An exploration of the relationship between greenspaces, physical activity and health

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Abstract

A growing body of evidence investigates whether access to greenspace, such as parks and woodland, is beneficial to health and well-being. Potential health benefits include physical and social activities within the space and psychological benefits of interacting with nature. However, findings from empirical research investigating relationships between greenspace access and health outcomes are mixed and there are major gaps in current understanding about the underlying causal mechanisms.

This thesis explores the relationship between access to greenspace and health outcomes, with a particular focus on examining use of different types of greenspaces for physical activity. Firstly, a systematic literature review is undertaken to evaluate studies examining relationships between access and obesity related health outcomes and behaviours. An evidence-based theoretical framework is then presented, which documents the relationship between access and health, illustrating potential moderating and mediating factors.

Using data from the PEACH study, a sample of global positioning system (GPS) and accelerometer data collected from children, two studies are presented: Analysis of how much activity occurs within different types of urban greenspace, and a test of associations between access to greenspace and time and moderate-vigorous activity within it. A third study analyses the Active People Survey, a sample of 190,000 adults across England, to test associations between neighbourhood greenness and recreational walking and explore if such associations mediate relationships with mortality.

Results show that living nearer greenspace is associated with recording more physical activity within it (for children) and higher levels of recreational walking (for adults). This supports the potential value of greenspace as a health promoting resource. Whilst this also supports the possibility that physical activity within greenspace is a mediator in relationships between access and wider health outcomes, the results do not support this conclusion and indicate that other mediators, such as psychosocial factors, may be more important.

Declaration

The research reported in this thesis is my own original work which was carried out in collaboration with others as follows:

Chapter 1 was written by Kate Lachowycz

Chapter 2: Kate Lachowycz was the lead author. She defined the terms of the review and the quality assessment criteria and carried out the review. Andy Jones contributed to and advised on the methodology, reviewed manuscript drafts and screened a random selection of the reviewed papers (20%) to confirm they were correctly selected. The following people each evaluated a selection of the reviewed studies to make an independent assessment of their methodological quality: Emma Coombes, Flo Harrison, Andy Jones, Cam Lugton, Esther Rind and Pauline Vissers.

> A version of chapter 2 has been published as:
> *Lachowycz K, Jones AP. Greenspace and obesity: a systematic review of the evidence. Obesity Reviews 2011:12: e183–e189. doi: 10.1111/j.1467-789X.2010.00827.x.*

Chapter 3: Kate Lachowycz was the lead author. She reviewed the literature, designed the framework and wrote the manuscript. Andy Jones contributed to and advised on the design of the framework and reviewed manuscript drafts

> A version of chapter 3 is 'in press' as:
>
> *Lachowycz K, Jones AP. Towards a better understanding of the relationship between greenspace and health: Development of a theoretical framework. Landscape and Urban Planning. In press.*

Chapters 4 and 5: Kate Lachowycz was the lead author. She carried out all the methodological work described in the chapters (processing of data, mapping and linkage of data, creation of greenspace access measures and other variables, statistical analyses) with the exception of linkage of the GPS-accelerometer data, which was done by Benedict Wheeler prior to receipt of the data. Andy Jones contributed to and advised on the methodological approach and reviewed drafts of the chapter. The data used was collected as part of the PEACH study, run by Bristol University, and was shared by Ashley Cooper and Angie Page, who also both reviewed final drafts of the chapters.

A version of chapter 4 has been published as:
Lachowycz K, Jones AP, Page AS, Wheeler BW Cooper AR. What can global positioning systems tell us about the contribution of different types of urban greenspace to children's physical activity? Health & Place: 18 (3),586–594

A version of Chapter 5 has been submitted for publication as:
Lachowycz K, Jones AP Page AS, Cooper AR Does neighbourhood greenness reflect use of greenspace for children's physical activity?

Chapter 6: Kate Lachowycz was the lead author. All methodological work described in the chapter (processing of data, linkage of data, creation of greenspace access measures and other variables, statistical analyses) was carried out by Kate Lachowycz. Andy Jones advised on the methodological approach and reviewed drafts of the chapter.

A version of chapter 6 has been submitted for publication as
Lachowycz K., Jones A.P. Does physical activity explain associations between access to greenspace and lower mortality?

Chapter 7 was written by Kate Lachowycz

Contents

Chapter 1

Introduction

Physical activity and health

The health benefits of physical activity are well established, with "irrefutable" (Warburton et al., 2006) evidence that regular activity is effective in the primary and secondary prevention of several chronic diseases, including cardiovascular disease, cancer, osteoporosis and diabetes. There is also compelling evidence that being physical active is associated with reduced risk of premature mortality from all causes and from cardiovascular disease (Warburton et al., 2006). Moreover, there appears to be a dose-response relationship, in that the most physically active people are at the lowest risk and even relatively low levels of activity are associated with health benefit compared with sedentary behaviours (Katzmarzyk, 2010).

Several mechanisms can directly or indirectly explain the reduced incidence of chronic disease and premature death among people who engage in physical activity. One key mechanism is through expenditure of energy, which reduces accumulation of body fat and protects against becoming overweight or obese (Caballero, 2007). Excess body fat is a risk factor for several chronic conditions, including diabetes, cardiovascular disease, hypertension, stroke and certain cancers. Examples of other biological mechanisms through which activity protects against disease are that it reduces blood pressure, augments cardiac function and improves glucose homeostasis and insulin sensitivity (Warburton et al., 2006). Futhermore, physical activity is associated with improved psychological welling (Penedo and Dahn, 2005), such as reduced stress and depression, which helps prevent and manage other chronic conditions. In summary, the overall body of evidence shows that physical activity protects against excess weight and is also important for maintaining general physical and mental health.

Within the United Kingdom, current levels of physical activity are low. The UK Government recommends that adults engage in five or more sessions of moderate intensity activity per week which lasts for at least 30 minutes (DH, 2011). Results from the Health Survey for England (HSE) 2008 showed that only 39% of men and 29% of women achieve this minimum recommendation (Craig et al., 2006). The HSE also objectively measured activity, using accelerometers, and found that achievement is even lower than this, with only 6% of men and 4% of women active at recommended levels. The equivalent recommendation for children and young people is 60 minutes of activity every day. The HSE 2008 for children found that 32% of boys and 24% of girls met this recommendation based on self reported data and excluding time spent at school.

There are limited data available to assess long term trends in physical activity. Trend data available from the HSE actually shows a slight increase in the number of adults achieving the recommended target between 1999 and 2004 (Stamatakis et al., 2007). This is perhaps a “paradox” (Wareham, 2007) given that is well documented that levels of obesity are rising over time, with a doubling of obesity prevalence in the last 25 years in the UK (Butland et al, 2007). Given that it is overall levels of energy expenditure that are important, it may be that other domains of activity, not well captured by the “5 X 30” measure, have decreased or that longer time trends are important. For example, the technological revolution in recent decades has caused a shift to greater use of labour saving devices in the home, an increase in the hours of television viewing, declining distances walked to school and a shift to occupations which are less physically demanding (Wareham, 2007). The energy imbalance which has led to the increase in obesity is almost certainly determined by a complex multifaceted system of factors (Butland et al, 2007), including dietary choices, psychosocial drivers and food availability. More fundamentally, whilst the exact mechanisms contributing to obesity levels are not well understood, it is clear that physical activity has a key role to play in the primary prevention of weight gain and assisting weight loss (Wareham, 2007). Therefore, in the face of the “obesity epidemic” (Caballero, 2007) and its associated health consequences, physical activity has become an increasingly important issue and focus of public health action. Academic research can support this work by developing a greater understanding of the determinants of physical activity and thus supporting development of evidence-based interventions aimed at increasing levels of activity at a population level.

Social ecological models and physical activity research

The determinants of physical activity broadly fall into two groups: those relating to the individual (such as genetic and biological factors) and those pertaining to the physical and social environment in which people live and work, such as the facilities available within the neighbourhood that a person lives in and the social attitudes of the society they operate in. Since the 1980s there has been a shift to a greater focus in understanding the role of the environment as a determinant of physical activity. Certainly the dramatic rise in obesity cannot be driven by individual factors (Pearce and Witten, 2010). Although still a relatively new field of research, a growing number of studies are concerned with the concept of ‘obesogenic’ environments, defined as ‘the sum of influences that the surroundings, opportunities, or conditions of life have on promoting obesity in individuals or populations’ (Swinburn et al., 1999). These studies examine how specific features of the physical and social environments may support or inhibit physical activity (Jones et al., 2007).

Research into how features of the physical environment may affect physical activity is part of a wider ‘social ecological’ approach to understanding health. Social ecological models seek to understand physical activity behaviours as the result of a broad spectrum of factors, including potential drivers at the intrapersonal, interpersonal, organisational, community and public levels (Sallis et al., 2008). These factors are represented as interacting states, as, for example, the response of individuals to features within the environment may depend on their own attitudes and motivations and also those of their surrounding friends and family. Understanding these interactions can be used to develop effective multi-level approaches to improve health behaviours. The basic premise of social ecological models is that, along with interventions aimed at changing behaviour at an individual level, environmental change can support people to be more active and make healthy choices.

The relationship between greenspaces, physical activity and health

Within socio-ecological literature discussing the role of the physical environment as a possible determinant of physical activity and improved health, access to public greenspace is frequently cited as a potential health promoting resource. This theory is based on the principle that neighbourhood greenspace supports nearby residents to be active because it can be used for physical activities such as walking, cycling and sports. In addition to its role as a resource which supports physical activity, greenspace has wider potential influences on health. These other theoretical health benefits include the psychological benefits of viewing and interacting with nature (Nilsson et al., 2011) and its role in bringing people together within a social space (Maas et al., 2009a). Moreover, there are well established reciprocal links between physical activity and mental health (Penedo and Dahn, 2005) and evidence suggests that activity in natural areas has greater psychological benefits than the equivalent exercise indoors (Coon et al., 2011) or in non-natural areas (Mitchell, 2012). Therefore, greenspace has a multifaceted potential to influence a range of health outcomes through several theoretically plausible and interacting causal pathways.

Defining what constitutes 'greenspace' is subjective and use of the term varies widely. The Oxford English Dictionary definition is "an area of grass, trees, or other vegetation set apart for recreational or aesthetic purposes in an otherwise urban environment" (Oxford Dictionaries Online, 2012), but a broader definition encompasses any publicly accessible area with natural vegetation, such as grass, plants or trees (Kit Campbell Associates, 2001, CDC, 2009). This broader definition includes built environment features in urbanised areas, such as the traditional municipal park and children's play areas, and also less managed or more natural areas, including woodland, nature reserves and green corridors like paths and disused railway lines. One important feature of greenspaces is that they are multifunctional and include not only areas to which the public has physical access but also visual access, for example views of parks from buildings.

Research into the relationship between greenspace and health is a relatively new discipline but the idea that greenspace is good for human health is far from a new concept. The use of greenspace for wellbeing can be dated as far back as ancient Egypt, when spending time in the Villa gardens was thought to help relieve stress (Walker and Duffield, 1983). It was not until the rapid urbanization of the nineteenth century that development in Britain reached such a high density that open space was almost excluded in urban areas, thus prompting the active promotion and creation of public parks during the Victorian era. One of the earliest documented advocates of the health value of greenspace was Richard Slanley, MP for

Shresbury, who, citing evidence to Parliament in 1831 of differences in death rates between counties, called for action to "...secure open space in the immediate vicinity of towns" and enable the working classes to take fresh air and exercise (cited in (Walker and Duffield, 1983)).

In recent decades, more academic theories of the relationship between greenspace access and health have emerged. Of particular note is the theoretical potential role of greenspace environments as a reliever of stress. This came to prominence in the 1980s through the work of Ulrich (Stress reduction theory (Ulrich, 1981)) and Kaplan (Attention Restoration Theory (Kaplan and Talbot, 1983)). More recently, greenspace availability has been framed within the context of social ecological models. From a policy perspective, there is a common view that greenspace is potentially beneficial to health and, theoretically at least, a key component of healthy urban planning. This is evidenced by numerous recent reviews and policy papers, including several commissioned by Governments, which make the case for the health importance of greenspace (for example Croucher et al., 2008; Davies and Deaville, 2008; (Health Council of the Netherlands and Dutch Advisory Council for Research on Spatial Planning, Nature and the Environment, 2004, Croucher et al., 2008). Within England, the new public health outcomes framework includes a measure of use of greenspace for exercise or health reasons as a local performance indicator, stating "There is strong evidence to suggest that green spaces have a beneficial impact on physical and mental wellbeing and cognitive function through both physical access and usage." (DH, 2011)

Despite this prevailing narrative that greenspaces are positive for human health, the emerging picture from empirical research is proving much less clear-cut, particularly with regard to how they support physical activity. Within a relatively new field of studies examining relationships between greenspace access and physical activity, a growing body of work has documented positive associations in the expected direction. However, other studies have found no clear relationship (for example (Maas et al., 2008)) or even counter-intuitive negative effects (for example (Duncan and Mummery, 2005)). Moreover, research is far from conclusive as to the mechanisms and processes underlying observed associations. Whilst there is some evidence that people living in greener environments have better health, for example reduced premature mortality (Mitchell and Popham, 2008a) and fewer chronic conditions (Maas et al., 2009b), little is known about why this is so and whether the use of the space for physical activity may partly explain these associations.

In a review paper discussing the links between greenspace and obesity (Townshend, 2012), Townshend concludes that researchers are "quite some way off understanding the exact causal pathways between greenness, green space, physical activity and obesity. Far more research in this field needs to be undertaken." (page 20). Some of the specific topics which the author identifies as needing more focus include the use of better measures of greenspace access, an improved understanding of how different types of greenspace support activity, and further exploration into the causal pathways that are operating. One of the major methodological limitations of existing research into relationships between greenspace access and physical activity is a lack of data about where physical activity occurs. Troped et al suggest that this lack of specificity with regard to measuring the location of activity could lead to a dilution of observed associations and consequent underestimation of the strength of the real associations between features of the environment and physical activity (Troped et al., 2010). A relatively new methodological approach to overcome this limitation is the use of accelerometers and global positioning systems (GPS) which can simultaneously measure the location and intensity of activity and thus provide an objective measure of physical activity occurring within greenspace (Krenn et al., 2011).

Aims and objectives

The thesis seeks to provide new evidence about the relationship between greenspaces, physical activity and health, aiming to address some of the key gaps in knowledge. This aim is achieved through the use of the following approaches: 1) A systematic review of the existing literature and development of a theoretical social-ecological model documenting the relationship between greenspace and health, 2) Analysis of a sample of GPS-accelerometer data to measure the green locations in which children's activity occurs and test how greenspace accessibility is related to its use and physical activity within it, and 3) Analysis of a sample of adults across England to test if living in greener neighbourhoods is related to levels of walking and explore the extent to which this relationship mediates associations with reduced premature mortality.

The overall theme of the thesis is to explore potential causal mechanisms underlying the relationship between access to greenspace, physical activity and health outcomes. The thesis has a particular focus on examining the use of different types of greenspace for physical activity and, in consequence, health outcomes known to be related to physical activity, such as reduced obesity and reduced mortality.

Five specific objectives are pursued:

1. **To summarise the current evidence base by carrying out a systematic literature review of peer-reviewed studies investigating relationships between objectively access to greenspace and obesity related health outcomes and behaviours, including an assessment of methodological quality (Chapter 2).**

   As described in the Introduction, there have been several policy-focussed summaries of the potential health benefits of greenspace. However, none have used a systematic search strategy which includes identifying studies not finding positive effects, or have focussed on peer-reviewed studies and assessed their methodological quality. Chapter two therefore aims to provide an objective evaluation of evidence to date.

2. **To develop an evidence-based theoretical framework, based on social ecological models, which documents the relationship between access to greenspace and health, illustrating potential moderating and mediating factors (Chapter 3).**

   This chapter addresses the need, widely acknowledged in the literature, for greater theoretical understanding in the potential mechanisms in the relationship between greenspace and health outcomes.

3. **To assess how different types of urban greenspace are used for physical activity for children and to quantify the contribution this activity makes this to total activity (Chapter 4).**

Although it is widely hypothesised that greenspaces are important venues for physical activity and their availability supports people to be active, their actual use for physical activity has not been objectively tested. Futhermore, very little is known about how different types of greenspace are used. Chapter four uses a sample of GPS-accelerometer data collected from children in conjunction with mapping data of different types of greenspace, to address this limitation.

4. **To test associations between neighbourhood based measures of children's access to different types of greenspace and the outcomes of overall moderate-vigorous activity (MVPA), time spent within greenspace and the amount of MVPA within them (Chapter 5).**

   One of the major limitations of most studies examining associations between access to greenspace and physical activity is that they have not been able to measure whether the activity occurs within greenspace. This chapter addresses this limitation through analysis of a GPS-accelerometer data to objectively measure time and moderate-vigorous activity within different types of greenspace in relation to measures of access.

5. **To test associations between access to greenspace and recreational walking hypothesised to be undertaken within it among adults and to explore the extent to which such associations mediate relationships with reduced premature mortality from circulatory disease (Chapter 6).**

   The analysis in this chapter contributes to the body of work exploring relationships between greenspace and physical activity through testing for associations between greenspace access and walking in a large national sample of adults. It also explores one of the key unanswered questions in the field which is whether physical activity acts a mediator in the documented associations between greenness and reduced mortality.

Secondary data sources

The analyses in this thesis use data from two main sources. The analysis of children in chapters four and five uses data from PEACH study. The adult data analysed in chapter six is from the Active People Survey.

Personal and Environmental Associations with Children's Health (PEACH)

The '**P**ersonal and **E**nvironmental **A**ssociations with **C**hildren's **H**ealth' (PEACH) project is a longitudinal study designed to investigate the environmental and personal determinants of physical activity, eating behaviours and obesity in young people as they transition from year six, the final year of primary school (aged 10 to 11 years) to year seven, the first year of secondary school (11 to 12 years). During September 2006 and July 2008, 1307 children in year six were recruited from 23 of the 72 state funded primary schools within Bristol. The 23 schools were selected because they had a high transition rate to eight state funded secondary schools chosen as representative of Bristol on the basis of deprivation and geographic location.

Data were collected from children when they were in year six and then followed up a year later when they had started secondary school. This thesis uses data obtained from this second phase, collected between November 2007 and July 2009. The data collected included: height, weight and waist measurements, a computerised questionnaire including items on physical activity, local area, personal growth and development and health behaviours. An activity monitor (accelerometer) was worn for one week and a global positioning system (GPS) monitor for four days. The pupils were also asked to complete an activity diary for three days.

The study was carried out by the University of Bristol and was led by Ashley Cooper. Further methodological detail is published elsewhere (Page et al., 2009). Data collection was carried out in accordance with the Declaration of Helsinki and ethical approval was provided by University of Bristol Ethics Committee (Ref: 009/006).

Active People Survey (APS)

The Active People Survey (APS) is an annual telephone survey of adults (aged 16 and over) across England conducted by Ipsos Mori on behalf of SportEngland. The primary purpose of the survey is to measure participation in sport and active recreation, including walking and cycling in addition to more formal sports. The survey was designed to allow detailed analysis in how participation varies from place to place and between different groups in the population. The survey records the frequency, duration and intensity of physical activity undertaken within the last four weeks, as well as a broad range of demographic information. The survey began in October 2005, and is repeated annually. This thesis uses data collected for Active People 2, the second survey, which began on 15 October 2007 and was completed on 14 October 2008.

The survey data were accessed via the UK Data Archive (Sport England, Active People Survey, 2007-2008). Further technical detail is available elsewhere (Ipsos Mori, 2007).

Thesis structure

The subsequent chapters (two to six) are presented as a series of papers, each with their own Background, Methods, Results and Discussion sections. The thesis does not have a formal methods section as each chapter contains an outline of the methods used within it and a critical appraisal of the strengths and limitations of the methods applied. Each chapter begins with a short Introduction, outlining how the chapter fits within the context of the wider thesis, and ends with a summary of findings and a brief discussion of the implications for the thesis as a whole.

Chapter one describes a systematic literature review of the relationship between greenspace and obesity-related health behaviours and conditions. This chapter reviews and summarises research published between 2000 and 2010 in peer-reviewed journals, including an assessment of methodological quality and strength of the evidence found in these studies.

Chapter two draws on social-ecological theories and literature to develop a novel theoretical framework which summarises current knowledge about the hypothetical causal pathway between access to greenspace and health outcomes. The framework illustrates the main tiers of moderating factors, the mechanism of moderation and the key processes of mediation. Future implications of using and developing the framework are discussed.

Chapter three reports on the analysis of data from GPS and accelerometers used to measure activity for 902 English children aged 11 and 12 participating in the PEACH study. The results summarise activity intensities in different types of greenspace on weekday evenings, weekend days, and by season. Findings highlight the extent to which different types of urban greenspace are used by children for play and physical activity and how much this activity contributes to overall levels of activity.

Chapter four presents analysis of PEACH data to investigate the association between access to different types of greenspace and: 1) overall physical activity, 2) use of greenspace, and 3) physical activity within greenspace, including an assessment of how socio-economic factors and gender may moderate this relationship. The results aim to provide insights into whether the current reliance of neighbourhood based measures accurately reflects actual use of greenspace for physical activity amongst adolescents.

Chapter five analyses the national Active People survey from 2007/08 to investigate the association between access to greenspace in the living environment and levels of walking amongst adults. A second phase of analysis explores the relationship between greenspace access and mortality outcomes, seeking to test the extent to which physical activity may in part mediate this relationship.

A concluding discussion, chapter seven, reflects on how the findings across the preceding five chapters advance our understanding of the relationship between access to greenspace, physical activity and health outcomes for both children and adults. Implications for policy and future research are also discussed.

Chapter 2

Greenspace and obesity – What do and don't we know? A systematic review of the evidence

Introduction

This chapter uses a systematic review of the literature to provide an objective evaluation about what is currently known about the relationship between access to greenspace and obesity related health outcomes and behaviours. The review serves to identify current gaps in knowledge and consider the methodological limitations of existing research. The insight gained is then used for inform the subsequent theoretical and empirical analysis within the remainder of the thesis.

Background

The rise in obesity is well documented (Caballero, 2007) and research has recently expanded from a focus on individual determinants of obesity to investigating upstream influences, including how the environment in which people live influences their lifestyle and weight gain. Such socio-ecological approaches consider how individuals interact with their environments. One potentially important factor in a person's living environment is their access to greenspace, as greenspace is theoretically a valuable resource for physical activity (Bedimo-Rung et al., 2005) and hence could contribute to reducing obesity and improving health.

Recent socio-ecological model based reviews identified greenspace as one of a range of potential environmental determinants of obesity (Feng et al., 2010, Papas et al., 2007, Sallis and Glanz, 2006, Kirk et al., 2010, Raine et al., 2008) and physical activity (Duncan et al., 2005, Wendel-Vos et al., 2007, Owen et al., 2004, Humpel et al., 2002, Davison and Lawson, 2006, Dunton et al., 2009). They say little specifically about greenspace but conclude that environmental factors have potential to influence bodyweight, although findings are mixed and associations complex, particularly given inconsistencies in methodological approaches. One systematic review evaluated empirical evidence regarding the association between parks and recreation settings and physical activity (Kaczynski and Henderson, 2007). However, whilst there has been a recent proliferation of research in this field and reviews commissioned by Government departments and charitable organisations in the UK (Croucher et al., 2008, Morris, 2003) and elsewhere (Health Council of the Netherlands and Dutch Advisory Council for Research on Spatial Planning, Nature and the Environment 2004, Maller et al., 2008), no systematic review has been published in a peer-reviewed journal which specifically evaluates the evidence for a relationship between greenspace and obesity. This chapter addresses this by carrying out a systematic literature review of available studies which investigate the relationship between access to greenspace, obesity, and obesity-related health outcomes and behaviours.

Methods

The review focuses on groups of health markers in relation to greenspace access in the home environment: 1) Indicators of physical activity 2) Weight status and 3) Health conditions known to be related to elevated weight status. Home environment is defined as the geographic area surrounding the place of residence.

Literature search

A literature search using four electronic databases (SCOPUS, Medline, Embase, PYSCHINFO) was conducted in February 2010. It was limited to peer-reviewed journal articles published between 2000 and the end of 2009, representing a phase of research characterized by a focus on environmental determinants of health (Sallis et al., 2005) and development of objective measures of living environments (Brownson et al., 2009).

Greenspace search terms were based on definitions used in health research and planning (Swanwick et al., 2003, Kit Campbell Associates, 2001, Harrison et al., 1995, Office of the Deputy Prime Minister, 2002). Key relevant environmental terms such as ‘walkability’ were also included to identify papers where greenspace was analysed but not reported in abstract findings. Obesity-related health terms included physical activity terms (e.g. exercise), weight status (e.g. BMI) and related health outcomes (e.g. diabetes) using a list of conditions known to be related to obesity (Kopelman, 2007). The terms were searched for in the title, abstract and key words of the articles, including plurals and alternative spellings, with formatting adapted to suit each database. Additionally, citation searching of all bibliographies of included papers and relevant review papers was conducted. The search was limited to English language articles. A full description of terms is shown in table 1.1.

