0.247

Note. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets. Values of 0.000 represent values > 0 AND < 0.001. Green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$].

Table A7.1.4

Regression results for total difficulties (including interaction terms)

	b	*SE*	95% *CI*	*p*
14 years (*n* = 227)				
Parks/gardens	0.126	0.334	[-0.550, 0.802]	0.708
Natural/semi-natural spaces	0.356	0.815	[-1.291, 2.004]	0.664
Outdoor sports facilities	-0.396	0.584	[-1.576, 0.784]	0.502
Perceived neighbourhood quality	-0.724	0.638	[-2.013, 0.565]	0.263
Quality * Parks/gardens	-0.596	0.277	[-1.156, -0.036]	0.038
Quality * Natural/semi-natural spaces	-0.114	0.393	[-0.908, 0.680]	0.772
Quality * Outdoor sports facilities	0.826	0.392	[0.033, 1.619]	0.042
13 years (*n* = 227)				
Parks/gardens	-1.444	0.261	[-1.972, -0.915]	0.000
Natural/semi-natural spaces	-0.447	0.434	[-1.326, 0.432]	0.310
Outdoor sports facilities	-0.519	0.360	[-1.249, 0.210]	0.158
Perceived neighbourhood quality	-1.244	0.441	[-2.139, -0.349]	0.008
Quality * Parks/gardens	-0.078	0.204	[-0.491, 0.335]	0.704
Quality * Natural/semi-natural spaces	0.725	0.348	[0.019, 1.430]	0.044
Quality * Outdoor sports facilities	-0.127	0.359	[-0.853, 0.600]	0.726

Note. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets. Values of 0.000 represent values > 0 AND < 0.001. Green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$].

Table A7.1.5

Regression results for happiness (including interaction terms)

	b	*SE*	95% *CI*	*p*
13 years (*n* = 227)				
Parks/gardens	0.060	0.068	[-0.078, 0.198]	0.382
Natural/semi-natural spaces	0.073	0.085	[-0.100, 0.245]	0.401
Outdoor sports facilities	0.143	0.067	[0.007, 0.279]	0.040
Perceived neighbourhood quality	0.152	0.090	[-0.029, 0.333]	0.098
Quality * Parks/gardens	0.003	0.044	[-0.085, 0.092]	0.940
Quality * Natural/semi-natural spaces	-0.176	0.054	[-0.286, -0.067]	0.002
Quality * Outdoor sports facilities	0.048	0.060	[-0.074, 0.170]	0.432

Note. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets. Green land use variables are based on cube root transformed data [$\sqrt[3]{\%}$].

Table A7.2.1

Regression results for conduct problems (models adjusted for perceived neighbourhood quality)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 215)				
Lives in an AoD	0.471	0.259	[-0.053, 0.996]	0.077
14 years (*n* = 227)				
Lives in an AoD	-0.080	0.298	[-0.683, 0.523]	0.791
13 years (*n* = 227)				
Lives in an AoD	-0.080	0.244	[-0.573, 0.414]	0.745
12 years (*n* = 266)				
Lives in an AoD	0.111	0.291	[-0.473, 0.694]	0.706
11 years (*n* = 203)				
Lives in an AoD	-0.313	0.550	[-1.430, 0.803]	0.573
10 years (*n* = 221)				
Lives in an AoD	-0.251	0.372	[-1.010, 0.508]	0.505

Note. AoD = Area of Deficiency. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets.

Table A7.2.2

Regression results for emotional symptoms (models adjusted for perceived neighbourhood quality)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 215)				
Lives in an AoD	-0.468	0.289	[-1.053, 0.117]	0.114
14 years (*n* = 227)				
Lives in an AoD	-0.296	0.467	[-1.241, 0.649]	0.530
13 years (*n* = 227)				
Lives in an AoD	-0.369	0.254	[-0.885, 0.146]	0.155
12 years (*n* = 266)				
Lives in an AoD	-0.285	0.246	[-0.778, 0.208]	0.252
11 years (*n* = 203)				
Lives in an AoD	-0.010	0.540	[-1.105, 1.085]	0.986
10 years (*n* = 221)				
Lives in an AoD	-0.847	0.387	[-1.637, -0.058]	0.036

Note. AoD = Area of Deficiency. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets.

Table A7.2.3

Regression results for hyperactivity and inattention (models adjusted for perceived neighbourhood quality)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 215)				
Lives in an AoD	-0.034	0.381	[-0.806, 0.739]	0.930
14 years (*n* = 227)				
Lives in an AoD	-0.835	0.437	[-1.718, 0.048]	0.063
13 years (*n* = 227)				
Lives in an AoD	-0.394	0.301	[-1.003, 0.215]	0.198
12 years (*n* = 266)				
Lives in an AoD	-0.053	0.261	[-0.575, 0.469]	0.839
11 years (*n* = 203)				
Lives in an AoD	-0.029	0.930	[-1.915, 1.858]	0.976
10 years (*n* = 221)				
Lives in an AoD	-0.323	0.345	[-1.027, 0.381]	0.356

Note. AoD = Area of Deficiency. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets.

Table A7.2.4

Regression results for peer relationship problems (models adjusted for perceived neighbourhood quality)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 215)				
Lives in an AoD	-0.141	0.211	[-0.568, 0.287]	0.509
14 years (*n* = 227)				
Lives in an AoD	0.499	0.339	[-0.187, 1.185]	0.149
13 years (*n* = 227)				
Lives in an AoD	0.053	0.218	[-0.388, 0.494]	0.809
12 years (*n* = 266)				
Lives in an AoD	-0.189	0.256	[-0.701, 0.324]	0.464
11 years (*n* = 203)				
Lives in an AoD	-0.207	0.318	[-0.853, 0.439]	0.520
10 years (*n* = 221)				
Lives in an AoD	-0.506	0.213	[-0.941, -0.071]	0.024

Note. AoD = Area of Deficiency. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets.

Table A7.2.5

Regression results for total difficulties (models adjusted for perceived neighbourhood quality)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 215)				
Lives in an AoD	-0.170	0.694	[-1.578, 1.237]	0.808
14 years (*n* = 227)				
Lives in an AoD	-0.711	1.084	[-2.902, 1.480]	0.516
13 years (*n* = 227)				
Lives in an AoD	-0.791	0.668	[-2.144, 0.562]	0.244
12 years (*n* = 266)				
Lives in an AoD	-0.416	0.690	[-1.799, 0.966]	0.549
11 years (*n* = 203)				
Lives in an AoD	-0.559	1.013	[-2.613, 1.495]	0.585
10 years (*n* = 221)				
Lives in an AoD	-1.927	0.993	[-3.955, 0.100]	0.062

Note. AoD = Area of Deficiency. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets.

Table A7.2.6

Regression results for happiness (models adjusted for perceived neighbourhood quality)

	b	*SE*	95% *CI*	*p*
15 years (*n* = 215)				
Lives in an AoD	0.144	0.108	[-0.075, 0.363]	0.190
14 years (*n* = 227)				
Lives in an AoD	-0.048	0.260	[-0.574, 0.479]	0.855
13 years (*n* = 227)				
Lives in an AoD	0.071	0.123	[-0.179, 0.320]	0.570
12 years (*n* = 266)				
Lives in an AoD	-0.212	0.108	[-0.428, 0.004]	0.054
11 years (*n* = 203)				
Lives in an AoD	0.188	0.217	[-0.252, 0.628]	0.392
10 years (*n* = 221)				
Lives in an AoD	0.111	0.085	[-0.062, 0.284]	0.199

Note. AoD = Area of Deficiency. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets.

Table A7.3.1

Regression results for conduct problems

	b	*SE*	95% *CI*	*p*
8 years (*n* = 451)				
Lives in an AoD	0.008	0.230	[-0.448, 0.465]	0.971
5 years (*n* = 430)				
Lives in an AoD	-0.082	0.273	[-0.624, 0.460]	0.764

Note. AoD = Area of Deficiency. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets.

Table A7.3.2

Regression results for emotional symptoms

	b	*SE*	95% *CI*	*p*
8 years (*n* = 451)				
Lives in an AoD	0.167	0.342	[-0.512, 0.846]	0.626
5 years (*n* = 430)				
Lives in an AoD	0.281	0.306	[-0.328, 0.889]	0.362

Note. AoD = Area of Deficiency. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets.

Table A7.3.3

Regression results for hyperactivity and inattention

	b	*SE*	95% *CI*	*p*
8 years (*n* = 451)				
Lives in an AoD	0.145	0.376	[-0.602, 0.892]	0.701
5 years (*n* = 430)				
Lives in an AoD	-0.063	0.453	[-0.963, 0.837]	0.890

Note. AoD = Area of Deficiency. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets.

Table A7.3.4

Regression results for peer relationship problems

	b	*SE*	95% *CI*	*p*
8 years (*n* = 451)				
Lives in an AoD	0.212	0.301	[-0.386, 0.810]	0.483
5 years (*n* = 430)				
Lives in an AoD	0.080	0.284	[-0.484, 0.644]	0.778

Note. AoD = Area of Deficiency. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets.

Table A7.3.5

Regression results for total difficulties

	b	*SE*	95% *CI*	*p*
8 years (*n* = 451)				
Lives in an AoD	0.532	0.882	[-1.221, 2.285]	0.548
5 years (*n* = 430)				
Lives in an AoD	0.216	0.941	[-1.654, 2.085]	0.819

Note. AoD = Area of Deficiency. Estimates are taken from separate models (i.e., one model for each age). Estimates are pooled estimates of 25 imputed datasets.