Inclusion criteria

Resulting papers were screened against inclusion criteria outlined in Table 1.2. The primary author reviewed results of the initial search and selected potentially relevant papers from paper titles. A second stage reviewed abstracts and then full papers to select papers which met the inclusion criteria. A random selection of 20% of papers was screened by an independent reviewer to confirm they were correctly selected.

Table 1.1: Search terms used in systematic review

Green space and environment search terms	**Obesity-related health terms**
Greenspace* OR green space* OR greenness/greeness OR greenery OR parkland OR wilderness OR vegetation (closely adjacent to) natural OR open land OR public land OR community land OR municipal land OR natural land OR wild land OR open space* OR public space* OR community space* OR municipal space* OR natural space* OR wild space* OR public garden* OR municipal garden* OR community garden* OR city garden* OR botanic garden* OR public park* OR municipal park* OR community park* OR city park* OR park land* OR park availability OR urban park* OR park area* OR park access* OR botanic park* OR wood* OR natural (closely adjacent to) environment* OR natural (closely adjacent to) place* OR natural (closely adjacent to) facilities OR natural (closely adjacent to) neighbourhood*/neighborhood* OR path* (closely adjacent to) walk* OR path* (closely adjacent to) cycl* OR path* (closely adjacent to) green OR trail* (closely adjacent to) walk* OR trail* (closely adjacent to) cycl* OR trail* (closely adjacent to) green OR trail* (closely adjacent to) recreation* OR belt (closely adjacent to) green OR wild area* OR green area* OR natural area* OR neighbourhood environment* OR neighborhood/neighborhood environment* OR living environment* OR residential environment* OR environmental feature* OR physical environment* OR physical activity resource* OR physical activity destination* OR recreation opportunities OR recreation destination* OR recreation facilities OR recreation resource* OR natural amenties OR physical activity amenities OR physical characteristic* OR urban design OR built environment* OR community design* OR physical character* OR walkability	Physical activity search terms exercise OR physical OR fitness OR *activ* OR walk* OR sedentary Weight status search terms obesity OR bmi OR adiposity OR body fat" OR body mass index OR waist to hip OR body fat OR skinfold OR waist circumference OR body composition OR healthy weight OR overweight OR over-weight OR over weight Obesity-related health outcomes Metabolic syndrome OR insulin resistan* OR (diabet* AND Type 2) OR dyslipidaemia OR “hypertens OR coronary OR CHD OR cardio* OR cardiac OR stroke OR heart disease* OR transient ischaemic attack* OR cancer* OR respiratory OR liver disease* OR hepatic disease* OR liver cirrhosis OR gallbladder disease* OR gall bladder disease* OR*arthriti* OR joint disease* OR bone health OR impoten* OR infertile* OR fertility OR health status OR health state* OR health outcome* OR health behaviour* OR health behavior* OR disease* OR mortality OR death* OR life expectancy

Table 1.2: Inclusion criteria used to select studies

1	The paper used empirical data to report analysis of obesity-related lifestyle and health outcomes in relation to access to greenspace.
2	The greenspace access measure was generated using objective methods, either by use of a Geographic Information System (GIS) or an assessment by trained auditors using a consistent tool.
3	Greenspace access was assigned based on location of residence e.g. 1) Distance to nearest greenspace or count of greenspaces within a certain distance 2) Amount of greenspace in the area. Experimental studies which looked at interactions with nature or simulated views of nature were not included.
4	Greenspace access was included as a separate variable within the analysis and results were reported specifically for greenspace, even if this was not the primary aim of the study. This excluded studies which only included greenspace as a potential confounder or as one variable in a composite environmental score.
5	One or more of the outcomes measure used in the study was an indicator of physical activity, weight status or health outcomes shown to be related to obesity. The outcome measure could be either self reported or objectively measured.
6	There was adequate consideration of and adjustment for confounding factors, defined as including (where appropriate) adjustment for age, sex and a marker of socio-economic status at a minimum

Methodological quality assessment

All included studies were assessed for methodological quality by the primary author and an independent reviewer using a ten-item scale (Table 1.3). Levels of agreement between reviewers were analysed using Cohen's Kappa for multiple raters, with agreement assessed on a dichotomous scale ('Positive'(1) versus 'negative'(0) and 'insufficiently described'(N)). In the case of disagreement, consensus was reached by discussion. There was no a-priori reason for weighting the scores, so studies scored one point for each item and points were summed between 0-10. Studies were classified as high quality if they obtained a score of six or more.

Strength of the evidence

A formal meta-analysis approach was judged inappropriate due to heterogeneity of the greenspace access measures and outcomes. Studies were thus summarised according to greenspace and health measures, confounding factors, findings, and effect sizes (See Table S2), with the terms ‘association’ and ‘relationship’ used to describe a statistical, rather than necessarily causal, relationship. Each study was assigned by the primary author and an independent reviewer to one of four levels describing the relationship between greenspace and health: 1) Positive 2) Equivocal (weak/mixed) 3) No relationship 4)Negative, with ‘positive’ defined as health promoting (e.g. increased walking) and ‘negative’ defined as health demoting (e.g. increased BMI). When summarising findings, papers reporting results from the same study were covered individually.

Results

The database search produced 2,473 hits in SCOPUS and 601 in the Ovid databases. Screening by the primary author identified 219 papers in SCOPUS and 118 in Ovid databases of potential relevance (including duplicates across databases). Review of these papers against inclusion criteria produced a final list of 60 papers. A summary, ordered by location, is available (appendix A).

Papers failed the inclusion criteria for the following reasons: Not statistical analysis of obesity-related health markers in relation to greenspace (132 papers), greenspace not objectively measured or not based on residential location (63), results not specifically presented for greenspace (74), health marker not related to obesity (6) or insufficient adjustment for confounders (2).

Table 1.4 gives a count of papers according to strength of evidence and grouped by health outcome and study age-group.

Table 1.3: Criteria for assessment of methodological quality and strength of the evidence

Item	Description	Scale
Methodological quality		
1. Population - Selection bias	Are the individuals selected to participate in the study likely to be representative of the target population?	1: Likely to be representative 0: Unlikely to be representative N: Insufficiently described
2. Population –Inclusion bias	Is there evidence of bias in the percentage of selected individuals who provided data for inclusion in the analysis?	1: No evidence of bias 0: Evidence of bias N: Insufficiently described
3. Outcome measure	Was the outcome objectively measured or self- reported?	1: Objectively measured outcome 0: Self reported N: Insufficiently described
4. Green space measure - derivation	Was derivation of the green space variable well described?	1: Derivation of green space measure well described 0: Derivation of green space measure not well described
5. Green space measure - type	Did the green space measure include information on type of green space?	1: Green space measure included information on type of green space 0: Green space measure did not include information on type of green space N: Insufficiently described
6. Use of green space	Use of green space was measured and included in analysis	1: Measured use of green space 0: Did not measure use of green space N: Insufficiently described
7. Statistical methodology	Was an appropriate statistical methodology used?	1: Evidence of appropriate methodology 0: No evidence of appropriate methodology N: Insufficiently described
8. Effect size	Was an effect size reported for green space variable?	1: Effect size reported for green space 0: Effect size not reported for green space N: Insufficiently described S: Green space not significant
9. Multiplicity	Was green space access the main exposure being measured or one of many variables being tested?	1: Green space variable main exposure 0: Green space variable one of many variables being tested N: Insufficiently described
10. Level of analysis	Was analysis of green space access in relation to outcome carried out at individual level or at ecological (area) level	1: Individual level 0: Ecological level N: Insufficiently described
Strength of the evidence		
Strength of association between greenspace and obesity-related health indicator	1: Positive relationship, judged as a statistically significant positive relationship (using significance threshold p<0.05) after adjustment for confounders, with 'positive' defined as health promoting (e.g. an increase in physical activity, a decrease in BMI). 2: Equivocal relationship, judged as a marginally statistically significant result or inconsistent results presented in the paper (for example, different results across sub-groups). 3: No evidence of a relationship, judged as no statistically significant relationship in results. 4: Negative relationship, judged as a statistically significant negative relationship (using significance threshold p<0.05) after adjustment for confounders, where 'negative' is defined as health demoting (e.g. a decrease in physical activity, an increase in BMI)	

Table 1.4: Count of papers by strength of the relationship between greenspace and obesity-related health indicators, by outcome measured and population age group

	Relationship between greenspace and health			
Outcome	**Positive**	**Equivocal**	**None**	**Negative**
Physical activity				
Objective	3 (3C)	2 (1C, 1A)	4 (3C, 1A)	0
Subjective	17 (3C, 10A 4O)	11 (2C, 8A, 1O)	11 (2C, 9A)	2 (2A)
Weight status				
Objective	2 (2C)	3 (2C 1A)	2 (1C 1A)	0
Subjective	1 (1A)	3 (1C, 2A)	2 (2A)	0
Obesity-related health outcomes	2 (2A)	1 (1C)	0	0

C=Child/teen (aged <16/18), A= Adult (aged >16/18 or all ages), O=Older people (aged >60/60/65)

Greenspace access measures

Studies were heterogeneous in the approaches and measures used. The most common measure was distance to nearest greenspace or count within a certain distance of home (27 studies), using either straight-line/Euclidean distances (13), network distances (14) or both (5). A further 15 studies calculated the percentage of greenspace within a certain distance or area. Two used an audit of greenness by trained assessors (De Vries et al., 2007, Ellaway et al., 2005), and one derived scores of 'recreational value' for different greenspace types (Bjork et al., 2008). Fifteen studies used multiple measures or more sophisticated approaches, including measures based on gravity models (Giles-Corti et al., 2005, Giles-Corti and Donovan, 2003, Giles-Corti and Donovan, 2002b, Hillsdon et al., 2006), quality of greenspace (Giles-Corti et al., 2005, Hillsdon et al., 2006), type of greenspace (Hillsdon et al., 2006, Jones et al., 2009a, Cohen et al., 2006), facilities available (Lackey and Kaczynski, 2009, Potwarka et al., 2008, Cohen et al., 2007) and park service areas (Potestio et al., 2009). A few studies focussed on greenspaces above a particular size (Lackey and

Kaczynski, 2009, Foster et al., 2009, Panter and Jones, 2008, Cochrane et al., 2009), whilst one removed large parks (Potestio et al., 2009).

Methodological quality assessment

There was 89.2% agreement on the 600 items scored during the quality assessment (kappa statistic 0.78, p<001; substantial agreement) and full consensus was reached after discussion. Overall, 20 papers (33.3%) were rated as high methodological quality. The items where the majority of studies were judged negatively were: potential inclusion bias (77% of papers), use of subjective outcome measure (70%), no consideration of type or quality of greenspace (73%), no measure of greenspace use (83%) and testing of multiple variables (72%).

Greenspace and physical activity

The search identified 50 studies examining the relationship between greenspace and physical activity. The majority (41) used self-reported measures, nine used accelerometers. These studies were conducted in USA (28), England (6), Australia (7), The Netherlands (4), Canada (2), New Zealand (1), Portugal (1), Sweden (1) and Europe-wide (1).

Twenty studies (40%) reported a positive association between greenspace and physical activity. They included six among children/teenagers (De Vries et al., 2007, Cohen et al., 2006, Kerr et al., 2007, Frank et al., 2007, Epstein et al., 2006, Roemmich et al., 2006, Pate et al., 2008), within which there was some evidence of moderation by gender (Kerr et al., 2007) and ethnicity (Kerr et al., 2007, Pate et al., 2008). Fourteen studies reported evidence of a relationship among adults (Ellaway et al., 2005, Bjork et al., 2008, Giles-Corti et al., 2005, Giles-Corti and Donovan, 2002b, Lackey and Kaczynski, 2009, Cohen et al., 2007, Kaczynski et al., 2009, Zahran et al., 2008, Lund, 2003, Hoehner et al., 2005), including four looking at older people living in Oregon (Nagel et al., 2008, Li et al., 2005, Li et al., 2008, Fisher et al., 2004). There were fifteen studies which found no evidence of a relationship and thirteen where results were weak or mixed. Two studies found negative relationships (Duncan and Mummery, 2005, Maas et al., 2008), and some negative findings were found in two studies for those with access to high quality large greenspaces (Hillsdon et al., 2006) and in sunnier weather (Cochrane et al., 2009).

Several studies examined how relationships might vary with the measure of greenspace access. Two Australian studies found no relationship between physical activity and parks, but found an association with distance to coastal environments (Ball et al., 2007, McCormack et al., 2008). Research in Perth found that accessibility of public open space was not associated with overall activity, but those with very good access to attractive, large spaces were more likely to achieve high levels of walking (Giles-Corti et al., 2005). Jones et al's study in Bristol measured greenspace type (formal, sports, natural etc) but reported no significant relationships with physical activity (Jones et al., 2009a). Cohen et al found that particular park amenities, for example shaded areas, were associated with higher activity (Cohen et al., 2006). Two studies (Frank et al., 2007, Kaczynski et al., 2009) used both counts of greenspaces and percentage area within various distances, and found the number of greenspaces within a certain distance was more important than size in relation to physical activity.

Six studies measured the relationship between greenspace access and utilisation. Cohen et al found living within 1 mile of a park was positively associated with park use and frequency of leisure exercise (Cohen et al., 2007). Three studies (Giles-Corti et al., 2005, Jones et al., 2009a, Hoehner et al., 2005) found that residents living closer to parks visited them more frequently and higher utilisation was associated with higher activity levels; however the direct relationship between park access and physical activity was statistically insignificant (Jones et al., 2009a, Hoehner et al., 2005) or significant only for those with access to attractive and large spaces (Giles-Corti et al., 2005). Mowen et al's analysis among older adults found that park visitation frequency mediated the relationship between proximity and daily physical activity (Mowen et al., 2007). A study in Baltimore (Ries et al., 2009) found no association between park access and use of parks for physical activity but a marginally significant association between access and total physical activity. Five studies surveyed if physical activity actually took place in the local neighbourhood or in greenspace. There was evidence of an association between access to greenspace and activity in the local neighbourhood (Lackey and Kaczynski, 2009, Li et al., 2005, Li et al., 2008, Fisher et al., 2004, Kaczynski et al., 2009) but Canadian research found mixed evidence for a relationship between access to parks and activity undertaken within them (Lackey and Kaczynski, 2009, Kaczynski et al., 2009).

Overall, the evidence for an association between access to greenspace and physical activity is mixed. The majority of studies (66%) found some evidence of a positive association, although only 40% found an association that appeared unambiguous.

Greenspace and weight status

Thirteen studies investigated the relationship with weight status, all using BMI as the marker, with seven using self/parent reported BMI and six using objective measures. Studies were from USA (10), Canada (2) and Europe-wide (1).

Three studies (23%) reported a positive (i.e. reduced BMI) relationship between greenspace and BMI. Liu et al found that increased vegetation was associated with reduced weight among young people living in high population densities (Liu et al., 2007), whilst Bell et al reported increased greenspace was associated with less weight gain over 2 years (Bell et al., 2008). Across eight European cities, people were 40% less likely to be obese in the greenest areas (Ellaway et al., 2005).

Six studies found mixed or weak evidence of a relationship between greenspace and BMI, and four found none. A study of adults living in Seattle (Tilt et al., 2007) examined both access to communal greenspace and vegetation indexes derived from remote sensing (NDVI), finding a negative relationship between access to greenspaces and BMI in low NDVI (low amounts of natural vegetation) areas, and a slight positive relationship in high NDVI areas. Several studies found slight evidence of a relationship between greenspace and BMI, which was either marginally significant (Oreskovic et al., 2009), heavily attenuated by adjustment for socio-economic status (Potestio et al., 2009), or only in some ethnic groups (Scott et al., 2009). There was also variation by greenspace type, with relationships found only for access to beaches in New Zealand (Witten et al., 2008) and park playgrounds among children in Canada (Potwarka et al., 2008).

Overall, the majority of studies found some evidence of a relationship with BMI, or report mixed results across sub-groups and according to the greenspace measure used.

Greenspace and obesity-related health outcomes

Just 3 studies examined the association between greenspace and markers of obesity-related health outcomes. Maas et al's study in The Netherlands found a lower prevalence of diseases in areas with more greenspace, including coronary heart disease and diabetes (Maas et al., 2009b). An England-wide study found an association between greenspace exposure and lower premature mortality from circulatory disease (Mitchell and Popham, 2008). A study of adolescents in Minnesota measured metabolic syndrome scores (MetS), a cluster of risk factors associated with cardiovascular disease and diabetes, finding lower scores in greener areas although this result was marginally significant (Dengel et al., 2009).

Effect size

Nineteen studies presented results as odds ratios of the binary health marker, mostly using least access to greenspace as the reference group. A European-wide study calculated that adults in the highest quintile of greenery were more than three times more likely to report they were physically active (OR 3.32, 2.46-4.50) compared with those in least green areas (Ellaway et al., 2005). Most studies had more modest estimates of effect. Some reported different effect sizes for sub-groups – for example boys aged 5-18 in Atlanta (Kerr et al., 2007) were 2.3 (1.7-3.2) times more likely to have walked recently if they had access to at least one greenspace, whereas the odds ratios for girls was 1.7 (1.2-2.4).

Discussion

This is a relatively new field of research and only 60 papers were identified by this review, of which almost half (28) were published in the last two years (2008 and 2009). Around two-thirds (33 out of 50 papers) found a positive relationship or some weak or mixed evidence of an association between greenspace and physical activity, 9 out of 13 reported a positive or equivocal relationship with BMI and 3 papers found some association with obesity-related health outcomes. However, around a third of studies found no relationship, two found a negative relationship and results were equivocal across many papers.

Given the large range of factors which affect weight status and potential time-lags between exposure and change in bodyweight, the lack of a strong association with weight outcomes found in these cross-sectional studies is unsurprising. Several studies found evidence that relationships varied by factors such as age and socio-economic status and also by the measure of greenspace used. Improvement in the theoretical understanding of the mechanisms through which greenspace may influence health would help study design and interpretation of reported findings. Advances could include identifying which factors within the social-ecological model of health are specifically important for the relationship between greenspace and obesity. In other words, when, how and for whom is access to greenspace associated with obesity? A recent review of recreation settings and physical activity (Kaczynski and Henderson, 2007) also notes the need for more specific models and calls for improved measures of greenspace. It is noteworthy that most reviewed studies used crude measures of greenspace, with no consideration of quality or other environmental features. More sophisticated approaches are needed (Brownson et al., 2009), particularly as several studies showed size and attractiveness to be associated with utilisation frequency.

All studies were cross-sectional and therefore suffer from widely acknowledged methodological limitations. Most importantly, it is not possible to determine if an observed relationship between greenspace and health is causal. There is the possibility of selection effects where more active people choose to live in greener environments (Boone-Heinonen et al., 2009). The studies also varied hugely in choice of confounding variables and therefore some positive results could be due to residual confounding. Particularly problematic may be inadequate adjustment for socio-economic factors given the well documented association between deprivation and obesity (Gidlow et al., 2006). Furthermore, greenspace was just one of many exposures being tested in several studies so statistically significant findings were more likely to arise due to multiple tests. The majority of studies (44 out of 60) relied on self reported physical activity or BMI, which is prone to recall bias. Nevertheless, this did not obviously lead to a bias in results. Few studies measured actual use of greenspace. The employment of new technologies such as global positioning systems (GPS) to record where people are active will help address this.

This review has a number of strengths and limitations. Weaknesses include that the search was restricted to English-language articles and just four databases were searched, although these were judged to best capture relevant studies. The search focussed on peer-reviewed literature but relevant studies may be reported elsewhere. However, limiting inclusion to peer-reviewed studies ensured a high quality of papers. Several papers were based on related populations and these were counted individually within the summary, which may over-estimate counts of particular findings. Strengths include the wide set of search terms used and assessment of study quality.

Conclusion

There is some evidence for an association between greenspace and obesity-related health indicators, but findings were inconsistent and mixed across the studies. Developing a more solid theoretical socio-ecological framework which considers the various correlates and interactions between different types of greenspace and health would help both formulation and interpretation of the body of research.

Chapter 2: Summary

Greenspace is theoretically a valuable resource for physical activity and hence has potential to contribute to reducing obesity and improving health. This chapter reports a systematic review of quantitative research examining the association between objectively measured access to greenspace and 1) Physical activity, 2) Weight status and 3) Health conditions related to elevated weight. Literature searches were conducted in SCOPUS, Medline, Embase and PYSCHINFO. Sixty studies met the inclusion criteria and were assessed for methodological quality and strength of the evidence. The majority (68%) of papers found a positive or weak association between greenspace and obesity-related health indicators, but findings were inconsistent and mixed across studies. Several studies found the relationship varied by factors such as age, socio-economic status and greenspace measure. Developing a theoretical framework which considers the correlates and interactions between different types of greenspace and health would help study design and interpretation of reported findings, as would improvement in quality and consistency of greenspace access measures. Key areas for future research include investigating if and how people actually use greenspace and improving understanding of the mechanisms through which greenspace can improve health, with a focus on physical activity.

Implications for thesis

The subsequent analysis in the thesis aims to address some of the key limitations in existing research identified by this systematic review. In particular, the use of GPS-accelerometer data allows measurement of how much activity occurs within different types of greenspace. One of the key conclusions arising from the review is that a greater conceptual understanding is needed of the relationship between greenspace access and obesity related health. This topic is explored further in the following chapter.

Chapter 3

Towards a better understanding of the relationship between greenspace and health: Development of a theoretical framework

Introduction

This chapter builds upon the preceding systematic review by evaluating the identified studies, along with a wider evidence base, to develop a theoretical framework which illustrates the potential causal pathways in the relationship between access to greenspace and health. Whilst the thesis as a whole has a particular focus on the causal pathway regarding the use greenspace for physical activity, this chapter explores the wider potential health benefits of greenspace. Given that greenspace has a multifaceted potential to influence health and use of it for physical activity is one of several mediating (and interacting) pathways, consideration of these other potential pathways is important when exploring associations between greenness and wider health outcomes such as reduced mortality.

Background

Social-ecological models of health seek to explain how environments in which people live and work offer constraints and opportunities for individuals to engage in health-promoting and demoting behaviours (Sallis et al., 2008). One environmental factor that has particular potential to influence health is availability of greenspace. Definitions of what constitutes greenspace are subjective and vary widely, but broadly encompass publicly accessible areas with natural vegetation, such as grass, plants or trees (Kit Campbell Associates, 2001, CDC, 2009). They include built environment features, such as urban parks, as well as less managed areas, including woodland and nature reserves.

Greenspace is important because of its multifaceted potential to influence health. It can be a resource for physical activity if used for walking, running, cycling and sports, all actions for which health benefits are well established (Manley, 2004). The wider benefits of experiencing ‘green’ environments are well documented, stemming from the seminal research by Kaplan in the 1980s which outlined the psychological benefits of experiencing nature (Kaplan and Talbot, 1983). Recent research has shown that time in natural environments is associated with reduced negative emotions and better energy levels, attention span and feelings of tranquillity compared with being in synthetic settings (Bowler et al., 2010). There are also wider non-physical potential benefits of greenspace (Lee and Maheswaran, 2010), such as promoting social cohesion by providing areas for people to participate in group activities (Maas et al., 2009a).

Given the evidence for the potential health value of greenspace, it follows that there may be health benefits to living and working in neighbourhoods which have good availability of public green areas. Indeed, access to greenery has historically been regarded as important in urban planning, evidenced by examples such as widespread creation of public parks in the UK during the Victorian era (Walker and Duffield, 1983). Recently there has been a re-emergence of the recognition of the importance of greenspaces when planning for healthy communities and a simultaneous proliferation of new studies examining associations between greenspace exposure and health, summarised in chapter two and other relevant reviews (Kaczynski and Henderson, 2007, Lee and Maheswaran, 2010).

Given the theoretical importance of greenspace it is perhaps surprising that, whilst some studies have reported evidence of positive associations between greenspace access and health, others have shown little or no relationship and some have even found negative associations. In the systematic review described in chapter two, of the 50 quantitative studies which examined relationships between greenspace access and physical activity, 20 reported positive associations (higher physical activity with increased greenspace access), 15 were weak or mixed, 2 were negative and 13 found no evidence of any association. Furthermore, several studies found associations only for certain groups, in particular areas or for particular types of greenspace, suggesting relationships are sensitive to specific populations and geographical areas. For example, within studies looking at greenspace access and BMI, Scott et al found that relationships differed by ethnic group (Scott et al., 2009), and others found that associations with BMI are only present for certain types of greenspace (Potwarka et al., 2008, Witten et al., 2008). The equivocal nature of the research evidence may in part reflect the disparate nature of study designs. This may partially result from the fact that there is no comprehensive evidence-based conceptual framework which documents key theoretical relationships and specifies likely causal mechanisms by which greenspace may influence health. Indeed, the need to generate improved theoretical models is well recognised in literature discussing socio-ecological approaches (Sallis, et al., 2008). There is also recognition of the need to identify mediators and moderators, terms which are commonly confused across the literature, particularly in topics such as this where research findings are mixed (Baron and Kenny, 1986, Bauman et al., 2002).

The lack of theoretical models means that research on links between access to greenspace and health is often based on loosely defined theoretical concepts, with little consideration of what particular casual pathways are being tested. An improved understanding of potential mediators, which sit on the causal pathway between greenspace access and health, could assist interpretation of research findings and help future studies test specific pathways of influence. In addition, identification of moderating factors which alter the strength or direction of associations could improve understanding of which groups benefit most from greenspace exposure, enabling planners to better identify when and how greenspace provision may lead to health improvement.

This chapter presents a novel conceptual framework which illustrates the theoretical relationship between access to greenspace and health. The framework documents key hypothesised causal pathways and illustrates potential moderating and mediating factors. The framework is then discussed in relation to available evidence, with a particular focus on factors which studies have identified as potential moderators. The chapter concludes with a discussion about future use and development of the framework to assist planning of research studies and target greenspace provision for population health gains.

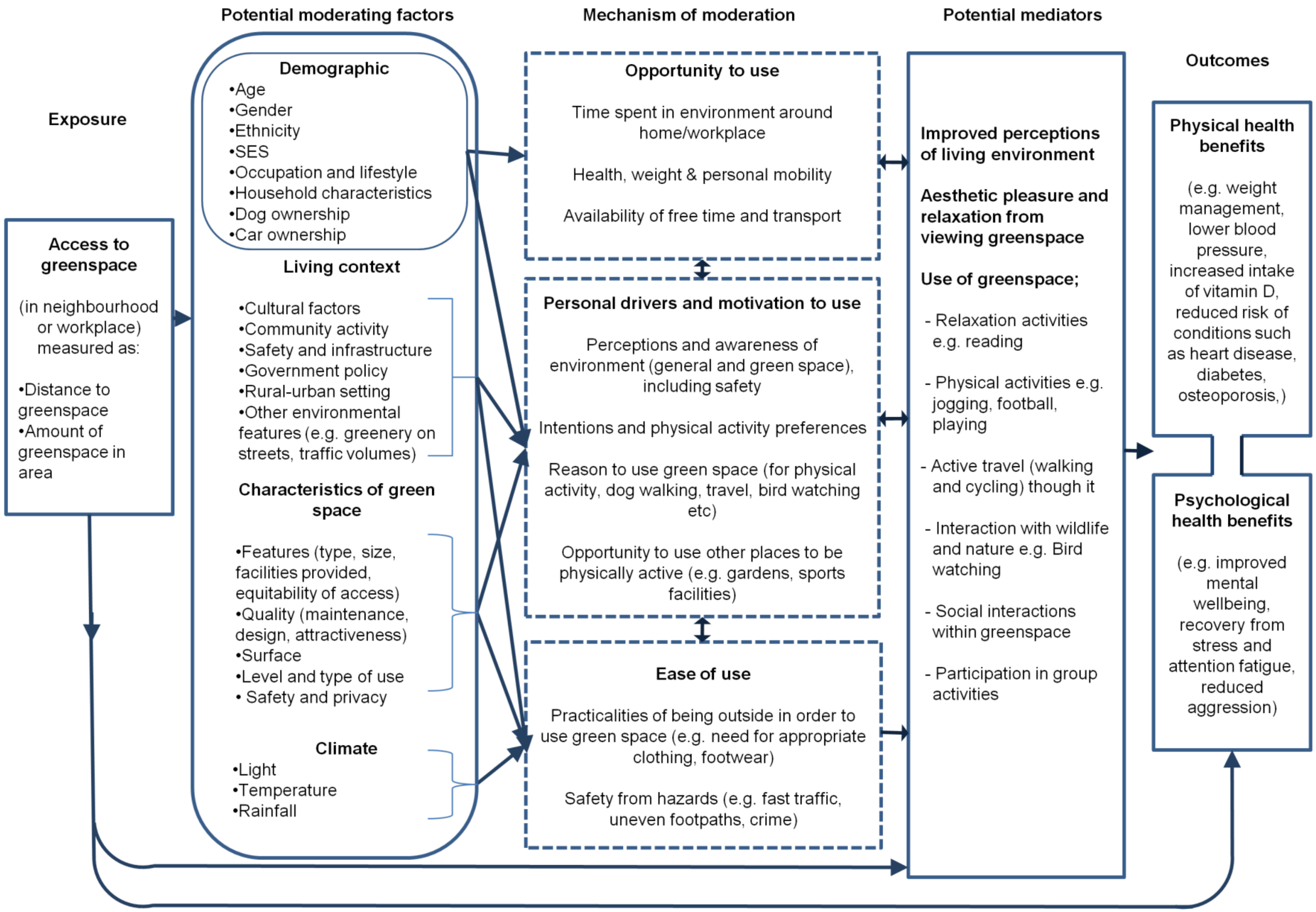
Development of a theoretical framework for greenspace and health

To develop the framework, the studies identified in the systematic review (described in chapter two) were evaluated, along with other relevant recent reviews (Kaczynski and Henderson, 2007, Lee and Maheswaran, 2010). In addition, a further search was undertaken to identify quantitative studies which looked at greenspace access in relation to indicators of health status other than those linked to obesity, including markers of general health and morbidity and measures of mental health and wellbeing. This additional search used the same literature databases as in chapter one (SCOPUS, Medline, Embase and PYSCHINFO) and was comprehensive, although not systematic. In addition, studies which had been excluded from the systematic review because they did not meet all the inclusion criteria, for example because they used subjective measures of greenspace access, were also checked for relevant material. The reference lists of identified studies were also reviewed and reverse snowballing was used to identify more recent publications. Grey literature was also scanned, found though searching the internet and checking key websites (e.g Commission for Architecture and the Built Environment (CABE) and Government sites).

Key examples of existing socio-ecological models looking at environmental influences on health and health-related behaviours were consulted, including mental health and physical activity (for a summary of models see (Sallis et al., 2008). Drawing on the literature, the hypothetical causal explanations for how objectively measured greenspace access could lead to health improvement were documented, therefore identifying potential health outcomes and mediators. Studies were reviewed to identify factors for which evidence exists of them acting as a moderator, i.e. stratification by the variable has resulted in different strengths of relationship between greenspace exposure and the health outcome. In addition, some factors were included which have not yet been empirically tested, but for which there is good theoretical basis to suggest they may act as moderators.

The resultant framework, shown in Figure 2.1, illustrates the hypothetical causal pathway between access to greenspace and health outcomes. The pathway illustrates the main tiers of moderating factors, the mechanisms of moderation and the key processes of mediation. The evidence used to construct the framework is discussed below, working in reverse, as this was the order used to construct the framework. Firstly the health outcomes are discussed, then the pathways of mediation which result in these outcomes and ending with a discussion of the moderating factors and mechanisms of moderation.

Figure 2.1: Socio-ecological framework for the relationship between greenspace access and health



Health outcomes

The potential health outcomes resulting from greenspace exposure are discussed extensively across the literature. The framework categorises these outcomes into two broad groups: physical and psychological. This dichotomy is commonly used, with physical health benefits generally attributed to physical activities within greenspace, and psychological benefits gained from exposure to nature and social interactions. This dichotomy belies the interaction between physical and mental health outcomes and, therefore, the framework shows them as interacting states and does not attempt to link them to specific mediators. For instance, visiting greenspace to interact with nature, or to read a book could have benefits to physical as well as mental health, such as blood pressure reduction (Hartig et al., 2003), and vitamin D absorption from sunlight exposure (Holick, 2004). There is evidence of the mental health benefits of physical activity (Penedo and Dahn, 2005) and, moreover, evidence of additional benefit from exercise in green environments compared with urban settings (Coon et al., 2011).

Potential mediators

To understand how access to greenspace could result in a change in health outcome, it is important to consider what underlying mechanisms, or mediators, are driving this change. A core principle of social-ecological models is that features within the physical environment lead to changes in health behaviours and psychological states (Cohen et al., 2000). Applying this principle to greenspace access suggests that, for example, living near a park enables individuals to behave or feel differently. These changes in behaviour or mental state are thus the mediators which explain associations between greenspace accessibility and improved health. The fact that a potential health benefit has been demonstrated in a experimental study –for example, that walking in natural areas is associated with lower blood pressure than in more urban settings (Bodin and Hartig, 2003)– does not imply that living near greenspace is associated with lower blood pressure amongst free-living populations. Here, the act of using the greenspace for exercise acts as a mediator between the exposure and the health benefit.

Within the framework, the mediators are illustrated as three broad groups; improved perceptions of the living environment and satisfaction from "having the park there" (Bedimo-Rung et al., 2005), aesthetic satisfaction and restoration from viewing natural features, and use of the space for relaxation, physical activities, socialisation and to interact with wildlife. These routes of mediation are identified in the literature aspotential causal explanations for the health impacts of greenspace and are supported by some evidence, mostly from experimental studies or surveys. However, research thus far has failed to find strong evidence for the role of a behaviour change mechanism – such as using greenspace - in relation to access. That close proximity of greenspace is associated with increased use seems ‘common sense’, but actual evidence remains elusive (Giles-Corti and Donovan, 2002a) and the systematic review in chapter two found that results from quantitative studies which have investigated how access affects use are ambiguous. For example, a study of Danish adults found no evidence that use of greenspace explains associations with BMI or levels of stress (Nielsen and Hansen, 2007).

Research from The Netherlands attempted to disentangle pathways of mediation and found the strongest evidence that social interactions in greenspace drive associations between access and health (Maas et al., 2009a). These researchers also found weak evidence for greenspace acting as a buffer from stressful life events (van den Berg et al., 2010) but no support for physical activity acting as an underlying mechanism (Maas et al., 2008). Overall, little has been established about how potential mediators operate in practice and for different health outcomes. Whilst an England-wide study found that inequalities in deaths from circulatory disease were reduced in greener areas (Mitchell and Popham, 2008), it is impossible to establish whether this could be due to amelioration of stress or increased physical activity, or indeed a combination of both, or due to another explanation entirely.

Potential moderators

A central principle of social ecological models is that environmental influences on individuals vary by intra-individual and intra-environmental factors (Sallis et al., 2008). For example, individuals with high motivation to be active may react differently to provision of sports facilities within their neighbourhood than those with lower motivation. Therefore, the framework aims to identify which particular factors may interact with, and hence moderate, the relationship between greenspace access (the exposure) and change in health state (the outcome). The role of moderators has been discussed in relation to physical activity (Bauman et al., 2002, Michael and Carlson, 2009) and within social psychological research (Baron and Kenny, 1986). Insight into potential moderators can also be drawn from research into leisure behaviours (Godbey, 2009) and factors which determine use of parks (Bedimo-Rung et al., 2005). Crawford et al (Crawford et al., 1991) conceptualised barriers to participation in recreation and leisure activities as three key types of constraint: interpersonal (e.g. psychological factors), intrapersonal (factors related to others such as family and friends) and structural constraints (e.g. lack of opportunity, time and money). Drawing on all of this evidence, it is hypothesised that moderation occurs by three broad mechanisms:

1) **Opportunity to use greenspace:** Individuals have constraints which limit their ability to use greenspace independently of how good their physical access is. These constraints include time limitations and physical constraints such as health-limiting factors. Possession of commodities such as private transport may make access easier and this is related to income, although income level per se is arguably not an important factor if public greenspace is free to use.

2) **Personal motivation and reasons to use greenspace:** Greenspace is one of many potential health promoting resources which individuals can use or choose not to. Motivations to use are influenced by factors such as personal reasons (e.g. walking the dog, bird watching, or cycling through it on route to work), perceptions of the environment, the composition and lifestyle preferences of the family and community, and opportunities to access alternative health promoting resources such as gyms, gardens etc. The type of greenspace and the facilities available will also affect the attraction for particular groups.

3) **Ease of use:** Environmental features may influence how practical it is to use greenspace. Extreme weather conditions or lack of light require individuals to overcome practical considerations, such as obtain appropriate clothing. Other environmental factors may influence use, such as speed of traffic or presence of greenery on routes to the park.

These mechanisms are intertwined and hence linked by two-way arrows on the framework. For example, perceptions of the environment will be influenced by how much time is spent at home and ease of use will be influenced by personal drivers and motivations e.g. it requires a personal choice (and financial ability) to purchase appropriate clothing and footwear in order to use greenspace in all weather conditions.

As socio-ecological models of health commonly divide factors influencing health into two main tiers, those relating to the individual and those pertaining to the environment (Sallis et al., 2008), the moderators are presented as a tier of individual factors and those relating to the social and physical environment. The social environment factors included in the framework are those which are specifically relevant to the use and health value of greenspace. Two groups of physical environment factors are included: greenspace characteristics, as these are key antecedents of use (Bedimo-Rung et al., 2005) and climatic factors, which are important drivers of use of the outdoors for leisure and physical activity (Tucker and Gilliland, 2007). These groups of moderators are discussed below in relation to evidence used to construct the framework.

Demographic factors

Demographic characteristics such as age, ethnicity and socio-economic status are key determinants of physical activity and health and affect participation in outdoor and recreational activity (Kemperman and Timmermans, 2008, Lee et al., 2001). Given that these factors influence the opportunity and motivation to use greenspace, they are likely to moderate relationships between access and health. One key mechanism of moderation is time spent at home, as those spending greater amounts of time in the living environment are more reliant on resources within it (de Vries et al., 2003). This could explain studies which have found that younger and older groups are more sensitive to greenspace provision than middle-aged adults (Kaczynski et al., 2009, Maas et al., 2009b) who are more likely to be at work. Other factors such as physical activity preferences, health, mobility and perceptions of the environment are strongly age-related and therefore the motivations and practicalities of using greenspace and the types of space most attractive to an individual are likely to vary by age. The majority of studies examining greenspace access and health have focussed on adults of working age (Giles-Corti and King, 2009). This is actually the group for which it may be hardest to find associations, given their complex daily activity patterns. There is a paucity of evidence into how older people’s health is affected by greenspace provision.

Gender is known to affect health related lifestyles (Bird and Rieker, 2008) and may be especially important for relationships with greenspace accessibility, as there is evidence that sex influences perceptions and use of the environment, as well as physical activity preferences (Cummins et al., 2005). Gender effects may also be age dependent. In youth, boys are known to roam more freely (Brown et al., 2008) and several studies support strongest associations between greenspace access and physical activity amongst them (Epstein et al., 2006, Gómez et al., 2004, Roemmich et al., 2006). Taylor et al found that views of nature were associated with improved self-discipline, such as the ability to concentrate, for girls only (Taylor et al., 2002). The authors suggest that boys are less affected by nature in the immediate vicinity of home as they play further away. Whilst empirical data is needed to test this hypothesis it certainly seems that gender differences can begin early in life, perhaps acting through parental attitudes and differences in play behaviours. In adults some evidence suggests that women have stronger relationships between greenspace access and physical activity (Cerin et al., 2007, Kaczynski et al., 2009), walking (Foster et al., 2004) and self-reported health (Bjork et al., 2008). Maybe this stems from the fact that women have historically spent more time around the home, especially during motherhood (Lee et al., 2001). Richardson et al found that relationships between greenspace access and reduced cardiovascular and respiratory mortality were present only for men across the UK (Richardson and Mitchell, 2010). The authors suggest that access measures which capture quality may be more important when looking at associations for women. It is noteworthy that women appear more influenced than men by safety concerns (Foster et al., 2004) and also the quality and type of available greenspaces (Bedimo-Rung et al., 2005, Cohen et al., 2007). How these factors affect their behaviours is not well understood and longitudinal studies are required to disentangle changes through the life-course in causal mechanisms associated with gender.

Ethnicity has been shown to influence perceptions of natural environments (Huston et al., 2003), preferences for recreation (Virdin, 1999) and the nature and frequency of use of greenspace (Tinsley et al., 2002). Some surveys suggest that Whites view environments more favourably than other groups (Huston et al., 2003) and several studies have found associations between greenspace exposure and improved health are stronger for White groups (Kerr et al., 2007, Scott et al., 2009, Wen et al., 2007). Given that ethnicity is strongly related to cultural and socio-economic factors, it is difficult to disentangle how these various factors interrelate (Franzini et al., 2009). Ethnic differences in environmental influences on health can be due to genuine differences in lifestyle and cultural values, or may arise because groups are, or feel, excluded from certain environments (Lee et al., 2001). Culture-specific research to elucidate the key factors and mechanisms of mediation across different groups would help planners consider how to make greenspace provision more culturally appropriate and specifically targeted to needs of local populations.

A key principle of much public greenspace provision is that it is free to use and particularly of value for groups of lower socio-economic status (SES), who may not have private gardens or have time or money to travel for physical and stress-relieving activities. Studies commonly adjust for SES as a confounder when investigating associations between greenspace and health, and indeed this is essential given that greener areas tend to be more desirable and expensive to live in. Several studies have found that positive associations between greenspace and health are actually stronger for lower income groups compared with those on higher incomes (Babey et al., 2008, Maas et al., 2006, Maas et al., 2009b). These findings are significant given evidence that lower SES groups tend to have poorer perceptions of greenspace and use it less, even when access is as good as in more affluent areas (Jones et al., 2009a, Schipperijn et al.). It is well established that wealthier groups are healthier (Smith et al., 1994) and more active (Gidlow et al., 2006) than those on lower incomes – therefore, it may be that having access to greenspace amongst higher SES groups helps maintain, rather than increase, their health. A survey following introduction of walking trials in Missouri found that lower SES groups were less likely to use the trails, but those that did showed increases in overall levels of walking, unlike wealthier trail users who used the trails to maintain their already higher levels of activity (Brownson et al., 2000). This implies that the relative health gain of increasing greenspace provision is greatest for those who need it most. Consequently, greenspace access could potentially reduce deprivation-related health inequalities, as suggested by an England-wide study which found that gradients in deprivation-related premature mortality were reduced in greener areas (Mitchell and Popham, 2008).

An individual's occupation, lifestyle and that of their family are included in the framework because it is hypothesised that these are important influences on both the opportunity and motivations for use of greenspace. People who are rarely at home, are very physically active in their job or are frequently outside and experiencing nature in their occupation may achieve little additional benefit from access to greenspace at home. Household factors such as dog ownership are also important, as owning a dog is associated with elevated physical activity (Cutt et al., 2007) and dog walkers are frequent users of greenspace. Lifestyle and household factors which studies have identified as moderating relationships between greenspace and health include being a housewife (de Vries et al., 2003), living with children (Kaczynski et al., 2009), and, for children, living in apartments (Babey et al., 2008). The lifestyle of the household is an important moderator for children, for whom the parents act as a gatekeeper to their use of the environment (Veitch et al., 2006). Davison et al (Davison and Lawson, 2006) argue that studies erroneously assume direct links between the environment and children's activity, whereas in reality this link is substantially moderated by parental attitudes to factors such as safety.

Living context

The second group of factors in the framework are those related to living context. These include socio-cultural factors, such as crime rates, government policy and social attitudes, which influence personal drivers and motivation to use greenspace and may affect ease of use. For example, the value of parks as a health promoting resource is diminished if the neighbourhood has high crime rates (perceived or real) which will discourage people from going outside. Since people need to travel through neighbourhoods to reach greenspace, factors such as busy roads or derelict housing may deter use (Bedimo-Rung et al., 2005).

Other social environment factors which are key components of social-ecological models - cultural attitudes, community activity and government policy - are likely to be important, but their effects are much harder to quantify and test. Factors that affect perceptions of the environment and use of greenspace are undoubtedly intertwined with cultural and historical attitudes to use of the outdoors, participation in physical activity and to nature and wildlife. Studies have documented differences between objective and self-reported measures of access, demonstrating how the concept of accessibility is strongly shaped by social and personal variables (Macintyre et al., 2008). In fact, the social meaning attached to greenspace and social perceptions of accessibility may be far more important drivers of health than merely having physical access. Social-ecological theories also acknowledge the existence of undefined 'place' effects on health; contextual differences in health between areas which are unexplained by measured variables (Macintyre et al., 2002). Consequently, determinants of greenspace use and mediating pathways could vary across different contexts and cultures. Therefore, applying conclusions from one study to a population elsewhere requires caution and consideration of what underlying contextual factors may be different.

One living context factor for which research findings are emerging is how the degree of urbanicity – how urban or rural an area is –moderates physical activity (Ewing et al., 2003). It may also moderate the association between greenspace and health. There is evidence that associations between greenspace access and health are stronger in more urban areas (Babey et al., 2008, Liu et al., 2007, Nielsen and Hansen, 2007, Maas et al., 2009b). If true, it could be that rural dwellers are less sensitive to provision of facilities in their local area as they are more used to travelling out of their neighbourhood to use services. An alternative explanation is the methodological problem of measuring greenspace in rural areas; whilst the countryside is, by definition, 'green' and therefore residents can easily obtain psychological benefits of viewing natural scenery, often a key driver for their choice to live there, the surrounding land is often inaccessible to the public, particularly if it is agricultural. Consequently, improved measures of publicly usable greenspace in rural areas are needed to test the degree to which urban-rural factors act as moderators and how pathways of mediation might vary across different contexts.

Characteristics of greenspace

The second group of environmental factors in the framework are characteristics of greenspace. It is proposed these influence an individual's personal motivation and practical opportunities to use greenspaces. Therefore, the effect of distance as a determinant of use and health value will be moderated by the 'attractiveness' of a greenspace for each individual (Giles-Corti and Donovan, 2002a). Research has shown that different groups value different characteristics, facilities and activities within greenspace (Cohen et al., 2010, McCormack et al., 2010). For instance, a jogger may want a large space with quiet paths whereas a family with young children might prefer smaller areas with play, toilets and parking facilities. In addition to using greenspace specifically for leisure purposes, people may choose to traverse through it on route to work or to the shops if, for example, the paths are hard surfaced and well lit. Whilst some evidence suggests that psychological benefits are greatest in areas which contain wildlife and are species rich (Fuller et al., 2007), these areas may be perceived as less safe for children (McCormack et al., 2010). Therefore, whilst there is evidence that factors such as size and attractiveness (Giles-Corti et al., 2005), greenspace type (Coombes et al., 2010) and amenities (Cohen et al., 2010) affect relationships with health, the particular health value of any type of greenspace is likely to vary according to the user group or specific health outcome being tested.

Simple measures of distance to parks cannot adequately capture these complexities and therefore it is unsurprising that many studies fail to find relationships between access and health. In particular, information about quality and type of greenspace is rarely available. Use of access scores which incorporate factors such as size and attractiveness (Giles-Corti and Donovan, 2002a) helps, as does using tools to assess park characteristics, particularly when developed for specific user groups (Floyd et al., 2009). Bedimo –Rung et al propose a conceptual model which considers how park characteristics and user requirements modify relationships between park use and health benefits (Bedimo-Rung et al., 2005). Their framework summarises key park characteristics, such as condition, safety and aesthetics, and the authors suggest future studies should test associations between physical activity levels and these characteristics. Ideally, the measure of greenspace used in studies should reflect the specific research question being investigated and with consideration of which causal pathways and mediators in the framework are being tested. This will depend on the population being studied and, importantly, the particular physical or mental health outcome being evaluated.

Climate

The final group of moderating factors within the framework are climatic factors, as these are specifically important for determining how people use resources in the environment. A study of the relationship between access and physical activity in Stoke, England, found a stronger association between increased greenspace access and increased physical activity in wetter weather (Cochrane et al., 2009). This seems counter-intuitive but the authors speculate that people travel further in dry conditions and therefore local facilities are less important. A systematic review of climate and weather effects on physical activity summarises how weather and day length act as barriers to outdoor activity, particularly among children (Tucker and Gilliland, 2007). The authors suggest that climatic factors are inadequately considered in creation and surveillance of physical activity interventions within the environment. Further research looking at seasonal and climate-related patterns in use of greenspace for physical activity would help improve understanding in this area and provide evidence to plan public areas which are weather-appropriate and maximise their health value throughout the seasons.

Discussion

In this chapter a framework is presented which illustrates the theoretical causal relationship between access to greenspace and health. The framework documents key mediators driving this relationship and proposes key moderating factors which influence the strength of association. The chapter discusses how available evidence informs the framework and highlight areas within the framework which would benefit from further research to develop understanding. The framework is novel as it is the first diagrammatic summary of current knowledge about causal pathways between greenspace exposure and health.

Research into the potential salutogenic benefits of having access to greenspace is a burgeoning field. Yet the vast majority of this research relies on cross-sectional study designs, for which limitations are well known and, in particular, are weak at testing for causality and identifying mediators. Therefore, despite good theoretical bases for how greenspace could influence health, evidence of mediators operating in practice remains elusive. The use of longitudinal study designs and 'natural experiments' where, for example, greenspace is provided in an area which previously had none and change in behaviour is measured will help us better understand behaviours associated with access to greenspace. Evidence from these studies could strengthen and modify the framework, as reliance on results from cross-sectional studies in its development is undoubtedly a limitation. Improved study designs would also help establish if there are genuine causative mechanisms at work and rule out selection effects, whether direct (people choose to live near greenspace if they are healthier or physically active) or indirect (people with certain characteristics, such as higher incomes, tend to live in greener areas) (Maas et al., 2009b). However, given the practicalities of data collection, it is likely that cross-sectional approaches will continue to dominate research in this field for some time. Therefore, the pragmatic argument is that such studies will be methodologically more robust if greater consideration is given as to what particular causal pathways are being tested and also what moderators may be important.

It is hoped that the framework could stimulate debate amongst researchers in this field. It is also hoped that it will support others to be more precise when specifying the theoretical relationships being tested and describing methods used, as currently terms are often used interchangeably when they mean different things (e.g. 'access' verses 'useage'). A practical future application is to use it when planning research in order to map out particular casual pathways to investigate, and design studies which test which mediators and moderators are operating. For example, the use of global positioning systems (GPS) to measure the location of activity (a technique used in chapters four and five) enables researchers to objectively test if use of greenspace is acting as a mediator in relationships between access and physical activity. Subject to data availability, theories can be empirically tested within the analysis, using statistical techniques to test for moderation and mediation (Baron and Kenny, 1986). However, this is a complex area, as a tenet of social-ecological models is that multiple factors inter-relate and this can make it difficult to know how to measure or test which particular factors may drive any observed relationships. As shown in this chapter, there is a wide body of literature documenting how preferences for recreation and use of greenspace vary across groups and in different contexts, yet there has been a general failure to consider how factors such as ethnicity, deprivation or age moderate relationships between greenspace and health. Many studies commonly adjust for various confounding variables – often with little justification for why they are considered to be confounders – but rarely consider how these factors may also moderate or mediate the associations being tested. Therefore, valuable information about differences in effects across sub-groups is lost. Furthermore, erroneous conclusions may be drawn which are not generalisable to other populations or environments, or studies may fail to find relationships even when they do exist.

The framework is deliberately broad and encompasses multiple greenspace types and both physical and mental health outcomes. More specific versions could be developed for particular health outcomes or types of greenspace, for example the use of playgrounds by children. One route of mediation not included in the framework is the role of greenspace as a protector from environmental stressors, such as pollution and heat (Bedimo-Rung et al., 2005). This was primarily excluded here due to a paucity of evidence, as no epidemiological studies testing for associations between access and health have looked at this as a mechanism of influence. Secondly, greenspace acting as a protector from stressors is likely to act directly on all those living nearby and thus be less affected by mediating and moderating pathways shown in the framework. As evidence emerges, this route of influence could potentially be incorporated.

The causal pathways represented in the framework are illustrated as predominantly uni-directional, whereas the reality is much more complex. For example, use of greenspace may affect perceptions of the local environment. Multiple mediator-moderator interactions may operate in practice but the figure does not attempt to illustrate specific and detailed connections between factors, as there is not yet robust evidence to inform this. The framework presents all the factors and pathways as if they are of equal importance and in the future measures of strength of effect could be incorporated as better evidence emerges. The available evidence which supports elements presented in the framework is discussed, but there is currently not enough information to generate robust measures of effect size. As more is published, meta-analysis could be used to pool findings and estimate the relative influence of the different moderating factors and quantify the impact of greenspace access on health across different routes of mediation. This could be of particular interest to policymakers, for whom indicators of strength of effect which can be clearly applied to population-level planning are the most useful. For example, understanding that certain population groups have low motivation to use greenspace may require specific interventions such as increased education, or facilitation and provision of particular programmes or facilities. This principle of multi-level interventions, where interventions in the environment are accompanied by group-specific targeting of individuals, is well recognised in social-ecological theory as being the most powerful approach to change behaviour and improve health (Sallis et al., 2008). Research has highlighted inequalities in physical access to greenspace, particularly by socio-economic group (Jones et al., 2009b, Moore et al., 2008); however, producing equitable health benefit from greenspace may not be as simple as just providing equal access to it.

Chapter 3: Summary

A growing body of evidence investigates whether access to greenspace, such as parks and woodland, is beneficial to well-being. Potential health benefits of greenspace exposure include opportunity for activities within the space and psychological benefits of viewing and interacting with nature. However, empirical research evidence on the effects of greenspace exposure shows mixed findings. Hence the key questions of "if, why and how?" greenspace influences health remain largely unanswered. In particular, an improved understanding of potential mediators and moderators is needed. This chapter draws upon social–ecological theories and a review of the literature to develop a novel theoretical framework which summarises current knowledge about hypothetical causal pathways between access to greenspace and health outcomes. The framework highlights how mediators – such as use of greenspace and perceptions of the living environment – drive associations between access and both physical and psychological health outcomes. The framework proposes key moderators, based on evidence that associations between greenspace and health differ by demographic factors such as gender, ethnicity and socio-economic status, living context, greenspace type and climate. The chapter discusses the evidence for how and why these factors act as moderators and considers the implications which arise from this improved understanding of the relationship between greenspace and health. The framework can be used to inform planning of research studies and could be developed in the future as more evidence emerges.

Implications for thesis

The framework presented in this chapter serves as the theoretical context for the subsequent empirical analysis, which aims to test some of the illustrated pathways. The potential moderating role of greenspace type is considered in chapter four, which quantifies how different types of urban greenspaces are used by children for physical activity. The use of greenspace as a mediating explanation for relationships between access and overall activity and associated health outcomes is then explored in chapters five (for children) and six (for adults).

Chapter 4

What can global positioning systems tell us about the contribution of different types of urban greenspace to children's physical activity?

Introduction

One of the limitations of the literature reviewed for the systematic review (chapter 2) and theoretical framework (chapter 3) was that the majority of studies are unable to measure where physical activity occurs. Thus it is not known how much activity occurs within greenspace. This chapter uses a large sample of GPS-accelerometer data collected from children to objectively measure how much activity occurs in different types of greenspace and how this contributes to total physical activity. This serves to quantify the extent to which different types of greenspace are supportive of physical activity and thus provide some insight into how type of greenspace may moderate relationships with physical activity and health, as illustrated in the theoretical framework.

Background

Physical activity during childhood is associated with improved health, including reduced likelihood of becoming obese (Trost et al., 2001) or developing symptoms of depression (Motl et al., 2004). Activity during childhood also contributes to development of healthy lifestyles later in life (Hallal et al., 2006) and has long term protective health effects, such as establishing healthy bone structure (Karlsson, 2004). Despite these benefits, low and declining levels of physical activity have been reported among children in developed countries (Dollman et al., 2005, Knuth and Hallal, 2009). In England, only 32% of boys and 24% of girls aged 2-15 meet the government's recommendations for physical activity of doing at least one hour of moderate activity per day (NHS Information Centre for Health and Social Care, 2009).

A growing body of evidence demonstrates the potential influence of environmental factors on children's physical activity (Davison and Lawson, 2006, Ferreira et al., 2007). One such environmental factor is greenspace, as areas such as parks, playgrounds and woodland can be used by children for play and leisure time physical activity. Public greenspaces can provide natural play spaces with multifaceted benefits to children as they, for example, provide opportunities to interact with nature, play creatively, socialise with others and develop independence and confidence in being in an outdoors environment (Muñoz, 2009). Given that children have less autonomy in their behaviour choices than older groups (Nutbeam et al., 1989) and that their use of the environment is influenced by parental attitudes (Veitch et al., 2006), the availability of suitable and safe play spaces outdoors may help parents feel more confident to allow their children to be more autonomous and play independently outdoors (Mulvihill et al., 2000). Research shows that children who spend greater amounts of time outdoors have higher levels of physical activity (Cleland et al., 2008), and that outdoor activities such as walking, playing informal ball games and unstructured free play are important contributors to overall energy expenditure (Mackett and Paskins, 2008). Furthermore, in addition to the physical activity benefits of playing in greenspace, a wide body of literature documents the psychological benefits of spending time in natural environments (Taylor and Kuo, 2006).

The systematic review in chapter two identified 14 studies which looked specifically at the relationship between access to greenspace and children's physical activity, of which 6 found a positive relationship. Therefore, the emerging evidence in this relatively new research field is equivocal. One reason for this inconsistency may be that studies are largely reliant on measuring cross-sectional associations between overall levels of physical activity and presence of greenspace within a child's living environment, and are often unable to consider the actual locations where physical activity takes place. Therefore, the locations children use for active free-play and physical activity remain largely unknown. One developing approach which can help address this gap is the use of Global Positioning Systems (GPS) to measure how children move around within environments. GPS devices pick up signals from satellites to record positions on the ground, with an accuracy of a few meters. The recent development of affordable, lightweight and accurate GPS allows these devices to collect location data from large samples of individuals and continuously track their movement through the environment. GPS can be used in combination with accelerometers (devices that detect speeds of body movement and generate intensities of physical activity) to simultaneously measure physical activity and location and thus record the environments where different intensities of physical activity take place (Rodriguez et al., 2005). A recent systematic literature review of applications of GPS to physical activity (Maddison and Mhurchu, 2009) concluded that one major advantage is the ability to collect valuable contextual information, such as the occurrence of activity within specific facilities, and thus improve our understanding about how individuals interact with their environments and use different locations for physical activity.

The first applications of these methods amongst children have recently emerged. Combined GPS-accelerometer methods can be used to objectively measure how different types of greenspace are used by children for play and physical activity. A New Zealand study of 184 children aged 5-10 years found that 1.9% of physical activity occurred in public parks with playgrounds (Quigg et al., 2010). That study did not measure activity within other types of greenspace, such as more natural areas and on playing fields. Jones et al collected GPS and accelerometer data from 100 school children in Norfolk, UK, and found that 7.3% of moderate-vigorous activity bouts occurred in areas defined as parks, 11.8% in grassland, 13.6% in farmland, 3.0% in woodland and 24.0% in gardens (Jones et al., 2009c). That study therefore suggests that different types of green areas, not just those designated as parks, may be important physical activity locations. However, Norfolk is a predominantly rural county and no studies have yet examined the extent to which different types of greenspace are used by children living in urban settings. Given that 82% of people aged less than 20 in the UK live in urban areas (Bayliss and Sly, 2009) it is a major gap in knowledge that so little is understood about how much activity occurs in urban green environments and the extent to which this contributes to overall activity levels. Moreover, there has been no research into how levels of activity within greenspace vary across the week and throughout seasons of the year. This information could inform design of environments which maximise their health value across different times and weather conditions.

This study uses data from the PEACH (Personal and Environmental Associations with Children's Health) project in Bristol, UK, to examine the use of different types of urban greenspace by children aged 11-12 years. The study uses data collected from the children during their first year at secondary school, as in this phase GPS data was collected during weekday evenings and at the weekend. Prior analysis of data collected from the children a year earlier, in their final year at primary school, found that around

2% of weekday evening time was spent in urban public parks and that activity within these parks was more likely to be of high intensity than activity in other areas, particularly for boys (Wheeler et al., 2010). This study extends this work by measuring the locations of activity during all non-school time, across different types of public parks as well as within other types of greenspace, such as in private gardens and on school playing fields.

The key aims of the analysis were to establish how much physical activity occurs within different types of urban greenspace in children and to assess how this activity contributes to total levels of non-school physical activity. The analyses were stratified by activity intensity, with a particular focus on levels of moderate-vigorous activity as this is thought to be particularly beneficial to health (Steele et al., 2009), and the UK government recommends that children are active at this level for at least one hour per day (NHS Information Centre for Health and Social Care, 2009). In order to investigate if patterns of use vary across the week, analyses were carried out separately for weekday evenings, for weekend days and separately for Saturday and Sunday. To investigate if use of parks varies across the year, summaries of the amount of moderate-vigorous activity occurring outdoors and within greenspace were produced for each season. The results reveal when greenspace is used by children for play and physical activity and which particular types are most used by children.

Methods

Data collection

The sample was drawn from the PEACH cohort in Bristol, UK, which originally recruited 1,307 children aged 10-11 years from 23 state primary schools. Bristol is the sixth largest city in England, with a population of over 400,000 residents. The city is relatively densely populated and has large socio-economic inequalities, containing areas of considerable affluence and others of significant deprivation (Tallon, 2007). Participants were selected from schools chosen as representative of Bristol according to deprivation and geography. The PEACH methodology is described in detail elsewhere (Page et al., 2009). This study uses data obtained from participants during their first year of secondary school (aged 11-12 years), collected between November 2007 and July 2009. In addition to collection of questionnaire and anthropometry data, participants were asked to wear an accelerometer (Actigraph GT1M) for seven consecutive days, set to record activity counts per 10 second epoch (CPE). Participants were also asked to simultaneously wear a GPS (Garmin Fortrex 201) on four school days between the end of school and bedtime (3pm-10pm) and on at least one weekend day between 8am-10pm. The GPS was set to record latitude-longitude coordinates (up to 10,000 points) every 10 seconds to an accuracy of <3 meters whenever there is sufficient satellite signal (Garmin, 2006). In order to preserve battery life, participants were asked to switch the GPS on after school or upon waking at the weekend and then to turn off at bedtime. The units were recharged after two days of use by research staff.

Data from the GPS and accelerometers were downloaded to a personal computer and integrated using STATA 10 (Statcorp, 2009), based on date/time fields. This produced an activity count and latitude-longitude coordinate (where recorded) for each 10 second epoch. Any 60-minute (or greater) period where accelerometer counts were continuously zero (allowing for up to two minutes of non-zeros per hour) were classified as 'missing', as these were judged to be periods when the accelerometer was recording but not being worn (Troiano et al., 2008). Any epoch record without a location coordinate were coded as 'indoors'. For sequential GPS locations, the speed of travel was calculated based on the change in location on the ground using Pythagoras theorem to calculate the straight-line distance between points and the time between points. Any datapoints with a travel speed above 15kph were excluded as these were judged to be either journeys in vehicles or erroneous locations caused by deficient signal quality, as GPS receivers are less accurate when the signal is obstructed, for example by heavy tree canopy or dense housing (Maddison and Mhurchu, 2009).

Linkage with land use mapping data

ArcGIS Geographic Information System (GIS) (ESRI ® ArcMap 9.2™) was used to prepare a map of land use across the Bristol Local Authority area. The Ordnance Survey Mastermap (OSMM) topography layer classifies every area within Bristol into one of the following land use types: Buildings, Roads and pavements, Private gardens, Parks, Farmland, Grassland, Woodland and Built surfaces (concreted surfaces such as car parks and pedestrianised thoroughfares). The OSMM is the most comprehensive, detailed and up-to-date digital map available for Great Britain and includes every feature larger than a few meters in size, captured with a positional accuracy scale of 1:1250 in urban areas, meaning that 99% of features are located to within 1 meter (Ordnance Survey, 2011). In addition, a map provided by Bristol City Council included information about the type of parks within the Bristol Local Authority area (Jones et al., 2009a), with each park area classified as: Formal (an organised layout and structured path network aiming for aesthetic enjoyment, and generally well maintained), Informal (an informal design with emphasis on informal recreation), Natural (habitats providing access to nature, such as heathland, woodland and wetland), Young People's (areas designed for use by children or teenagers, including those with play and games equipment), and Sports (areas used for organised and competitive sports, such as playing fields and tennis courts) (Bristol City Council, 2008). Areas designated as parks within the OSMM layer were compared with the map of public parks to confirm a match and any discrepancies were checked and recoded as appropriate. Then the two map layers were combined to create one land use map for the whole of Bristol.

Comparison of the Mastermap data with raster maps and satellite imagery showed that the OSMM landuse categories grassland, woodland and farmland encompassed a wide variety of landuse types, including areas such as school grounds, cemeteries, private sports grounds, allotments, footpaths and small patches of scrubland and grassland such as verges and banks. Any grassland, woodland or farmland area which had been used by a child was visually inspected using maps of Bristol and consultation of online mapping resources in order to determine the specific land use. These areas were then sub-classified into three groups: 1) School grounds: land identified by OSMM as grassland and within an area clearly defined as primary or secondary school, 2) Other greenspace : vegetated areas not defined as public parks, including private sports and recreation facilities, cemeteries, golf courses and gardens of publicly accessible buildings such as universities and hospitals, 3) Green verges: small areas of vegetated land with grass or fragmentary vegetation, such as in the centre of roundabouts and narrow strips or banks of vegetation alongside pavements. These first two classifications were categorised as types of greenspace, whereas green verges were judged unlikely to be specifically used for physical activity due to their small size and fragmentary nature, and were more likely to be walked across whilst traversing roads and paths.

The GPS latitude-longitude coordinates for each 10-second epochs were imported in ArcGIS and plotted as datapoints on a map layer overlaying the land use map. Spatial queries were then conducted to assign these datapoints to a landuse type. Each epoch for which GPS data were available was classified as either Greenspace, sub-classified as specific type of park, private garden, school playing field or other greenspace, or Other land use, sub-classified as roads and pavements, green verges or built surfaces.

Datapoints falling outside Bristol Local Authority area were assigned a category of 'Out of study area'. In order to measure how close the parks were to the children's homes, the straight-line distance from each child's home (based on their home postcode) to the nearest park boundary was calculated for each park type.

Analytical methods

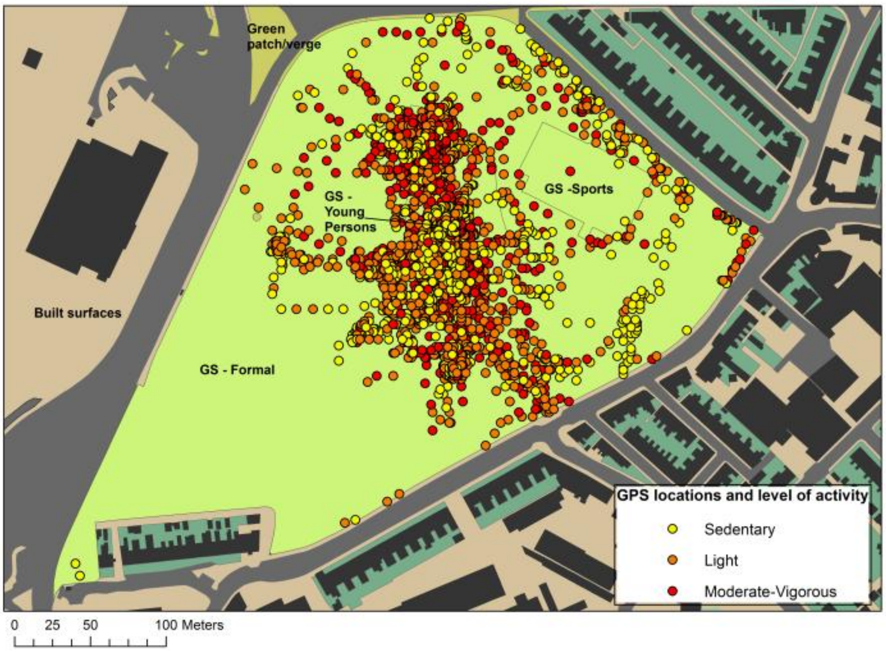
Data were included from days when the participant registered at least 1 minute of GPS time. Children with postcodes outside Bristol Local Authority were excluded, as environmental overlay data were only available for this area. Each 10 second epoch was classified into one of three levels of activity: Sedentary (<100 counts per minute (CPM)), <17 counts per epoch (CPE)), Light (Between 100-2296 CPM, 17-383 CPE), Moderate-Vigorous activity (MVPA) (>=2296 CPM, >=383CPE). These cut-points were chosen as a comparison of activity thresholds (Trost et al., 2010) showed that the thresholds produced the most accurate match with energy expenditure for each of the activity levels among children. Each epoch was assigned a season based on the month of data collection. Meteorological seasons were used with Spring defined as March, April and May; Summer as June, July, August; Autumn as September, October, November; and Winter as December, January, February.

Figures 4.1 and 4.2 show examples of the overlay of GPS points on the landuse maps, with GPS points shaded according to the level of activity. Figure 1 shows an example of GPS points collected during one hour from one child on a weekday evening. Figure 2 shows an example of one park within Bristol and displays all points within this park collected on weekend days by the eight children who recorded activity within this park. This is a community park in South Bristol, classed as a formal park by Bristol City Council, and also has a children's play area and tennis courts. The two figures illustrate the land classifications used and demonstrate how the GPS coordinates were overlaid with the landuse maps.

Epochs were summarised into total counts per activity level per child per day across all the categories of land use. The data was then expressed as mean minutes (and standard deviations) of activity per child per day across land use types. In addition, total counts of activity for all children were summarised and the percentage of activity within each land use was calculated for each activity level. Analyses were performed separately for weekday evenings, weekend days and for Saturday and Sunday as it was hypothesised that play and activity behaviours might vary across the days at the weekend. A summary of moderate-vigorous activity occurring outdoors, within greenspace and within parks was produced for each season. All analyses were conducted using STATA 11.

Figure 4.1: An example of data collected from one child during one hour on a weekday evening, showing GPS locations and intensity of physical activity.

Figure 4.2: Example of all GPS data collected within one park at the weekend, showing GPS locations and intensity of physical activity



Results

Accelerometer and GPS data were collected from 902 secondary school children. Exclusion criteria removed 9 participants for having non-Bristol postcodes. After deletion of days with <1 minute GPS activity, data were available for 614 participants on one or more weekday evening and 301 participants on one or more weekend day. Following deletion of any epochs with a speed greater than 15kph, a total of 5,765 person-hours of data were included in the weekday analysis (average 9.4 hours per child) and 3,833 person-hours of data were included in the weekend analysis (average 12.7 hours per child).

Table 4.1 summarises demographic, anthropometric and physical activity characteristics of the original sample and those included in the analysis. The sample is relatively deprived based on national deprivation scores, with over a third of children living in areas classified within the 25% most deprived areas in England. Compared with the original sample of 902 participants, those included in the analysis included a higher proportion of females and those of White ethnic group, and were less overweight or obese and had higher moderate-vigorous physical activity. These differences were statistically significant ($p<0.05$) for the weekend sample, but not for the weekday evening participants. There were no significant differences between groups in the average distance to the closest parks for all types.

Table 4.2 summarises the mean minutes of activity per child per day according to level of activity and stratified by whether the activity was classified as indoors, outdoors and within the study area, or outside the study area. The majority of activity took place indoors, with 26.4% of MVPA occurring outdoors and within Bristol during weekday evenings and 17.6% at the weekend.

Table 4.3 summarises intensities of activity occurring outdoors and within Bristol by the type of land use within which the activity occurred. Results are expressed as mean times per day and percentages of overall outdoor activity across each intensity level. The average amount of time spent in MVPA per child taking place in greenspace was relatively low (4.8 minutes per weekday evening and 3.5 minutes on weekend days), but the contribution of these times to total MVPA was substantial. During weekday evenings, 33.6% of outdoor MVPA was within green environments, with 10.1% in parks and 22.3% in private gardens. Corresponding values for weekends were 46.0%, 29.3%, and 16.1% respectively. The percentage of outdoor MVPA taking place in greenspace overall was higher at the weekend compared with weekday evenings ($p<0.001$) and the percentages of outdoor MPVA occurring within parks were also higher at the weekend for all park types ($p<0.001$) with the exception of sports areas. The percentage of outdoor MVPA taking place in private gardens was higher during weekday evenings than weekend days ($p<0.001$).

Table 4.4 details the summary of activity separately for Saturdays and Sundays. The percentage of outdoor MVPA occurring in greenspace was highest on Sundays ($p<0.001$). The use of informal and natural park areas was particularly high on Sundays, with over a quarter of all outdoor MVPA occurring in these areas.

Table 4.5 shows the amount of MVPA by season, expressed as mean times of MVPA per day per child and percentages of overall MVPA activity across the seasons for all children. There were no statistically significant differences across the seasons in the average amount of time spent in MVPA per child in total, outdoors, within all types of greenspace, and within greenspaces classified as parks. Whilst the percentage of total MVPA occurring outdoors and within greenspaces overall was similar across seasons during weekday evenings, the percentage of outdoor MVPA occurring in parks was lower in winter and spring compared with summer and autumn ($p<0.001$). At the weekend, the percentage of MVPA occurring outdoors was highest in the winter and lowest in the summer ($p<0.001$), although the percentage of outdoors MVPA in greenspace overall and within parks was similar across the year.

Table 4.1: Characteristics of the study sample

	Total sample N = 902	Included in analysis of weekday evenings N = 614	Included in analysis of weekends N = 301
Age*			
- Mean (SD)		12.0 (0.39)	12.1 (0.40)
Gender (%)			
- Male	47.5	46.7	39.9
- Female	52.5	53.3	60.1
Ethnicity (%)			
- White	85.1	86.2	91.7
- Asian	3.2	3.3	1.7
- Black African	6.4	5.7	2.0
- Mixed	4.2	3.7	3.7
- Unknown	1.0	1.1	1.0
IMD deprivation (%)			
- Most deprived (Quartile 1)	34.5	32.6	31.6
- Quartile 2	22.2	22.2	21.3
- Quartile 3	28.1	28.8	31.2
- Least deprived (Quartile 4)	15.3	16.5	16.0
IOTF weight categories (%)			
- Underweight (BMI <18.5)	8.8	9.0	9.3
- Healthy weight (18.5 to <25)	68.6	69.2	70.8
- Overweight (25 to <30)	17.7	17.4	16.3
- Obese (30+)	4.7	4.1	3.0
- Unknown	0.2	0.3	0.7
Physical activity:			
Mean counts per minute (SD)			
- Weekday evenings 3pm-10pm	562.0 (373.5)	572.4 (389.7)	-
- Weekend days 8am-10pm	453.9 (317.5)	-	512.3 (343.4)
Distance to nearest park:			
Mean meters (SD)			
- All types	193.1 (153.8)	192.7 (157.1)	194.3 (156.6)
- Formal	239.8 (172.8)	238.0 (176.5)	244.6 (177.2)
- Informal	770.8 (604.9)	780.2 (630.3)	796.1 (599.5)
- Natural	442.0 (278.8)	451.6 (288.0)	458.6 (286.1)
- Sports	651.8 (367.0)	641.5 (379.1)	652.9 (384.3)
- Young Persons	389.7 (226.9)	391.2 (227.5)	381.4 (224.6)

*Mean age of participants on first day they provided GPS/accelerometer data Therefore, ages not available for children not providing data.
N = Number of children included in the analysis
IMD = Index of Multiple Deprivation 2007. Lower Super Output Area (LSOA) scores assigned to participants using their home postcode. Quartiles based on ranking of all LSOAs in England.
IOTF = International Obesity Task Force.
BMI - Body Mass Index (kg/m2) adjusted for age and sex.

Table 4.2: Time spent in different activity intensities on weekday evenings and weekend days by location. Values are mean minutes (standard deviation) per day and percentage of total time spent either sedentary or in light or moderate to vigorous physical activity

Location of activity		**Weekday evenings 3pm-10pm N = 614**			**Weekend days 8am-10pm N = 301**		
		Sedentary	**Light**	**Mod-Vig**	**Sedentary**	**Light**	**Mod-Vig**
Indoors	Mean (SD)	195.7 (90.8)	68.2 (38.6)	19.3 (17.2)	363.4 (154.0)	135.5 (70.7)	33.7 (27.9)
	Percentage	92.5	87.7	72.6	93.2	89.1	78.7
Outdoors	Mean (SD)	14.5 (28.8)	9.1 (14.9)	7.0 (1.4)	20.7 (41.3)	13.0 (24.6)	7.5 (17.2)
	Percentage	7.0	11.7	26.4	5.3	8.5	17.6
Out of study area	Mean (SD)	1.1 (17.2)	0.5 (6.0)	0.3 (4.1)	5.7 (30.0)	3.7 (16.1)	1.6 (10.4)
	Percentage	0.5	0.6	1.0	1.5	2.5	3.7
Total	Mean (SD)	211.4 (74.3)	77.9 (27.4)	26.6 (9.3)	389.8 (145.1)	152.2 (75.8)	42.8 (36.1)

Table 4.3: Time spent in different activity intensities on weekday evenings and weekend days by location. Values are mean minutes (standard deviation) per day and percentage of outdoor time spent either sedentary or in light or moderate to vigorous physical activity

Location of activity		Weekday evenings 3pm-10pm N = 614			Weekend days 8am-10pm N = 301		
		Sedentary	**Light**	**Mod-Vig**	**Sedentary**	**Light**	**Mod-Vig**
Greenspace (overall)	Mean (SD)	6.0 (16.1)	3.5 (7.9)	2.4 (4.8)	9.0 (26.9)	6.1 (15.7)	3.5 (9.1)
	Percentage	41.1	38.8	33.6	43.7	46.7	46.0
- **Parks (all types)**	Mean (SD)	1.1 (6.8)	1.2 (7.8)	0.7 (4.7)	3.4 (19.1)	3.5 (16.7)	2.2 (10.5)
	Percentage	7.4	12.9	10.1	16.4	26.7	29.3
Formal	Mean (SD)	0.2 (3.0)	0.3 (4.1)	0.2 (3.3)	0.5 (8.7)	0.7 (8.5)	0.4 (4.3)
	Percentage	1.5	3.0	2.7	2.4	5.1	4.8
Informal	Mean (SD)	0.5 (4.9)	0.4 (4.1)	0.2 (1.6)	1.0 (11.9)	1.1 (7.7)	0.7 (5.0)
	Percentage	3.2	4.4	3.2	5.1	8.3	9.9
Natural	Mean (SD)	0.1 (2.3)	0.1 (1.5)	0.1 (1.1)	0.7 (15.2)	0.6 (8.8)	0.5 (6.6)
	Percentage	0.6	0.8	0.8	3.6	4.7	6.1
Sports	Mean (SD)	0.1 (10.2)	0.1 (10.6)	0.1 (7.4)	0.1 (3.2)	0.1 (1.9)	0.05 (1.2)
	Percentage	1.0	1.6	1.5	0.4	0.6	0.6
Young Persons	Mean (SD)	0.2 (4.0)	0.3 (6.6)	0.1 (3.4)	1.0 (19.1)	1.0 (13.9)	0.6 (7.6)
	Percentage	1.1	3.3	2.0	5.0	7.9	7.8
- **Private gardens**	Mean (SD)	4.8 (15.1)	2.2 (4.2)	1.6 (2.8)	5.6 (23.4)	2.5 (7.7)	1.2 (3.2)
	Percentage	32.9	24.5	22.3	26.9	19.2	16.1
- **School grounds**	Mean (SD)	0.1 (5.5)	0.1 (5.2)	0.1 (3.3)	0.1 (2.5)	0.1 (5.1)	0.1 (1.8)
	Percentage	0.7	1.3	1.1	0.3	0.7	0.5
- **Other greenspace**	Mean (SD)	0.01 (0.5)	0.01 (0.5)	0.01 (0.4)	0.03 (1.3)	0.01 (0.4)	0.01 (0.3)
	Percentage	0.1	0.1	0.1	0.1	0.1	0.1
Other land use							
- **Roads/ pavements**	Mean (SD)	2.8 (7.2)	2.0 (3.7)	1.9 (3.2)	3.9 (12.5)	2.2 (7.6)	1.6 (6.5)
	Percentage	18.9	21.6	26.6	18.9	17.1	20.9
- **Green verges**	Mean (SD)	0.3 (2.7)	0.2 (2.3)	0.2 (1.8)	0.6 (7.0)	0.5 (5.1)	0.3 (2.7)
	Percentage	2.0	2.6	2.9	3.1	3.5	3.8
- **Built surfaces**	Mean (SD)	5.5 (12.4)	3.4 (6.1)	2.6 (4.4)	7.1 (14.1)	4.2 (9.3)	2.2 (7.1)
	Percentage	38.0	37.0	36.9	34.3	32.6	29.3

Table 4.4: Time spent in different activity intensities on Saturdays and Sundays by location: Values are mean minutes (standard deviation) per day and percentage of outdoor time spent either sedentary or in light or moderate to vigorous physical activity

Location of activity		Saturday 8am-10pm N = 216			Sunday 8am-10pm N = 177		
		Sedentary	**Light**	**Mod-Vig**	**Sedentary**	**Light**	**Mod-Vig**
Greenspace (overall)	Mean (SD)	7.8 (16.7)	6.5 (15.7)	3.6 (9.0)	10.6 (36.2)	5.5 (15.7)	3.3 (9.2)
	Percentage	38.6%	42.9%	40.3%	49.6%	53.4%	56.6%
- **Parks (all types)**	Mean (SD)	3.2 (16.8)	3.6 (16.7)	2.1 10.2)	3.6 (22.1)	3.3 (16.8)	2.3 (11.0)
	Percentage	15.9%	23.7%	23.8%	17.0%	32.0%	39.4%
Formal	Mean (SD)	0.7 (10.8)	0.8 (9.6)	0.4 (3.8)	0.3 (3.0)	0.5 (6.3)	0.3 (5.2)
	Percentage	3.5%	5.3%	4.5%	1.2%	4.7%	5.3%
Informal	Mean (SD)	0.9 (6.7)	1.1 (7.0)	0.7 (4.3)	1.3 (16.5)	1.1 (8.7)	0.8 (5.7)
	Percentage	4.4%	7.2%	7.5%	5.9%	10.3%	14.4%
Natural	Mean (SD)	0.3 (3.7)	0.5 (6.9)	0.3 (5.5)	1.3 (22.6)	0.8 (10.9)	0.6 (7.6)
	Percentage	1.3%	3.0%	3.5%	6.2%	7.9%	11.0%
Sports	Mean (SD)	0.1 (1.4)	0.1 (1.8)	0.1 (0.7)	0.1 (4.9)	0.1 (2.0)	0.1 (1.8)
	Percentage	0.3%	0.7%	0.5%	0.5%	0.5%	0.9%
Young Persons	Mean (SD)	1.3 (22.6)	1.1 (13.2)	0.7 (7.5)	0.7 (11.6)	0.9 (15.5)	0.5 (8.0)
	Percentage	6.5%	7.5%	7.8%	3.3%	8.6%	7.8%
- **Private gardens**	Mean (SD)	4.4 (11.2)	2.8 (6.8)	1.4 (3.0)	6.9 (33.0)	2.2 (8.7)	1.0 (3.4)
	Percentage	22.2%	18.2%	15.9%	32.3%	21.1%	16.5%
- **School grounds**	Mean (SD)	0.1 (2.9)	0.1 (6.2)	0.1 (2.1)	0.01 (0.6)	0.03 (1.4)	0.03 (1.0)
	Percentage	0.4%	0.9%	0.5%	0.1%	0.2%	0.4%
- **Other greenspace**	Mean (SD)	0.01 (0.2)	0.02 (0.4)	0.01 (0.3)	0.04 (2.1)	0.01 (0.3)	0.01 (0.4)
	Percentage	0.1%	0.1%	0.1%	0.2%	0.1%	0.1%
Other land use							
- **Roads/ pavements**	Mean (SD)	4.0 (11.8)	2.9 (9.8)	2.1 (8.3)	3.8 (13.3)	1.4 (3.0)	0.9 (2.7)
	Percentage	19.9%	19.2%	23.9%	17.8%	13.4%	15.3%
- **Green verges**	Mean (SD)	0.8 (6.8)	0.6 (6.3)	0.3 (2.9)	0.4 (7.3)	0.3 (2.6)	0.3 (2.5)
	Percentage	4.0%	4.0%	3.5%	2.0%	2.6%	4.3%
- **Built surfaces**	Mean (SD)	7.5 (12.4)	5.1 (10.3)	2.9 (8.9)	6.6 (16.1)	3.2 (7.8)	1.4 (3.5)
	Percentage	37.5%	33.8%	32.3%	30.6%	30.6%	23.8%

Table 4.5: Time spent in moderate-vigorous activity per Season by location: Values are mean minutes (standard deviation) per day and percentages of MVPA occurring outdoors, outdoors in greenspaces, and outdoors within parks.

	Weekday evenings 3pm-10pm				**Weekend days 8am-10pm**			
	Spring	**Summer**	**Autumn**	**Winter**	**Spring**	**Summer**	**Autumn**	**Winter**
Number of children	170	147	128	190	102	81	62	56
MVPA – Mean (SD)								
- Total	27.7 (22.3)	30.0 (22.4)	25.5 (16.6)	23.8 (20.1)	44.1 (40.0)	39.4 (27.9)	43.0 (28.7)	45.1 (46.1)
- Outdoors	7.5 (12.6)	6.2 (10.6)	7.2 (8.9)	7.0 (9.0)	6.6 (13.8)	3.2 (7.2)	11.0 (15.7)	12.2 (28.7)
- Within greenspace	2.5 (3.9)	2.5 (3.4)	2.4 (2.5)	1.9 (2.0)	3.3 (8.9)	1.7 (5.4)	4.6 (9.9)	5.0 (11.8)
- Within parks	0.6 (4.2)	1.1 (7.7)	0.8 (2.8)	0.5 (3.5)	2.1 (10.0)	1.0 (5.6)	2.7 (11.6)	3.7 (14.1)
Percentage of total MVPA occurring outdoors	27.5	21.1	28.3	29.6	15.7	8.5	26.1	27.8
Percentage of outdoor MVPA in greenspaces (overall)	34.0	41.4	34.6	27.4	52.3	51.9	42.0	40.9
Percentage of outdoor MVPA in parks (all types)	7.7	17.2	11.2	7.0	32.0	30.8	24.5	30.5

Discussion

The results show that the amount of activity occurring within greenspace per child is low when expressed as an average daily time, although these figures are broadly in line with a prior study based on the same cohort a year earlier (Wheeler et al., 2010) and also a study of 9-10 year olds in Norfolk (Jones et al., 2009c). However, when expressed as a percentage of total MVPA across all children, time spent in greenspace contributes over a third of all outdoor MVPA occurring during weekday evenings, over 40% on Saturdays and almost 60% on Sundays. This suggests that some children are particularly high users of green environments for play and physical activities and provides some evidence that, at a population level, greenspace use may be an important contributor to overall levels of activity.

The findings show that all types of parks were used by children for sedentary, light and moderate-vigorous activities. It is noteworthy that a high proportion of weekend light and moderate-vigorous activity was within areas specifically designated for use by children or teenagers, in which around 8% of light and moderate-vigorous activity occurred on both Saturdays and Sundays. These areas are few and small (representing <1% of total park area), but their relatively high usage for activity suggests that provision of facilities specifically targeted at young people is effective and that these facilities are valuable resources for physical activity.

The percentage of weekend outdoor MVPA occurring in greenspace overall and specifically in parks did not differ by season. This is contrary to the prior expectation that greenspace would be used more during warmer weather, and may partly reflect their use for team sports such as football, which predominately take place in colder seasons. Previous analysis also found evidence of decreased MVPA during longer daylight hours and during British Summer Time (Wheeler et al., 2010). Further research looking at seasonal and climate-related patterns in the use of different environments is needed, potentially linking GPS data with weather variables. This could help plan provision of greenspace which are weather-appropriate and maximise their potential use for physical activity across the seasons. The percentage of outdoor MVPA taking place in parks during weekday evenings did vary throughout the year, with a lower percentage of moderate-vigorous activity undertaken within parks in winter and spring. This almost certainly reflects the fact that parks are less suitable for activity on darker evenings and may indicate a need to provide better lighting in them, particularly along pathways and in play areas. Adequate lighting is a key factor for parents when selecting play spaces for children to use (Sallis et al., 1997).

The majority of activity occurred in non-green environments, such as on roads and pavements and concreted surfaces. This illustrates the broad ways in which children gain physical activity outside of school and the need to consider the many environmental contexts which may be important. In addition to activity within parks, children also made some use of school playing fields, even at the weekend, and other green areas including cemeteries, golf courses and gardens of publicly accessible buildings. Therefore, studies simply looking at access to a public park may miss important contextual factors about other environments which children may be using. These findings reflect the versatility of children’s play and physical activity behaviours and the potential health value of greenspace not formally designated and managed as a public park.

A large proportion of MVPA occurred within private gardens, particularly during weekday evenings, showing the value of private greenspace as a physical activity resource. Evidence suggests that in recent decades children’s play behaviour has become less autonomous and increasingly occurs in private gardens and the space surrounding the home, a trend attributed mainly to parental safety concerns (Valentine and McKendrck, 1997). Children are more likely to use parks and play spaces in the neighbourhood if they have a network of other children to play with (Veitch et al., 2006). The analysis shows how both private and public greenspace are used for activity, with private space used more during the week and public space at weekends, indicating that both types are important resources for physical activity and their combination allows children to gain their activity in different ways across different outdoor settings. This has policy implications for ensuring adequate provision of both private gardens and public greenspace in housing developments in the context of increased higher density housing and the potential loss of greenspace. For example a study in Merseyside, England, found that between 1975 and 2000 land identified as greenspace decreased by 6%, with reduction in private garden space and conversion of public open space into new housing (Pauleit et al., 2005).

Strengths of the study include the use of a large sample of GPS and accelerometer data, meaning that objective methods could be used to measure the intensity and location of physical activity. The mapping data was detailed and well characterised and consequently this was one of the first studies which has used GPS data to examine activity within different types of greenspace which also includes information about types of parks. Data was collected throughout the week and across the year, allowing a detailed breakdown of the times when greenspaces are used by children.

In terms of study limitations, Bristol is a relatively deprived and predominantly urban area and, therefore, findings may not be generalisable to other living contexts or other age groups. More rural areas may have different challenges in measuring greenspace, as the need to distinguish inaccessible agricultural land from useable grassland, parks and footpaths will be particularly important. The comparison of included participants with the wider sample showed that children providing GPS data were not representative of the wider PEACH cohort, particularly at the weekend. Excluded participants are those who provided no GPS data, which either means that their GPS receivers were turned off/not worn, or that the children were continually indoors during the data collection period and so not using the outdoors for any activity or play. The comparison of Saturday and Sunday was based on small and different samples as not all participants provided GPS data on both weekend days.

This analysis did not consider how use of greenspace may be affected by how accessible it is to the child (such as how close it is to the child's home) or by demographic factors such as sex, socio-economic factors and other environmental variables which have been shown to influence children's activity and may affect their use of greenspace, such as road layouts, traffic flows and crime rates. Future research could investigate how these factors moderate the use of greenspace. Whilst inclusion of information about type of parks was a major advantage of this study, no information was available about the quality of park, or the specific facilities available in them, both factors which may determine use. The availability of detailed online mapping and visualisation tools potentially allow greenspace quality to be assessed remotely (Taylor et al., 2011), and these methods might be used to supplement GIS data in future research.

The linkage of GPS and accelerometer data with land use maps of the environment is a new and developing approach and there are limitations and uncertainties in the methods used. The exclusion of activity occurring outside the study area meant that the use of greenspaces in the surrounding countryside was not considered. This means the overall amount of activity within greenspaces is probably underestimated. There are also issues with the accuracy of the GPS data (Duncan et al., 2009). GPS signal dropout occurs when the receiver temporarily loses satellite reception and this creates gaps in the data. Nevertheless, based on the identification of periods of missing GPS data lasting 30 seconds or less which occurred while child was outdoors, this was found to represent only around 2% of outdoors time in this study. Location data may also be missing during longer dropout periods or due to delays acquiring a sufficient satellite signal upon turning the receiver on (Duncan et al., 2009). However, as the analysis did not require generation of street-level routes, further cleaning or the use of algorithms to impute the missing GPS data was not judged necessary in order to meet the aims of this study.

The removal of any points where participants were travelling >15kph was an attempt to remove time spent in vehicles and erroneous GPS locations, but consequently may also exclude fast bouts of cycling or running and include time spent in slow traffic. Nevertheless, a sensitivity analysis (results not presented) tested the use of 20kph as an alternative threshold and found this made no substantive difference to the findings. A further source of potential error is misclassification in the overlay of GPS points with mapping data, particularly across the land use types 'roads and pavements', concreted 'built surfaces' and 'gardens', as these areas are small and often adjacent, thus requiring extremely accurate location data. In particular, the some of the large proportion of activity in gardens may be in part due to misclassification from children who are actually indoors or who are walking past.

Conclusion

This chapter has demonstrated a new use of GPS to describe how different types of urban greenspace are used by children and provide an insight into how activity within different types of greenspace varies throughout the week and across the year. The findings show that whilst children gained the majority of their activity in non green environments, urban greenspaces, both public and private, are valuable resources for children's play and physical activity.

Chapter 4: Summary

Urban greenspace is hypothesised to be an important location for physical activity in children, but their actual use of the resource to be active is not well known. In this chapter, global positioning systems (GPS) and accelerometers were used to measure activity within green environments for 902 English children aged 11-12. The results summarised activity intensities in different types of greenspace on weekday evenings, weekend days, and by season. Parks were used for as much as 30% of outdoors moderate-vigorous activity at weekends and use was consistent across seasons. The findings suggest the importance of certain types of greenspace to children's physical activity.

Implications for thesis

This chapter has used GPS-accelerometer data to objectively test how different types of urban greenspace are used by children for physical activity. As illustrated in the theoretical framework, it is hypothesised that greenspace type is a moderator in the relationship between access and health. That certain types of greenspace, such as those with play facilities, appear to be particularly supportive for physical activity indicates that relationships between access and health outcomes are likely to be sensitive to the type of space and facilities within it.

Chapter 5

Does neighbourhood greenness reflect use of greenspace for children's physical activity?

Introduction

The preceding analysis, in chapter four, used the PEACH sample of GPS-accelerometer data to quantify how much physical activity occurs across different types of urban greenspace. This demonstrates the potential health value of greenspace to the child population as a whole. The objective of chapter five is to investigate the extent to which use of and physical activity within different types of greenspace is affected by how accessible they are to the children. The analysis also tests relationships between measures of access and total physical activity, given that total physical activity (and its role in improving health) is a potential mediator in the potential causal relationship between access and health outcomes in the theoretical framework (chapter three).

Background

A growing body of research has investigated whether neighbourhood access to greenspaces, such as public parks, grasslands, and woodlands, is associated with higher levels of physical activity and improved health outcomes (Lee and Maheswaran, 2010, Kaczynski and Henderson, 2007, Lachowycz and Jones, 2011). The work comprises part of a wider focus on how attributes of the physical environment influence physical activity behaviours (Jones et al., 2007) and is predicated on the principle that individuals living in areas with increased accessibility to greenspace have greater opportunity to use it for recreational physical activities. This potential salutogenic effect of access to greenspace may be particularly important for children, who can use the space for unstructured free play and outdoor activities such as informal ball games. Playing outdoors also enables young people to socialise with others and to develop confidence and autonomy (Muñoz, 2009) and outdoor activity is an important contributor to overall levels of children's physical activity (Cleland et al., 2008).

The systematic review described in chapter two identified fourteen studies which measured the relationship between access and children's physical activity, of which just under half (6) found that children living in areas with more greenspace are more active. Therefore, evidence to date is mixed. However, a major methodological limitation shared by virtually all published works is a reliance on simple neighbourhood-based metrics of greenspace access as a proxy for likely levels of use, based on the assumption that people living in greener neighbourhoods are making use of the greenspace. Whilst studies to date have measured relationships between access and children's overall physical activity, they have not identified where the activity actually takes place. A consequence is that it is not possible to ascertain whether higher levels of physical activity in children living in neighbourhoods with better greenspace access may be due to activity being undertaken within the greenspace itself, or alternatively are due to uncontrolled confounding with, for example, unmeasured population characteristics. Indeed, it is noteworthy that the few adult studies which have explored associations between greenspace access and utilisation have failed to establish clear associations between adult's living nearer to greenspace being more active within them and achieving overall higher levels of physical activity (Giles-Corti et al., 2005, Jones et al., 2009a, Hoehner et al., 2005).

A novel approach to address this gap in knowledge involves the use of Global Positioning Systems (GPS), which allow individual's locations to be continuously monitored. When used in conjunction with accelerometers, they can thus be used to collect objective data about the level and location of physical activity (Wheeler et al., 2010). The use of GPS thus allows researchers to test whether the results from studies using neighbourhood based measures accurately reflect actual use of greenspace for physical activity among children. Recent studies have applied combined GPS-accelerometer methods to document the amount of children's activity within different types of greenspace (Jones et al., 2009c, Quigg et al., 2010, Lachowycz et al., 2012), but none have yet used these methods to investigate whether there is a relationship between children living in greener areas and their use of greenspace, and if this use contributes to higher activity levels.

This chapter reports on a study from Bristol, UK, where GPS and accelerometer data were collected from 902 children aged 11-12 as part of the PEACH (Personal and Environmental Associations with Children's Health) project. Analysis of the PEACH sample in chapter four shows that around 34% of children's weekend outdoor MVPA occurs within green environments and a previous study found that that activity within them is more likely to be of high intensity than activity in other locations (Wheeler et al., 2010). The present analysis tests if there is an association between neighbourhood based measures of access to greenspace and the outcomes of overall levels of moderate-vigorous physical activity (MVPA), time spent within greenspaces, and the amount of MVPA undertaken within them.

Methods

Data collection

Participants were recruited from 23 schools across Bristol, purposely sampled to maximise environmental and socio-economic diversity. The full methodology of the PEACH project is described elsewhere (Page et al., 2009). The data used here were collected between November 2007 and July 2009 from children during their first year of secondary school (aged 11-12 years).

In addition to collection of survey and anthropometric data, participants were asked to simultaneously wear an accelerometer (Actigraph GT1M) and a GPS device (Garmin Fortrex 201) on four school days between the end of school and bedtime (3pm-10pm) and on at least one weekend day between 8am-10pm. The accelerometer was set to record activity counts per 10 second epoch (CPE) and the GPS device to record latitude-longitude coordinates at 10 second intervals whenever there was sufficient satellite signal. STATA 10 (Statcorp, 2009) was used to combine the GPS and accelerometer data, thus producing an activity count and latitude-longitude coordinate (where recorded) for each 10 second epoch. Data were included from days when participants registered at least 1 minute of GPS recording. Epochs with an activity count of 383 or higher were classified as being of moderate-vigorous intensity (equivalent to >=2296 counts per minute) (Trost et al., 2010). Datapoints with a travel speed above 15kph (based on the change in the latitude-longitude coordinate) were excluded as these were judged to be either journeys in vehicles or locational instability due to deficient GPS signal quality. Further information about the processing of the GPS data from the

PEACH project is given in the previous chapter and in published papers (Wheeler et al., 2010, Cooper et al., 2010, Lachowycz et al., 2012).

Data processing

The definition of 'greenspace' used in this study encompassed all areas identified by Bristol City Council as free-to-use public parks within the Bristol Local Authority area. The location of all public parks within the Bristol Local Authority area were mapped in ArcGIS Geographic Information System (GIS) (ESRI ® ArcMap 9.2™) using data provided by Bristol City Council. The data classified each park area into one of five types of greenspace: Formal (an organised layout and structured path network aiming for aesthetic enjoyment, and generally well maintained), Informal (an informal design with emphasis on informal recreation), Natural (habitats providing access to nature, such as heathland, woodland and wetland), Young person's (areas designed for use by children or teenagers, including those with play and games equipment), and Sports (areas used for organised and competitive sports, such as playing fields and tennis courts).

The home locations of participants were mapped in ArcGIS based on their postcode centroid (centre point). Children with postcodes outside the Bristol Local Authority were excluded from this analysis, as greenspace locations were not available for their neighbourhoods. For each child, three measures were generated to describe access to greenspace, with each being generated for all greenspaces combined and separately for each of the five types. The measures were:

1) Distance measure: The shortest distance via the road network between the postcode centroid and the boundary of the nearest greenspace.
2) Area measure: The total area of greenspace (in square meters) within each child's neighbourhood. The neighbourhood was defined as the area accessible within a 10 minute walk (equating to 800m) along the road network from the child's home postcode. This definition of neighbourhood was selected to be consistent with prior studies (Jennings et al., 2011, Harrison et al., 2001, Panter et al., 2010, Coombes et al., 2010).
3) Potential measure: A summed 'potential accessibility' score produced by summing the distances from each child's home postcode to all available greenspaces within the

study area, including weightings for distance and size. The formulae used to generate this score is specified in a prior study based in Birmingham, UK (Jones et al., 2009b).

Three alternative measures of greenspace access were used as there is not yet consensus as to what factors are important when measuring accessibility in relation to physical activity. For example, it is not known whether distance to the nearest space is a key determinant of use or if the total space available within the vicinity is more important. The alternative methods represent some of the most commonly used approaches within the extant literature and so including all three allowed exploration of how sensitive the results are to the different approaches and consideration of what these differences may mean.

The latitude-longitude coordinates collected by the GPS device for each 10-second epoch were imported in ArcGIS and plotted as datapoints on a map layer. Spatial queries were then conducted to identify epochs of physical activity occurring within the greenspaces of each type. As the type of greenspace is likely to moderate the relationship between access and physical activity (Bedimo-Rung et al., 2005) and the amount of use was shown in chapter four to vary by greenspace type as well as by day of the week in this sample, analyses were carried out separately for different types of greenspace and for weekday evenings (capturing after-school use) and weekend days. Hence, for each child, three summary measures of activity were generated separately for weekday evenings and weekend days: 1) Mean minutes per weekday evening (3pm-10pm) or weekend day (8am-10pm) of MVPA occurring across all locations and including activity indoors and across all outdoor locations, such as on roads and pavements, in gardens and in greenspace; 2) Time (minutes) spent within each specific greenspace type and across all types of greenspace; 3) Minutes of MVPA occurring within each specific greenspace type and across all types of greenspace.

Analytical methods

All statistical analyses were carried out using STATA 11 (Statcorp, 2009) during 2011. Negative binomial regression models were fitted to explore associations between each of the three greenspace access measures (divided into 3 tertiles) and the three activity outcomes. Negative binomial models were used in preference to Poisson models as the outcomes were found to be overdispersed, with greater variance than would be consistent with a Poisson model. Differences in the three outcomes were examined across the tertiles of access, expressed as rate ratios to compare the difference in means across the tertiles, using the tertile with the worst access to greenspace as the reference group, i.e. the ratio of mean minutes per evening/day in tertiles 2 and 3 compared with the baseline tertile 1. Tests for trends were made across the access tertiles.

All analyses were adjusted for child sex and age, month of data collection, area socio-economic deprivation (using the Index of Multiple Deprivation 2007 (Government, 2008) score at the Lower Super Output Area census level) and distance from the child's home to the edge of city. This latter measure was included in order to account for the fact that children living near the edge of the city may use unmeasured greenspaces outside the city boundaries. Based on the research discussed in chapter three which suggested that gender and socio-economic deprivation may moderate relationships between greenspace access and children's physical activity, separate analyses were run including these variables as interaction terms to test if there was a statistically significant interaction.

Results

After removal of children with non-Bristol postcodes and those who provided insufficient GPS data, 614 participants were included in the analysis of weekday evening data (5,765 hours of data, average 9.4 hours per child overall) and 301 participants were included in the weekend day analysis (3,833 person-hours of data, average 12.7 hours per child).

Table 5.1 shows the trend in total MVPA across tertiles of greenspace access for each of the three access measures. Few associations were apparent. During weekday evenings, better access to Formal greenspace was associated with higher total MVPA for the distance and potential access measures. No other greenspace type showed a significant association with evening MVPA. For weekend activity, better access to Young person's greenspace measured by the distance and area access measures was associated with higher MVPA, whilst shorter distance to Sports greenspaces was counter-intuitively associated with lower MVPA.

Table 5.2 shows trends in time spent within greenspace across the tertiles of access. For most types of greenspace, better access is generally associated with more time spent in it, although not all trends reach statistical significance and not all associations show clear trends across the tertiles. Some of the results show a trend in rate ratios across the tertiles, but the trends do not reach statistical significance due to wide confidence intervals associated with low levels of use of certain types of greenspace. The strongest and most consistently positive associations are for Formal and Sports greenspaces, with particularly strong trends across the tertiles for the potential access measure. Natural greenspace also has strong and statistically significant associations for all the access measures during weekday evenings.

Table 5.3 shows the trend in minutes of MVPA undertaken within greenspace across the tertiles of access. The findings show similar patterns to those in Table 2 and indicate that better access to certain types of greenspace is associated with higher amounts of MVPA within it. The associations are strongest and most consistent for access to Formal greenspaces. Trends for Natural and Sports greenspaces areas are mixed, with access to Natural greenspace showing some significant associations for evening MVPA but not at the weekend, whilst access to Sports areas is associated with higher evening MVPA for the potential access measure.

When interactions for gender and socio-economic status were tested, there were some statistically significant interactions present but their directions were not consistent, suggesting that they were the result of multiple testing. As stratification reduced the analytical power to an unacceptable level, the interactions were not explored further.

Table 5.1: Rate ratios of means (and 95% confidence intervals) of overall MVPA, by tertiles of access to greenspace, during weekday evenings (3pm-10pm) and at the weekend (8am-10pm)

	Distance measure		Area measure		Potential measure	
Type of greenspace	**Evening**	**Weekend**	**Evening**	**Weekend**	**Evening**	**Weekend**
All types						
Tertile 1 (worst access)	1.0	1.0	1.0	1.0	1.0	1.0
Tertile 2	1.01 (0.83, 1.24)	0.85 (0.64,1.13)	0.98 (0.80,1.19)	1.13 (0.85,1.50)	1.08 (0.88,1.32)	0.77 (0.57,1.04)
Tertile 3 (best access)	0.99 (0.80, 1.22) ns	1.07 (0.78,1.47) ns	0.95 (0.78,1.17) ns	0.99 (0.73,1.34) ns	1.07 (0.88,1.30) ns	0.95 (0.71,1.26) ns
Formal						
Tertile 1 (worst access)	1.0	1.0	1.0	1.0	1.0	1.0
Tertile 2	1.34 (1.09,1.64)	0.79 (0.60,1.04)	1.11 (0.90, 1.35)	0.98 (0.74,1.32)	1.39 (1.06,1.83)	0.84 (0.58,1.20)
Tertile 3 (best access)	1.29 (1.04,1.60)*	0.88 (0.65,1.20) ns	1.04 (0.84,1.28) ns	0.92 (0.67,1.25) ns	1.34 (1.02,1.76) ns	0.99 (0.69,1.41) ns
Informal						
Tertile 1 (worst access)	1.0	1.0	1.0	1.0	1.0	1.0
Tertile 2	0.91 (0.74,1.11)	0.77 (0.58,1.02)	1.04 (0.85,1.27)	1.09 (0.82,1.46)	1.10 (0.90,1.34)	0.99 (0.74,1.32)
Tertile 3 (best access)	0.94 (0.76, 1.15) ns	0.87 (0.65,1.16) ns	0.95 (0.77,1.16) ns	0.98 (0.73,1.32) ns	1.04 (0.84,1.27) ns	0.99 (0.74,1.31) ns
Natural						
Tertile 1 (worst access)	1.0	1.0	1.0	1.0	1.0	1.0
Tertile 2	0.88 (0.72,1.08)	0.88 (0.66,1.17)	0.87 (0.70,1.08)	1.04 (0.77,1.40)	1.05 (0.86,1.30)	1.10 (0.81,1.49)
Tertile 3 (best access)	0.88 (0.71,1.09) ns	0.88 (0.64,1.21) ns	0.86 (0.69,1.05) ns	0.91 (0.66,1.24) ns	1.12 (0.91,1.37) ns	1.05 (0.79,1.39) ns
Young persons						
Tertile 1 (worst access)	1.0	1.0	1.0	1.0	1.0	1.0
Tertile 2	0.96 (0.80, 1.16)	1.14 (0.87,1.48)	0.98 (0.81,1.18)	1.31 (1.00, 1.71)	1.22 (0.94,1.59)	0.95 (0.68,1.32)
Tertile 3 (best access)	0.94 (0.78, 1.13) ns	1.30 (0.97,1.69)*	0.98 (0.81,1.18) ns	1.34 (1.03,1.75)*	1.26 (0.92,1.73) ns	0.89 (0.56,1.41) ns
Sports						
Tertile 1 (worst access)	1.0	1.0	1.0	1.0	1.0	1.0
Tertile 2	0.97 (0.79, 1.18)	0.75 (0.57,0.99)	1.04 (0.86,1.26)	0.89 (0.67,1.19)	1.25 (0.94,1.65)	1.05 (0.75,1.47)
Tertile 3 (best access)	0.98 (0.81, 1.19) ns	0.70 (0.54,0.91)**	0.93 (0.76,1.12) ns	0.82 (0.67,1.19) ns	1.23 (0.94,1.60) ns	0.94 (0.65,1.36) ns

[a]Definitions of tertile 1 (worst access to greenspace) for 3 access measures: Distance = longest distance to closest greenspace, Area measure = no greenspace within 800m neighbourhood, Potential measure = lowest potential accessibility.

All analyses adjusted for gender, age, month of data collection, area socio-economic deprivation, distance to edge of city.

Test for trend across tertiles: *p<0.05, **p<0.01, ns=not significant

Table 5.2: Rate ratios of means (and 95% confidence intervals) of time spent within greenspace, by tertiles of access to greenspace, during weekday evenings (3pm-10pm) and at the weekend (8am-10pm)

	Distance measure		**Area measure**		**Potential measure**	
Type of greenspace	Evening	Weekend	Evening	Weekend	Evening	Weekend
All types						
Tertile 1 (worst access)	1.0	1.0	1.0	1.0	1.0	1.0
Tertile 2	1.60 (0.94,2.72)	0.99 (0.41,2.39)	0.99 (0.61,1.62)	0.71 (0.47,0.73)	1.05 (0.63-1.74)	0.53 (0.19-1.46)
Tertile 3 (best access)	1.10 (0.62,1.97) ns	1.61 (0.51,5.08) ns	0.75 (0.41,1.35) ns	0.83 (0.29,2.40) ns	1.06 (0.64-1.75) ns	1.15 (0.46-2.91) ns
Formal						
Tertile 1 (worst access)	1.0	1.0	1.0	1.0	1.0	1.0
Tertile 2	1.25 (0.542.91)	1.78 (0.39,8.07)	1.26 (0.54,2.97)	2.03 (0.44,9.32)	8.28 (2.16-31.73)	1.44 (0.95-21.78)
Tertile 3 (best access)	3.09 (1.36,7.01)**	3.10 (0.69,13.85) ns	2.41 (0.96,6.06) ns	3.89 (0.70,21.58) ns	6.84 (1.98-22.88)**	7.70 (1.28-46.16)**
Informal						
Tertile 1 (worst access)	1.0	1.0	1.0	1.0	1.0	1.0
Tertile 2	1.35 (0.72,2.52)	1.36 (0.50,3.69)	0.69 (0.39,1.21)	1.73 (0.64,4.67)	1.74 (0.99-3.07)	0.81 (0.29-2.31)
Tertile 3 (best access)	1.06 (0.58,1.93) ns	1.42 (0.49,4.12) ns	0.78 (0.42,1.46) ns	1.34 (0.47,3.84) ns	0.82 (0.44-1.53) ns	1.21 (0.44-3.33) ns
Natural						
Tertile 1 (worst access)	1.0	1.0	1.0	1.0	1.0	1.0
Tertile 2	2.03 (0.97,4.25)	1.29 (0.07,23.80)	1.93 (0.90,4.14)	0.44 (0.09,2.03)	0.82 (0.36-1.85)	0.16 (0.12-1.60)
Tertile 3 (best access)	7.04 (3.03,16.36)**	1.49 (0.04,55.69) ns	5.98 (2.68,13.34)**	6.30 (1.03,38.81)*	2.48 (1.13-5.43)**	0.53 (0.05-5.73) ns
Young persons						
Tertile 1 (worst access)	1.0	1.0	1.0	1.0	1.0	1.0
Tertile 2	1.80 (0.48,6.70)	1.50 (0.21,10.91)	1.77 (0.49,6.37)	2.32 (0.15,36.38)	0.04 (0.01-0.38)	3.09 (0.19-49.24)
Tertile 3 (best access)	2.06 (0.58,7.31) ns	2.73 (0.34,21.93) ns	2.21 (0.66,7.44) ns	2.60 (0.32,21.17) ns	0.11 (0.01-1.51) ns	0.30 (0.01-17.86) ns
Sports						
Tertile 1 (worst access)	1.0	1.0	1.0	1.0	1.0	1.0
Tertile 2	3.34 (0.52,21.50)	0.97 (0.14,6.90)	2.69 (0.50,14.43)	0.85 (0.10,7.47)	2.92 (1.57-18.7)	8.44 (1.89-16.01)
Tertile 3 (best access)	3.83 (0.60,24.40)*	4.30 (0.60,30.66) ns	5.55 (1.05,29.37)*	11.41 (1.49,87.05)*	7.52 (1.04-15.4)**	17.5 (10.76-29.3)**

[a]Definitions of tertile 1 (worst access to greenspace) for 3 access measures: Distance = longest distance to closest greenspace, Area measure = no greenspace within 800m neighbourhood, Potential measure = lowest potential accessibility.

All analyses adjusted for gender, age, month of data collection, area socio-economic deprivation, distance to edge of city.

Test for trend across tertiles: *p<0.05, **p<0.01, ns=not significant

Table 5.3: Rate ratios of means (and 95% confidence intervals) MVPA within greenspace, by tertiles of access to greenspace, during weekday evenings (3pm-10pm) and at the weekend (8am-10pm)

	Distance measure		**Area measure**		**Potential measure**	
Type of greenspace	Evening	Weekend	Evening	Weekend	Evening	Weekend
All types						
Tertile 1 (worst access)	1.0	1.0	1.0	1.0	1.0	1.0
Tertile 2	1.53 (0.80,2.92)	1.02 (0.29,3.54)	0.92 (0.50,1.71)	1.17 (0.30,4.49)	1.05 (0.56-1.95)	0.40 (0.10-1.63)
Tertile 3 (best access)	1.21 (0.59,2.52) ns	2.63 (0.48,14.55) ns	0.77 (0.38,1.59) ns	1.40 (0.28,7.02) ns	1.04 (0.56-1.95) ns	0.62 (0.17-2.20) ns
Formal						
Tertile 1 (worst access)	1.0	1.0	1.0	1.0	1.0	1.0
Tertile 2	2.95 (1.27,6.87)	1.00 (0.16,6.29)	1.55 (0.63,3.81)	1.58 (0.23,10.94)	9.13 (2.23-37.39)	1.16 (0.02-71.61)
Tertile 3 (best access)	8.38 (3.41,20.56)**	1.31 (0.22,7.92) ns	3.42 (1.37,8.57)**	2.23 (0.24,20.98) ns	11.47 (3.25-40.50)**	6.56 (0.47-90.63)*
Informal						
Tertile 1 (worst access)	1.0	1.0	1.0	1.0	1.0	1.0
Tertile 2	1.93 (0.85,4.36)	0.70 (0.17,2.84)	1.32 (0.62,2.81)	0.59 (0.15,2.42)	1.93 (0.85-4.36)	0.70 (0.17-2.84)
Tertile 3 (best access)	1.29 (0.59,2.81) ns	1.33 (0.26,6.75) ns	0.84 (0.37,1.89) ns	0.83 (0.18,2.77) ns	1.29 (0.5902.81) ns	1.33 (0.26-6.75) ns
Natural						
Tertile 1 (worst access)	1.0	1.0	1.0	1.0	1.0	1.0
Tertile 2	2.54 (0.78,8.32)	0.03 (0.01,1.18)	3.06 (0.88,10.60)	0.22 (0.03,1.56)	0.79 (0.19-3.26)	0.09 (0.01-6.16)
Tertile 3 (best access)	11.01 (2.29,53.06)**	0.06 (0.00, 2.97) ns	4.42 (1.04,18.77)*	3.12 (0.33,29.99) ns	1.45 (0.40-5.28) ns	0.17 (0.00-11.49) ns
Young persons						
Tertile 1 (worst access)	1.0	1.0	1.0	1.0	1.0	1.0
Tertile 2	1.36 (0.32,5.77)	1.45 (0.22, 9.67)	1.65 (0.37,7.46)	2.62 (0.22. 31.25)	0.12 (0.01-1.29)	3.20 (0.24-42.07)
Tertile 3 (best access)	0.92 (0.24,3.59) ns	3.04 (0.45,20.60) ns	1.22 (0.34,4.34) ns	2.89 (0.42, 19.76) ns	0.17 (0.01-2.89) ns	0.35 (0.01-12.82) ns
Sports						
Tertile 1 (worst access)	1.0	1.0	1.0	1.0	1.0	1.0
Tertile 2	1.94 (0.15,25.52)	0.64 (0.07,6.22)	1.61 (0.16,16.04)	1.03 (0.06,18.77)	5.71 (4.10-17.9)	15.65 (1.0-25.4)
Tertile 3 (best access)	3.63 (0.36,36.28) ns	0.79 (0.08,7.80) ns	5.03 (0.51,49.58) ns	1.15 (0.08,16.84) ns	15.53 (11.67-206.9)**	10.80 (0.25-47.95) ns

[a]Definitions of tertile 1 (worst access to greenspace) for 3 access measures: Distance = longest distance to closest greenspace, Area measure = no greenspace within 800m neighbourhood, Potential measure = lowest potential accessibility. All analyses adjusted for gender, age, month of data collection, area socio-economic deprivation, distance to edge of city.

Test for trend across tertiles: *p<0.05, **p<0.01, ns=not significant

Discussion

The findings suggest that greenspaces appear to be an important venue for physical activity amongst children in the PEACH study, although their presence did not necessarily mean that children were more active overall. Whilst little evidence was found that living in a neighbourhood with better access to greenspace was consistently associated with higher levels of overall MVPA, there was stronger evidence that children who lived near certain types of greenspace spent more time in the space and also recorded a greater number of minutes of MVPA in them than their counterparts in less green areas.

In particular, access to Formal space showed the most consistent associations across the different access measures and for both weekday evenings and the weekend. These areas represent what many would describe as a public or municipal park. A prior study, also based in Bristol and using the same greenspace classifications, found that adults who reported living nearer Formal greenspace reported visiting them more and had lower levels of obesity. The authors suggested that Formal areas are often well maintained and have good path networks and lighting, making them suitable for adult physical activity and attractive to traverse when walking and cycling. These factors may also apply to children's physical activity, particularly if Formal areas are viewed as safe by parents, as parental perceptions of safety are known to be important (Mulvihill et al., 2000).

Three alternative measures of greenspace were used in the analysis in order to explore if the way in which greenspace is measured affects the relationships. Previous research exploring this is mixed, in that some studies have found that the number of greenspaces within a certain distance is more important than size in relation to physical activity for adults (Frank et al., 2007, Kaczynski et al., 2009), whereas other research indicates that greenspace needs to be a particular size threshold to show associations with walking (Giles Corti et al., 2005). There are differences in the strength of associations between access to greenspace and time and MVPA within it across the three measures of access tested and between evenings and weekends, although no clear patterns are apparent overall. For Formal and Sports areas, the potential accessibility measure showed the strongest associations, whereas the weekday evening relationships for Natural greenspace were strongest for the distance measure. This may indicate that having one Natural space within a short walking distance is more important than having a network of these types of spaces within the vicinity. Given that this is the first study to analyse different access measures for different types of greenspace, further research can additionally elucidate these findings, but the results do indicate that the best measure of accessibility – in terms of understanding how it relates to children's physical activity – may differ for different types of greenspace.

Some of the effect sizes for the associations between greenspace access and time spent and MVPA undertaken within them were particularly large. For example, children living in the tertile of neighbourhoods with the best potential access to Formal green space recorded almost twelve times more minutes of MVPA in the space during evenings and more than six times more at the weekend. Given that this was after adjustment for key covariates, it provides evidence that children living nearer certain types of greenspace make good use of them. As documented in the previous chapter, the mean amount of MVPA undertaken within greenspaces by PEACH participants is small, at around 0.7 minutes per weekday evening and 2.2 minutes per weekend day. Therefore, whilst a several-fold difference in MVPA may represent an average of only a few minutes of MVPA per child, such effects could still provide large health gains at a population level due to the fact they represent a substantial percentage of total MVPA undertaken daily by many children.

The finding that children who live nearer greenspace use it more for MVPA is important, as it provides robust evidence that use of greenspace may be an explanatory mediator in the relationship between increased greenspace access and improved health outcomes, a relationship which is documented by several studies (Mitchell and Popham, 2008, Maas et al., 2009b) but for which the casual mechanisms are poorly understood. Nevertheless, the fact that increased access to greenspace was not associated with higher levels of overall MVPA implies that children with poorer greenspace access are compensating by gaining a higher proportion of their activity within other locations. Results from another study amongst similar-aged children showed the importance of streets and private gardens as venues for MVPA (Jones et al., 2009c). Whilst these locations may provide physical activity benefits, it is unclear whether they provide the more general health and mental well-being benefits that have been associated with contact with nature (Taylor and Kuo, 2006).

This study has a number of strengths and weaknesses. Strengths include the use of detailed and well characterised data on greenspace locations, allowing the moderating effects of greenspace type to be examined. A major advantage was the availability of objective measures of physical activity intensity and of the actual use of greenspaces. Indeed, Troped et al have previously suggested that a lack of specificity with regard to measuring where physical activity occurs may lead to a dilution of observed associations and therefore an underestimation of the strength of the real associations between features in the environment and physical activity (Troped et al., 2010). It may also lead to an over-estimation of the importance of greenspace if an observed correlation between greeenspace access and total physical activity could in fact be due to residual confounding with other unmeasured factors.

In terms of weaknesses, some clear trends across the tertiles did not reach statistical significance due to the wide confidence intervals around the estimates. This was due to the limited power of some of the tests, particularly for the smaller types of greenspace such as those for young people and sports, for which only a small proportion of the children registered any activity within these areas during the few days of data collection. The use of zero-inflated models was tested to overcome the problem of many children registering no activity within certain greenspace types. Whilst a previous study has demonstrated the value of zero-inflated approaches when using physical activity outcomes (Slymen et al., 2006), there was no a-priori hypothesis that the zeros were the result of an explanatory process different from that driving the non-zero values, and a comparison of models in STATA showed that the non-zero-inflated models best fitted the outcomes. Although this is one of the largest samples of GPS-accelerometer sample collected from children to date, larger samples and ideally longer time series are needed to improve power and facilitate more highly stratified analysis. The relatively small sample size may also explain why the analysis found no evidence of moderation by gender and socio-economic status.

Deprivation is a key potential confounder in the relationship between greenspace access and physical activity. In this analysis deprivation was adjusted for using area-level scores (the index of multiple deprivation) allocated to the children based on their postcode of residence. This was because individual-level deprivation data was poorly completed in the PEACH sample, with only around half or the participants providing data about income and education. There may be residual confounding by deprivation as the area-level measures represent the average for the neighbourhood and thus does not discriminate between local differences e.g. the properties closest to the greenspace or with views of it may be the most desirable and expensive to live in. However, analysis of the subset of data for which individual level SES data was available (results not shown) suggests this makes little difference to the results.

Further limitations of the study include potential misclassification of the location of activity caused by inaccuracy of the GPS data. The distance measures were based on the nearest greenspace boundary rather than access points such as gates and pedestrian entrances because information on the location of these points was not available. Calculation of the potential accessibility score was based on work which had derived distance decay weightings (Jones et al., 2009b) and size-based attractiveness (Giles-Corti et al., 2005) from adult surveys and therefore may not apply to children, although there is no reason to believe they would differ, particularly as they favour short travel distances. A final limitation is that multiple exposures and outcomes were tested and therefore some statistically significant results may emerge due to chance.

In conclusion, this study has demonstrated a novel use of Global Positioning Systems to provide new evidence on the role of greenspace as a venue for physical activity in children. The findings indicate that some types of greenspace are an important venue for moderate to vigorous physical activity in young children, although children in greener areas are not necessarily more active overall. The analysis also demonstrates the value of using physical activity outcome measures which are appropriate and specific to the research question being tested. The findings therefore cautiously lend support to a growing body of research which documents the potential health value of living in areas with good access to greenspace.

Chapter 5: Summary

A growing body of evidence suggests that access to greenspace is associated with higher levels of physical activity. However, a major methodological limitation is reliance on neighbourhood-based metrics to measure associations between access and total physical activity. Consequently, little is known about how much activity actually occurs within greenspace. This chapter reports on analysis of data collected using Global Positioning Systems (GPS) from 902 children aged 11-12 years to investigate relationships between living in green neighbourhoods, spending time within greenspace and overall levels of moderate-vigorous activity (MVPA). Measures of access to five types of greenspace were generated for each child. Negative binomial regression models were used to test the associations between these measures and use of greenspace, moderate-vigorous activity (MVPA) within greenspace, and MVPA across all locations. Results show that better access to greenspace is not associated with higher levels of overall MVPA. However, children living in greener neighbourhoods spend more time in greenspaces and also record a greater number of minutes of MVPA in them than counterparts in less green areas. Results varied by greenspace type, with the most consistent associations found for Formal parks. Greenspace is an important venue for MVPA in children, although children living in greener areas are not necessarily more active overall. Therefore this study lends qualified support to a growing body of research documenting the potential health value of living in areas with good access to greenspace.

Implications for thesis

A major limitation identified in the literature review (chapter 2) was reliance on neighbourhood-based metrics to measure associations between access and physical activity, without measuring where the activity occurs. The work in this chapter addresses this limitation through analysis of a sample of GPS-accelerometer data. The finding that accessibility was associated with time and activity within greenspace indicates that use may be a mediator in the relationship between better greenspace access and improved health outcomes, as illustrated in the theoretical framework (chapter 3). However, better access to greenspace was not associated with higher levels of overall non-school MVPA, suggesting that children living in less green neighbourhoods gain their activity in alternative non-green locations.

Chapter 6

Does physical activity explain associations between access to greenspace and lower mortality?

Introduction

The preceding chapters have explored the relationship between greenspace accessibility and physical activity for children. Chapter six now turns to adults and evaluates the association between access and self-reported levels of walking, including a measure of health and recreational walking which it is hypothesised could be undertaken within green environments. The potential role of recreational walking as a mediator in the association between greenspace and health outcomes is then explored.

Background

A number of studies have found that living in neighbourhoods with good access to greenspace, such as parks and woodland, is associated with improved health outcomes including lower rates of contact with GPs (Maas et al., 2009b) and better self reported health (Mitchell and Popham, 2007). Associations have also been observed with mortality. Mitchell et al found longer life expectancy in greener areas amongst English adults (Mitchell and Popham, 2008), Takano et al that older residents of Tokyo had improved five year survival rates if they lived near parks and tree-lined spaces (Takano et al., 2002), whilst Villenueve et al's cohort study followed Canadian adults over 2 decades and reported more greenspace in urban environments was associated with long term reductions in mortality (Villeneuve et al., 2012).

Despite emerging evidence of lower morbidity and mortality in greener areas, little is understood about what causal mechanisms may drive this association. Greenspace has a multifaceted potential to influence health, and potential routes of mediation include using the space for physical and social activities and mental health benefits from viewing greenspace. The mechanism which has been most researched to date is use of greenspace for physical activity. Physical activity contributes to the prevention of a range of disorders, including heart disease, some cancers, and osteoporosis, as well as improving mental well-being and control of weight, hypertension, and diabetes (Warburton et al., 2006). However, the systematic review in chapter two suggests that findings from the recent proliferation of studies examining access to greenspace and levels of physical activity are mixed and the relationship between access to greenspace and physical activity is far from clearly established. This may be in part due to heterogeneity in the methods used and the methodological limitations of a reliance on cross sectional methods. If there is evidence that people with more greenspace in their environment are more physically active, then it follows that these populations may exhibit improved health outcomes, with lower mortality. Nevertheless, this potential relationship has not yet been empirically tested.

This study seeks to address this gap in the research evidence by evaluating the relationship between access to greenspace, physical activity and mortality. Firstly, associations between access to greenspace and self-reported levels of walking are tested for a large sample of adults across England after adjustment for potential confounding factors. The second part of the analysis examines the extent to which any associations between greenspace and physical activity may mediate the relationship between access to greenspace and reduced premature mortality from circulatory disease, a relationship previously documented for adults living in England (Mitchell and Popham, 2008). This prior research found stronger associations between greenspace availability and mortality in less deprived areas, so the analysis is stratified by deprivation, and also adjusted for potential confounding factors such as urban-rural classification.

Methods

Data sources

Data for this study were combined from individual (person based) and area level sources. The individual level data were sourced from the Active People Survey (APS), an annual survey organised by SportEngland and conducted by Ipsos Mori (Ipsos Mori, 2007). The survey consists of telephone questionnaire of a random sample of adults across England and collected information about participation in a range of physical activities. This analysis uses the data collected between October 2007 and October 2008.

In order to assign individuals to an area measure based of greenspace access and population mortality (individual mortality was not available for the APS), Ipsos Mori provided the research team with the 2001 Middle Super Output Area (MSOA) code within which each respondent resided. MSOAS are geographical units used in the UK census, of which there were 6,781 in England at the 2001 Census, with a minimum population size of 5,000 residents and an average of 7,200 residents. The linked survey data were provided in an anonymised form without sharing the postcodes of individual participants to ensure that individuals could not be identified, thus complying with confidentiality restrictions on the data.

Measure of walking

The APS included two questions about walking: "On how many days in the last four weeks have you walked for at least 30 minutes?" (Respondents were asked to include all walks of that duration, but to exclude time spent walking around shops), and "How many of those days were you walking for the purpose of health or recreation, not just to get from place to place?" Two walking outcomes were generated for each survey participant, each counting the number of days reported in response to each question.

As only area based mortality was available for the mediation analysis, an area based indicator of recreational walking was also generated for each MSOA that took account of the age and sex of respondents. Indirect standardisation was used to compute the mean per capita expected number of days walked in the last 4 weeks. This was based on the age and sex profile of the respondents in each MSOA and computed using the ratio of the observed mean number of days divided by the expected mean.

Measure of greenspace access

Access to greenspace was measured using the Generalized Land Use Data (GLUD) 2005 dataset (CLG, 2005). This classification allocates all identifiable features from national mapping agency (UK Ordnance Survey) data into ten landuse categories. One of the categories is ‘greenspace’ which includes areas such as parks, agricultural land, woodland and grassland but excludes private gardens. These data were used to compute three measures of greenspace for each MSOA. These were the percentage of land area classified as greenspace in the MSOA, the percentage classified as greenspace in MSOAs within 5 kilometers (defined as summed total area classified as greenspace within the MSOA and other MSOAs for which the centre point fell within a 5km radius, divided by the total area of these MSOAs), and the percentage classified as greenspace in MSOAs within 10 kilometers, calculated using the same method.

These three alternative measures of access were used as studies have shown that the distance at which greenspace is measured can affect the relationships with health outcomes (for example, (Maas et al., 2009b)).

Measure of mortality

The measures of premature mortality from circulatory causes (age <75 years) for MSOAs were obtained from the Association of Public Health Observatories (APHO, 2011) in the form of standardised mortality ratios (SMRs), standardised by age and sex, over the period 2006 to 2010. Mortality from circulatory causes (ICD10 I00-I99) was used because previous research had shown these causes to have the strongest associations with greenspace access (Mitchell and Popham, 2008).

Statistical analysis

The first part of the analysis examined associations between the three greenspace access measures and the two walking outcome measures, using individual participants in the APS as the unit of analysis. Negative binomial regression models were used as the walking outcomes were counts (days walked) and their distribution was more overdispersed than would be found in a Poisson distribution. A three level multilevel structure was used to take account of the hierarchical nature of the data set (survey respondents nested within MSOAs nested within Local Authorities). All analyses were carried out using MLWLIN (Rasbash et al., 2000) accessed through STATA 11 (Statcorp, 2009) using the “runmlwin” command (Leckie and Charlton, 2011).

Models were run in three stages: First the relationships between the three measures of greenspace access and the two walking variables were tested. As the relationships may not be linear, the greenspace access measures were grouped into quintiles with the first being those respondents with the worst access. Secondly, the relationships were tested with adjustment for potential individual-level covariates collected in the APS (age, gender, ethnicity, social class, car ownership, month of data collection). Thirdly the relationships were further adjusted for MSOA-level environmental variables (Index of multiple deprivation 2010 (CLG, 2011), urban-rural classification (CLG, 2005) and population density (ONS, 2001). Deprivation is a key potential confounder in the relationship between access to greenspace and health and so was controlled for at both an individual level (using social class) and at MOSA level (using the index of multiple deprivation). This additional control at area-level was included to capture characteristics present in deprived neighbourhoods which may be associated with reduced physical activity, for example if deprived areas have higher rates of crime or busier roads.

Differences in the two walking outcomes were examined across the quintiles of greenspace access, and these were expressed as Incidence Rate Ratios (IRRs) to compare the magnitude of effect size across quintiles (i.e. the ratio of mean days walked in quintiles 2 to 5 compared with the baseline quintile) and with a test for trend across the quintiles.

The second part of the analysis examined if greenspace access was associated with area mortality and whether physical activity appeared to mediate this association. It employed negative binomial regression models and was carried out in STATA, using MSOAs as the unit of analysis. The approach used to test for mediation was based on that proposed by Baron and Kenny (Baron and Kenny, 1986) using three regression models: 1) Regression of the mediator (recreational walking) on the independent variable (greenspace); 2) Regression of the dependent variable (circulatory mortality) on the independent variable (greenspace); 3) Regression of the dependent variable (circulatory mortality) on both the independent variable (greenspace) and the mediator (walking). There was judged to be evidence of mediation if significant associations were observed in the first and second models and the magnitude of association between greenspace and mortality was less in the third model than in the second. Perfect mediation was defined to occur if greenspace showed no association with mortality after control for walking.

In order to consider how area deprivation may modify relationships between greenspace, physical activity and mortality, the MOSA data were stratified into four deprivation quartiles based on the index of multiple deprivation 2010. The sequential Baron and Kenny test were then carried out separately for each of the four groups. All models included adjustment for urban-rural classification and population density in line with prior analysis (Mitchell and Popham, 2008). Age and sex had already been accounted for in derivation of the area mortality and walking variables.

Results

Of the 191,325 participants in the APS, 165,424 (86.5%) provided valid postcodes and so could be allocated an MSOA code and assigned measures of greenspace access.

Table 6.1 shows the socio-demographic factors for participants included in the analysis. Compared with the adult population of England using data from the 2011 census (ONS, 2012), survey respondents were slightly older (22.7% aged over 65 compared with 20.3% in England), more female (60.0% compared 51.3%) and less ethnically diverse (84.0% white compared 86.0%). There was an average of 24.4 respondents per middle super output area (standard deviation 15.9), with respondents from all but 8 MSOAs in England. Based on the area-level deprivation scores of the MSOAs in which respondents lived, 18.5% lived in areas classified as in the most deprived quartile of England and 32.3% lived in the most affluent quartile of areas in England.

Table 6.2 shows the relationship between the three greenspace access measures and the two walking outcomes. The values of the IRRs across quintiles of greenspace are shown with no adjustment, after adjustment for individual-level confounders and after additional adjustment for area-level confounders. There is clear evidence of better greenspace access being associated with higher reporting of recreational walking, both before and after adjustment. Across the three measures of greenpace access, there were between 13% and 18% more days of recreational walking reported in the greenest quintile compared with the least green after adjustment for individual and area-level confounders.

Results for the total walking indicator were somewhat less strong (Table 6.2), although the highest prevalence was always recorded amongst participants living in the quintile with best access to greenspace. The strongest trend was with greenspace within 10km of each MSOA, whereby there was a 10% higher post-adjustment reported prevalence of total walking in the greenest quintile compared with the least green.

Table 6.1: Characteristics of the survey participants

	Number (%)	Mean (SD)
Individual characteristics		
Gender (% female) n=165,424	97,544 (60.0)	
Age n= 165,424		55.0 (17.3)
- Working age (16-64)	127,899 (77.3)	
- Older adult (65+)	37,525 (22.7)	
Ethnic group, n = 159,881		
- White	150,360 (94.0)	
- Asian	4,455 (2.8)	
- Black African	3,156 (2.0)	
- Mixed	1,202 (0.8)	
- Chinese/Other	708 (0.4)	
Social class, n = 156,561		
- Managerial/Professional (SEC 1,2)	69,036 (44.1)	
- Intermediate (SEC 3)	17,685 (11.3)	
- Small employers (SEC 4)	14,618 (9.3)	
- Lower supervisory/ routine/ never worked/unemployed (SEC5,6,7,8)	55,222 (35.3)	
Days reported walking in last 4 weeks		
- Total walking		8.3 (9.7)
- Walking for recreational and health		5.4 (8.4)
Area characteristics		
IMD deprivation		
- Most deprived (Quartile 1)	30,518 (18.5)	
- Quartile 2	40,889 (24.7)	
- Quartile 3	40,561 (24.5)	
- Least deprived (Quartile 4)	53,456 (32.3)	
Rural-urban classification		
- Urban	122,804 (75.1)	
- Town and fringe	20,276 (12.4)	
- Rural	20,344 (12.4)	
Area of land classified as greenspace		
- Within MSOA		56.7 (26.2)
- Within 5km		67.8 (21.4)
- Within 10km		73.0 (19.1)

Table 6.2: Rate ratios (and 95% confidence intervals) of number of days reported walking for recreation and health purposes and in total within the last 4 weeks: By quintile of access to greenspace

	Walking for recreation and health			Total walking		
	Unadjusted	Adjusted for individual variables (1)	Adjusted for individual and area variables (2)	Unadjusted	Adjusted for individual variables	Adjusted for individual and area variables
Greenspace within MSOA						
Quintile 1 (worst access)	1	1	1	1	1	1
Quintile 2	1.03 (1.00-1.06)	1.01 (0.98-1.04)	1 (0.98-1.03)	0.97 (0.95-0.99)	0.97 (0.95-0.99)	0.97 (0.95-0.99)
Quintile 3	1.12 (1.09-1.16)	1.07 (1.04-1.04)	1.05 (1.02-1.08)	0.99 (0.97-1.01)	0.99 (0.97-1.01)	0.98 (0.96-1.01)
Quintile 4	1.21 (1.18-1.25)	1.14 (1.10-1.17)	1.08 (1.04-1.11)	1.01 (0.98-1.03)	1.01 (0.99-1.03)	0.99 (0.96-1.01)
Quintile 5 (best access)	1.42 (1.37-1.46)**	1.30 (1.26-1.34)**	1.13 (1.08-1.18)**	1.08 (1.05-1.10)**	1.09 (1.06-1.11)*	1.02 (0.99-1.05) ns
Greenspace 5k						
Quintile 1 (worst access)	1	1	1	1	1	1
Quintile 2	1.06 (1.07-1.14)	1.05 (1.01-1.08)	1.03 (1.0-1.06)	1.00 (0.98-1.02)	0.99 (0.97-1.02)	0.99 (0.96-.1.01)
Quintile 3	1.19 (1.14-1.23)	1.11 (1.07-1.15)	1.07 (1.04-1.11)	1.02 (0.99-1.05)	1.01 (0.98-1.02)	1.00 (0.97-1.02)
Quintile 4	1.29 (1.24-1.34)	1.18 (1.14-1.23)	1.11 (1.07-1.15)	1.05 (1.02-1.07)	1.05 (1.02-1.07)	1.02 (0.99-1.05)
Quintile 5 (best access)	1.51 (1.45-1.57)**	1.35 (1.30-1.41)**	1.18 (1.13-1.23) **	1.13 (1.10-1.17)**	1.13 (1.10-1.16)**	1.08 (1.04-1.11) **
Greenspace 10k						
Quintile 1 (worst access)	1	1	1	1	1	1
Quintile 2	1.16 (1.12-1.21)	1.10 (1.07-1.14)	1.08 (1.04-1.11)	1.03 (1.00-1.05)	1.02 (0.99-1.05)	1.02 (0.99-1.04)
Quintile 3	1.22 (1.17-1.26)	1.15 (1.11-1.19)	1.1 (1.06-1.14)	1.05 (1.02-1.08)	1.04 (1.01-1.07)	1.03 (1.00-1.06)
Quintile 4	1.27 (1.22-1.32)	1.20 (1.15-1.24)	1.12 (1.07-1.16)	1.08 (1.05-1.11)	1.07 (1.04-1.10)	1.04 (1.01-1.07)
Quintile 5 (best access)	1.46 (1.40-1.52)**	1.34 (1.29-1.40)**	1.17 (1.13-1.22) **	1.16 (1.13-1.19)**	1.15 (1.12-1.19)**	1.10 (1.06-1.14) **

Test for trend across quintiles: *p<0.05, **p<0.01, ns=not significant

(1) Individual level variables included in model: age, gender, ethnicity, social class, car ownership, month of data collection

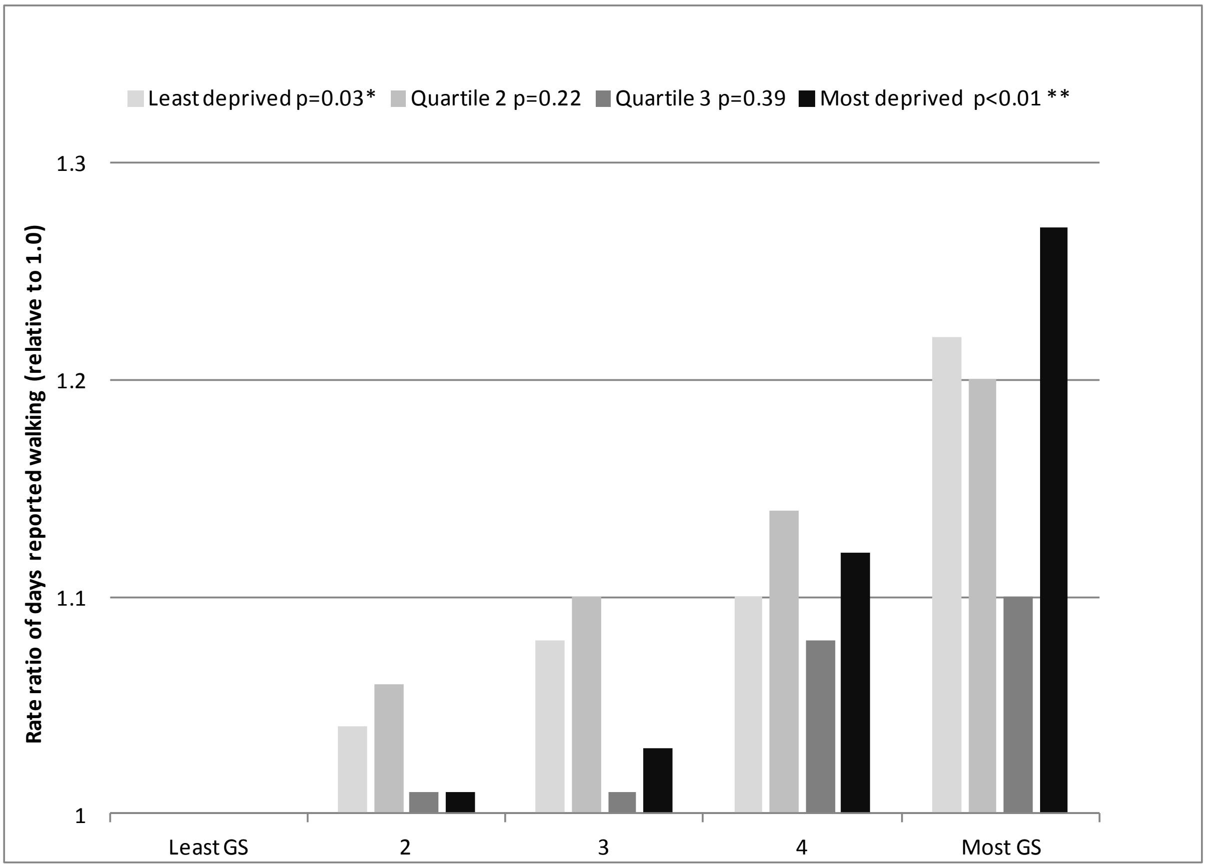
(2) Area level variables included in model: Index of multiple deprivation 2010, urban-rural classification, population density

The results from the first model of the mediation analysis, regressing the mediator (recreational walking) on the independent variable (greenspace), are illustrated in Figure 6.1. Only the findings for the 5km measure of greenspace are presented as those from the other two measures are similar. For each of the deprivation groups, there was more reported recreational walking in greener areas. This trend was strongest for the most deprived group, whereby people living in greenest areas reported 27% more days with walking for recreational or health purposes compared with those in the least green areas (test for trend; $p<0.001$).

The results from the second model - regressing the dependent variable (circulatory mortality) on the independent variable (greenspace) are illustrated in Figure 6.2. For the most deprived group, there was evidence of decreased premature circulatory mortality in greener areas. Relationships were strongest for the most deprived areas in which people living in the greenest areas had a 14% lower mortality rate compared with those in the least green areas (test for trend; $p<0.001$). For the other deprivation groups, there was no clear evidence of trends in the association between greenspace and mortality.

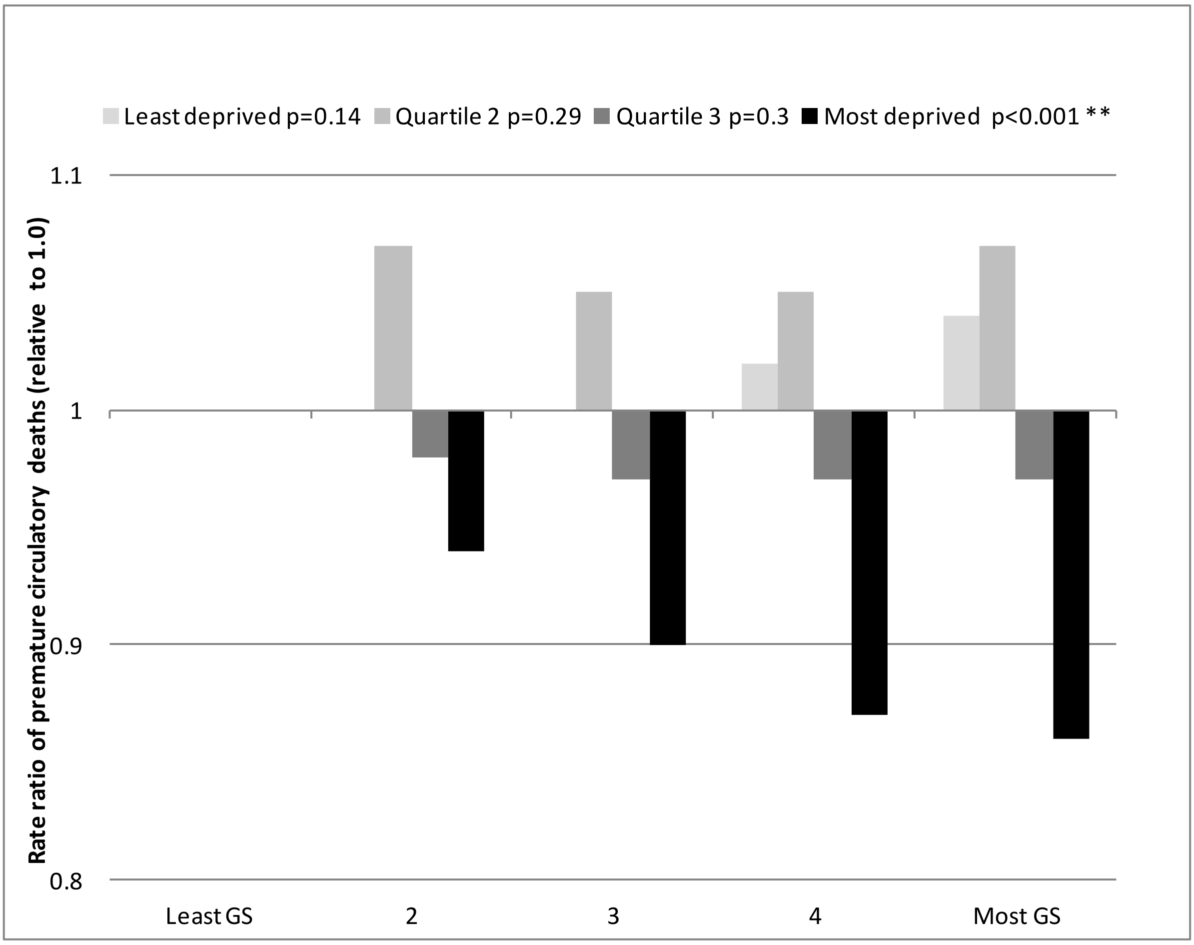
The IRRs and levels of statistical significance in the third model - regressing the dependent variable (circulatory mortality) on both the independent variable (greenspace) and potential mediator (recreational walking) –were almost identical to those obtained from the second model. Therefore, there was no evidence that physical activity, measured by participation in walking, mediates the association between access to greenspace and mortality. For example, in the second model the IRR for the most deprived population living in areas with the most greenspace compared with the baseline least greenspace was 0.95 (0.88-1.02) for the second model and 0.96 (0.90-1.04) in the third model. Many coefficients did not change at all and there was no overall pattern of increase or decrease in values.

Figure 6.1: Rate ratios of days reported walking for recreation and health purposes within the last 4 weeks: By quartile of deprivation and relative to the group with the poorest access to greenspace (group 1).



Test for trend shown in legend (p=). * = p<0.05, ** = p<0.001

Figure 6.2: Rate ratios of premature circulatory deaths: By quartile of deprivation and relative to the group with the poorest access to greenspace (group 1)



Test for trend shown in legend (p=). * = p<0.1, ** = p<0.05

Discussion

The results show that people living in greener areas reported a greater number of days on which they walked for at least 30 minutes, even after control for potential confounding factors. These findings are consistent with some previous studies which have found associations between greenspace access and walking (Giles-Corti et al., 2005) although research to date in this field has been mixed. The associations were stronger for recreational and health walking than walking overall, which supports the hypothesis that this particular physical activity behaviour is likely to be encouraged by presence of greenspace in the local neighbourhood.

After control for confounding factors, people living in the greenest areas, based on a 5km radius from their home MSOA, reported around 18% more days of 30 minute walks undertaken for health or recreation purposes in the last month compared with those in the least green. This equates to walking around one day more per month based on the average reported 5.4 days of walking per month. Given that the UK Government recommends that people engage in five sessions of moderate-vigorous activity lasting at least 30 minutes per week (DH, 2011), this is a relatively small contributor to achieving this target. However, there is evidence that exercise outdoors may infer additional health benefits compared with indoor settings (Coon et al., 2011), particularly for mental health, and so the health advantages of walking in green environments may be more than just their contribution to overall physical activity, especially if the walks are in natural environments. A recent study of England adults found no association between greenspace access and overall walking or with activities hypothesised to be undertaken in greenspace (Mytton et al., 2012) but this study used a dichotomised outcome based on whether the recommended five sessions of activity had been achieved, which may explain why their results differed.

The results confirmed the association between greenspace access and reduced cardiovascular mortality found in other studies (Mitchell and Popham, 2008, Villeneuve et al., 2012) but only amongst the most deprived groups and found no evidence of physical activity, at least when measured by recreational walking, mediating this relationship. The results showed that the relationship between more greenspace and higher levels of physical activity held across all levels of deprivation, although was stronger for the most deprived group than other groups. In contrast, the relationship between more greenspace and reduced premature mortality from circulatory causes was only present and statistically significant for the most deprived group. Given these differences in how deprivation is moderating the relationships, this is further evidence that physical activity is not acting as an underlying mechanism between access to greenspace and reduced premature mortality. The finding that greenspace access is associated with reduced mortality only for the most deprived is consistent with some other studies which have found strongest relationships between greenspace and health outcomes for more deprived groups (e.g.(Maas et al., 2009b)). Potential explanations for this include that more deprived groups spend more time in their living environment (Maas et al., 2009b) or that wealthier groups use local greenspace to maintain, rather than improve, their health as they already incorporate health promoting activities into their lifestyle. The finding that mortality is lower only amongst the most deprived but that all socio-economic groups report more recreational walking when living in greener areas indicates that wealthier groups use local greenspace when it is available to them but achieve the same health outcomes without greenspace.

The results found no evidence of recreational walking acting as a mediator in the relationship between greenspace access and reduced circulatory mortality. Therefore it may be that alternative causal mechanisms explain this relationship, with the most likely potential alternative mediator being the psychosocial benefits of greenspace given that these are associated with cardiovascular health (Yusuf et al., 2004). Maas et al's study of greenspace access and diagnosis specific morbidity recorded by GPs in the Netherlands found that associations were strongest for anxiety disorder and depression and suggest that mental health in particular might be affected by the amount of local green space (Maas et al., 2009b). A recent exploratory study examining patterns of salivary cortisol secretion as a biomarker of stress levels found that greenspace in the living environment was associated with reduced stress, as measured by levels and patterns of cortisol secretion amongst 25 inhabitants of Dundee, Scotland (Ward Thompson et al., 2012). The study found that this effect was not due to physical activity, pointing to the likelihood that regular visits and/or views of greenspace lie behind the association. This study demonstrated the potential to use objectively measured biological markers of mediation effects operating in practice. If used on large samples, approaches such as this could help unpick the mechanisms driving associations between greenspace exposure and health outcomes.

The study has a number of strengths and weaknesses. The large sample of adults was a major strength of the study, as was the use of an objectively derived measure of greenspace generated for small areas for the whole of England and linkage with mortality at a small area level. Coverage of the whole country provided good heterogeneity in greenspace exposure and sociodemographic factors. A particular strength was the attempt to examine mediation mechanisms in the relationships observed but there are caveats to using the Baron and Kenny method to test for mediation, particularly for cross sectional data (Maxwell and Cole, 2007). However, whilst there has been recent development in statistical methods to test for mediation (Emsley et al., 2010) , no superior methodology is yet available which specifically fits the particular example of this dataset. There are clearly methodological limitations in using cross sectional area-level data, as testing for mediation assumes that levels of walking measured by the recent Active People Survey reflect historic levels of walking which would have contributed to levels of health and, ultimately, to premature mortality. Futhermore, the mortality data may not be based on the same people who participated in the APS. However, in the absence of longitudinal studies tracking people's exposure to greenspace and their health outcomes over the long term, the approach used makes the best of available data.

The sampling approach excluded individuals without a landline telephone and, as with any survey, there is the risk of response bias although significant effort was made to maximise participation (Ipsos Mori, 2007). A large proportion of the sample reported no recreational walking in the last 4 weeks (45.5%) and 7.7% of the sample reported the maximum 'ceiling' value of 28, meaning they walked every day. An advantage of the survey was that respondents were asked to give the number of days they had walked, rather than defining their responses into categories. Other weaknesses include that the measure of walking was self-reported, and thus subject to reporting bias. The analysis only looked at walking, although walking is a major contributor to overall activity for most people (Bauman et al., 2009) and the survey only asked about walks of at least 30 minutes, thus excluding shorter bouts of activity which can have beneficial effects on health and may contribute to the overall health benefits of physical activity, Participants were not asked where their walking occurred and so it cannot be assumed that the walking occurred within greenspace. The measures of greenspace access are based on the UK Ordnance Survey digital map data. Validation of this data in chapter five for Bristol showed it to be accurate, but there may be some classification error, in particular for rural areas where the automated process used may not accurately distinguish between accessible greenspace and inaccessible farmland. It would also be preferable to incorporate measures of quality and type of greenspace. However, it was not feasible to generate such measures for the whole country, and it suggested that these limitations are outweighed by the ability to measure local greenspace on a national scale.

The study included adjustment for socio-economic factors at an individual and area level. However, there remains the possibility of residual confounding by socioeconomic characteristics or possibly other unmeasured lifestyle variables, such as smoking, given that this is a leading cause of premature mortality and a Canadian study found that current and long term smokers live in areas with less greenspace (Villeneuve et al., 2012). There may also be selection effects, whereby people who are healthier or more active choose to live in greener areas. The finding that people living in greener areas have a lower mortality rate was consistent with previous studies but it may be that this relationship is not causal, particularly given the finding that levels of physical activity do not appear to be mediating the relationship.

Understanding the mechanisms by which greenspace is associated with health improvement is key to inform how provision of green areas could support communities to live healthily. In England, recent changes in health service configurations has seen the public health function transfer from the National Health Service to local authorities, potentially offering greater opportunity to make evidence-based planning decisions and investments aiming at improving health and reducing health inequalities. The results indicate that, across England, people living in greener areas engage in slightly higher levels of recreational walking. They also have slightly lower rates of premature mortality from circularly disease in the most deprived areas, although the analysis suggested physical activity may not mediate the relationship between greenspace and mortality. Whilst these findings offer support to the body of evidence that documents the health value of public greenspace, future research should concentrate on understanding the causal mechanisms underlying observed associations.

Chapter 6: Summary

Despite emerging evidence of lower morbidity and mortality in greener areas, little is understood about what causal mechanisms drive this association. This chapter evaluates the relationship between access to greenspace, physical activity and mortality. The analysis tests for associations between access to greenspace and self-reported levels of walking using a survey of 165,424 adults across England. Negative binomial regression multilevel models were used to examine associations between access to greenspace (measured as percentage cover at small area level) and self reported number of days walked in the last month, in total and for recreational and health purposes. Secondly an area level analysis of 6,781 middle super output areas across England is used to examine the extent to which recreational walking mediates the relationship between greenspace access and reduced premature mortality from circulatory disease. The results show clear evidence of better greenspace access being associated with higher reporting of recreational walking. There were between 13% and 18% more days of recreational walking reported in the greenest quintile areas compared with the least green after adjustment for individual and area-level confounders. Tests for mediation found no evidence that levels of recreational walking explain the area-level associations between greenspace and mortality. Futhermore, whilst the relationship between greenspace access and walking was observed for all areas, the relationship between greenspace access and reduced mortality was only apparent in the most deprived areas. These findings indicate that the association between greenspace and mortality, if causal, may be explained by mediators other than physical activity, such as psychosocial factors. The chapter therefore offers support to the body of evidence documenting the health value of public greenspace, but future research should concentrate on understanding the causal mechanisms underlying observed associations.

Implications for thesis

Analysis in this chapter show clear evidence of better greenspace access being associated with higher reporting of recreational walking among adults. This is consistent with chapter five’s finding that children living near more greenspace make greater use of it. However, just as there was no evidence that children in greener areas were more active overall, results from this chapter suggest that levels of recreational walking may not mediate associations between greenspace and reduced deaths from cardiovascular disease.

Chapter 7

Conclusions and implications

This thesis explores the relationships between access to greenspace, physical activity and a selected set of health outcomes. The overall aim of the thesis is to explore potential causal mechanisms underlying the relationship between access to greenspace, physical activity and health outcomes.

Starting with a systematic review of the literature, a novel theoretical framework is presented which summarises current knowledge about the hypothetical causal pathways between access to greenspace and health outcomes. Subsequently, the thesis explores the use of different types of urban spaces for physical activity by children and assesses the association between access to greenspaces and time and physical activity within them. A study of adults across England then explores relationships between neighbourhood greenness and recreational walking, and explores if there is evidence that physical activity mediates relationships with reduced mortality.

This final chapter summarises findings from the previous chapters and draws overall conclusions from them. The implications of the research findings are highlighted, firstly in relation to policy and planning and secondly in relation to theoretical and methodological applications. The key strengths and weaknesses of the thesis as a whole are then discussed, followed by some suggestions for future research.

Summary of principal findings

Chapter two reports findings from a systematic review of quantitative studies examining relationships between objectively measured access to greenspace and obesity-related health indicators. Whilst the majority (68%) of the 50 identified studies published between 2000 and 2010 found some evidence of a positive or weak association, the overall picture emerging from this relatively new field of research is that the relationship between greenspace and health is far from unequivocal, with inconsistency in results across studies and indications that relationships vary by factors such as age, socioeconomic status and measure of greenspace used. In particular, there is not yet consensus as to what mechanisms underlie observed associations. Quality assessment of the published papers highlighted key methodological challenges facing the field, such as reliance on subjective outcome measures (70% of reviewed papers), measures of greenspace access which take no account of quality or type (73%) and that the majority of studies (83%) do not test whether people are actually using the greenspace.

One of the main conclusions of the evidence review is the need for a theoretical framework which documents the conceptual underlying processes linking greenspace access with health outcomes. Chapter three presents such a framework, developed following assessment of research identified in the review plus an additional review of studies concerned with wider markers of health status related to greenspace access, including mental health, and a review of existing social-ecological models. The framework highlights how mediating processes – such as use of greenspace and perceptions of the living environment – drive associations between access and both physical and psychological health outcomes. Potential moderators are presented, drawing on evidence that the strength of association between greenspace and health varies by subgroup. These factors are illustrated in the framework as four groups: Demographic factors, such as gender, socio-economic status; Living context, such as rural-urban setting and other features in the environment; Characteristics of green space, such as type, quality and features within it; and Climate, including light, temperature and rainfall. The chapter outlines the theoretical mechanisms of moderation and the mediating processes, highlights the factors for which evidence of moderation exists in published research and suggests other areas which have not yet been empirically tested but for which there is good theoretical basis to suggest they may act as moderators.

The review of evidence and the theoretical framework presented in chapters two and three summarised the current knowledge base and also identified key areas requiring further research or development of methodological approaches. This knowledge subsequently informed the empirical research described in the following three chapters, which aimed to tackle some of the key gaps in knowledge.

Chapters four and five were concerned with analysis of GPS and accelerometer data collected from 902 children aged 11-12 years participating in the PEACH study. Chapter four quantified how much physical activity occurs within different types of greenspace, assessed how this activity contributes to total non-school activity and measured how useage varies by different types of greenspace. The analysis found that time in greenspace contributed over a third of all outdoor MVPA during weekday evenings, over 40% on Saturdays and almost 60% on Sundays. This provides evidence that, at a population level, greenspace may be an important contributor to overall levels of activity. The majority of activity occurred in non-green environments, such as on roads and pavements, indicating the broad ways in which children gain physical activity.

Chapter five used the GPS-accelerometer data from the PEACH study to investigate relationships between living in green neighbourhoods, spending time in greenspace and overall levels of MVPA. As illustrated in the theoretical framework, being active within greenspace is one of the principal routes of mediation through which living in greener neighbourhoods could lead to improved health outcomes. The analysis aimed to address a major limitation identified in the majority of reviewed research, which was reliance on neighbourhood-based metrics to measure associations between access and total physical activity. Results showed that children living in greener neighbourhoods spent more time in greenspace and also recorded a greater number of minutes of MVPA in them than their counterparts in less green areas. Relationships varied by greenspace type, with the strongest and most consistent associations for formal areas. However, better access to greenspace was not associated with higher levels of overall non-school MVPA.

Chapter six continued to explore the potential causal processes between greenspace access and health outcomes, with a shift in focus to look at adults. The analysis of a large sample of adults across England evaluated the relationships between greenspace access, physical activity and mortality from circulatory causes. One of the key gaps in knowledge highlighted by the review of existing evidence was the need to understand the mediating processes linking greenspace access with health outcomes such as reduced mortality. The analysis tested if there was an association between access to greenspace and self-reported levels of walking using a survey of 165,424 adults across England. Secondly an area level analysis of 6,871 middle super output areas examined if there was evidence of recreational walking mediating the relationship between greenspace access and reduced premature mortality from circulatory causes. Findings showed clear evidence of better greenspace access being associated with higher reporting of recreational walking. However, tests for mediation found no evidence that recreational walking explains the area–level associations between greenspace and mortality. Whilst the relationship between greenspace access and walking was observed for all areas, the relationship between greenspace access and reduced mortality was only apparent in the most deprived groups. These findings indicate that the association between greenspace access and mortality, if causal, may be explained by mediators other than physical activity, such as psychosocial factors.

Taken together, these analyses offer some support to the body of evidence documenting the positive relationship between access to greenspace and physical activity. Living in greener areas was associated with using greenspace more and recording more physical activity within it for children in Bristol and with reporting higher levels of recreational walking for adults across England. However, how these apparent relationships relate to wider health outcomes is less clear. Children in greener areas were not more active overall, suggesting that those with less access were obtaining their activity in non-green environments. Similarly, adults across England in greener areas did not exhibit reduced premature mortality from circulatory causes, except in the most deprived locations. Overall, there was no evidence of recreational walking mediating the relationship with mortality.

The finding that children living nearer greenspace are more active within it and adults living in greener areas walk more for recreational purposes may still represent important health benefits of greenspace, even if these associations do not appear to explain the relationships with total physical activity or wider health outcomes, such as reduced mortality, which other studies have documented. The benefits of spending time outdoors and in natural environments are well established. Whilst research evidence into the relationships between greenspace and health is mixed, evidence that spending time outdoors and in natural environments is good for your mental health does appear to be emerging as a robust conclusion (Ward Thompson et al., 2012, Groenewegen et al., 2012, Bratman et al., 2012). Moreover, the mutually supportive links between mental health and physical health are also well established, in that those with greater mental health tend to be physically more active and healthy and vice versa (Penedo and Dahn, 2005).

In terms of how the findings relate to other recent research, publications subsequent to the evidence review (which was of studies up to end of 2009) have continued to paint a mixed and often contradictory or counter-intuitive picture. For example, two recent studies within England found that people living in greener areas have higher rates of obesity (Cummins and Fagg, 2012) and report higher levels of physical activity types not plausibly related to the presence of greenspace (gardening and do-it-yourself, and occupational physical activity) (Mytton et al., 2012). Recent international studies include those reporting no association between greenspace access and mortality in New Zealand (Richardson et al., 2010) and across US cities (Richardson et al., 2012).

Given these mixed findings, it is appropriate that research moves beyond merely describing relationships and begins to unpick the potential causal mechanisms at work, as demonstrated in this thesis and in some other concurrent research. A noteworthy other example is the "Vitamin G" research programme in the Netherlands, which recently summarised several years of research exploring greenspace and health (Groenewegen et al., 2012). The authors conclude that stress reduction and social cohesion are more likely explanatory mechanisms underpinning relationships between greenspace access and health outcomes than physical activity. The summary also refers to a forthcoming analysis (not yet published) which has found that activities related to greenspace, such as walking and cycling, were at best a partial mediator of the relationships with wider health outcomes, with stronger evidence for stress reduction and social cohesion acting as mediators.

In conclusion, this thesis documents positive associations between access to greenspace and physical activity within it (for children) and recreational walking which is plausibly undertaken within it (for adults). This supports the potential value of greenspace as a health promoting resource. Whilst this also supports the possibility that physical activity within greenspace could be an explanatory mediator in relationships between greenness and wider health outcomes, indications from this thesis and a converging body of work do not support this conclusion and suggest instead that other mediators, such as stress reduction, are more important.

Implications for policy and planning

As outlined in the introductory chapter, there is a historical tradition of recognising greenspace as a valuable asset in towns and cities, valued both for its benefits to nature and the potential advantages to human health. There has been a resurgence of these ideas in recent years, as reflected in this recent statement by the charity Groundwork (2012): "*For the past three decades public, private and voluntary sector organisations – urged on by campaigners and academics - have been collaborating to ensure communities everywhere have access to good quality green space and the opportunity to learn from and look after the natural environment on their doorstep*". However, parallel trends over the same time period threaten this achievement. For example, a rising and ageing population, with a trend to smaller household sizes and increasing numbers of people living alone (ONS, 2012), creates pressure on planners to provide sufficient housing stock. There has also been a trend to replace front gardens with parking areas to accommodate rising vehicle ownership (Bates and Leibling, 2012). A study of greenspace in Merseyside found that between 1975 and 2000 land identified as greenspace decreased by 6%, with reduction in private garden space and conversion of public open space into new housing (Pauleit et al., 2005). It is a challenge to create and protect public greenspace areas in the face of a myriad of other competing planning priorities. Moreoever, given the trend in other factors which contribute to reduced physical activity and rising obesity, such as reduced physical effort at work, the importance of neighbourhood greenness to support physical activity may well be heightened.

In the UK, planning policy is currently in a time of transition since the change of Government in 2010 and the subsequent transformation of planning policy represented by the new national planning policy framework (NPPF) published in March 2012 (CLG, 2012). The NPPF requires local planning policies to set locally derived standards for open space, protect and enhance rights of way and access, and identify specific needs and deficits or surpluses of open space. It also states that existing open space, buildings and land, including playing fields, should not be built on unless an assessment clearly shows that the space is surplus to requirements or that the benefits of the development clearly outweigh the loss.

Alongside the NPFF, other key policy instruments relevant to greenspace accessibility are the Localism Act 2011 (HMG, 2011a) and the Natural Environment White Paper 2011 (HMG, 2011b). The Localism Act 2011 was a far-reaching reform of the planning system aimed at devolving decision making to a local level and introducing a new voluntary neighbourhood planning process. It sets the tone for much of the NPFF and in particular, is the driver behind a new power to communities to designate areas as 'local green space' which then rules out new development other than in very special circumstances. This designation is only intended for greenspace which is "demonstrably special to a local community and holds a particular significance" (such has having beauty, historic significance, recreational value, tranquillity or richness of its wildlife), is in close proximity to the population and relatively small in size. Whilst the aims of the Natural Environment White Paper are predominantly to protect nature (e.g. halting biodiversity loss) rather than to improve human health, the paper establishes several initiatives which are relevant to the interface between greenspace provision and health improvement. For example, the paper suggests that local nature partnerships (LNPs) should work closely with health and wellbeing boards (new statutory bodies at local authority level which bring together health care, social care, public health and other public service practitioners to oversee commissioning decisions and aim to reduce health inequalities) to contribute to local planning and decision making.

Overall, the current UK policy position makes clear that greenspace should be considered an important priority in planning decisions and thus be protected and maintained. However, how this priority plays out at a local level, alongside the myriad of other planning principles, is less clear. The publication of the NPPF represented a major overhaul of planning policy and begins a much less prescriptive approach to planning in general than previously. For several years the policy guidance PPG17, published in 2002, required local authorities to audit local greenspace provision in relation to the needs of residents, and ensure that the space was fit for purpose, economically and environmentally sustainable (CLG, 2002). This guidance (along with a whole raft of other planning policies) has now been superseded by the all-purpose NPPF, a principles-based system in which local areas have freedom to choose their own direction. Whilst an advantage of this change in policy direction is greater local interpretation and flexibility, concerns have been expressed among advocates of greenspace (e.g. Greenspace, 2011) that abandonment of specific and detailed planning guidance offers less protection for greenspace and could increase inequalities if approaches vary between councils. Certainly the "golden thread" running through the NPPF is a presumption in favour of sustainable development. Alongside this, current economic pressures mean that councils face budget cuts, and the future of non-statutory services are at risk. Furthermore, the removal of public funding from agencies such as the Commission for Architecture and the Built Environment (CABE), which advised the Government on urban design and public space from 1999 to 2011, risks the loss of key expertise and advocacy in the field, particularly as agencies such as CABE provide a key bridge between academic evidence and practice.

Given this current state of change in planning policy and the prevailing climate of economic pressures, research into the relationships between greenspace access and health is particularly important if it can support local agencies to make planning and investment decisions which are based on robust evidence. Within England, the public health function has recently transferred from health service control to Local Authorities, which may represent a greater opportunity for health research to influence decision making and inform evidence-based planning. The literature review and the resultant framework presented in this thesis summarises what is currently known about the topic and could assist practitioners to apply the evidence when developing greenspace strategies for their local population. Knowing that the effect of greenspace on physical activity and health outcomes may vary by population group or by context prompts local analysis to assess the needs of their specific population and consider appropriate and targeted greenspace provision.

In terms of how the conclusions in this thesis could guide policymakers, the finding that adults across England living in greener areas walk more and those in deprived areas live longer lends support to the importance of greenspace as a health promoting resource. Within Bristol a substantial proportion of children's activity occurred within public and private greenspace and access to certain type of greenspace was associated with more activity within them. These findings serve as a message to urban planners to provide adequate levels of public and private green space when designing new residential developments. There was also evidence that certain types of greenspace are more supportive for physical activity than others. A high proportion of children's outdoor activity was in areas specifically designed for use by children or teenagers, indicating that these facilities are valuable resources for physical activity. In the analysis comparing access with use, formal space showed the most consistent associations, which supports a prior study of adults in Bristol (Jones et al., 2009a) and suggests that this traditional or municipal park type may be particularly supportive for physical activity across the age groups. The finding of under-utilisation of parks during weekday evenings may be because these areas are inadequately lit or not weather-appropriate and so interventions which make these spaces more usable all through the year could help increase their value as a physical activity resource.

Other findings in the thesis offer more mixed messages to policymakers, in that access to greenspace was not associated with children being more active overall and recreational walking did not appear to explain associations between greenspace access and reduced mortality. This mixed picture is consistent with much of the other research in this field and indicates that the long-standing policy rhetoric which emphasises the value of greenspace is not (yet) strongly supported by empirical evidence that this space is important for physical activity and certainly not supported by clear understanding of the mechanism underpinning this relationship. It may be that this support will emerge and more clearly inform policy as evidence accumulates and research methods develop. Moreover, in addition to its use for physical activity, greenspace has a whole range of other potential benefits to health, as illustrated by the theoretical framework. There are also the wider benefits of greenspace to society, such as maintaining ecosystems and diversity, mitigating against climate change and its economic role as a leisure and tourist destination - all benefits which may infer some human health advantage, albeit indirectly. A consortium of environmental organisations, led by the Town and Country Planning Association and the Wildlife Trust, have produced guidance to sit alongside the NPPF which offers advice as to how to manage and enhance green infrastructure through the planning system (Town and Country Planning Association & The Wildlife Trusts, 2012). Whilst this guidance does mention the potential human health benefits of greenspace, its focus is predominantly about protecting the natural environment. As consensus emerges as to the role of greenspace as a health promotion resource, summarising findings in guidance materials similar to this example could be a useful aid to support practitioners and policymakers translate evidence into practice.

A key group who may benefit from greenspace provision are those who are socio-economically disadvantaged. It is well established that more deprived populations are less physically active (Gidlow et al., 2006), have higher rates of obesity (Butland, et al., 2007) and have poorer health outcomes (Marmot et al., 2010). Despite a concerted public health focus on reducing health inequalities in recent decades, inequalities in health outcomes and life expectancy persist between communities with different levels of deprivation across England (Marmot et al., 2010). The analysis in this thesis of the Active People Survey found that associations between greenspace access and reduced premature mortality from circulatory causes was only present in the most deprived areas of England, possibly indicating that more disadvantaged groups gain most from provision of greenspace. Previous research found that deprivation-related gradients in mortality were reduced in greener areas across England (Mitchell and Popham, 2008), suggesting that green environments have potential to help reduce health inequalities.

The causes of health inequalities are undoubtedly due to multiple mechanisms and therefore interventions operating at multiple levels are required to tackle them. There is increasing recognition that macro-level strategies, such as enhancing the built environment and providing greenspace, could be effective alongside micro level interventions (e.g., individually targeted) (Pearce and Maddison, 2011). Moreover, evidence suggests that strategies aimed at individuals encouraging them to change behaviour and bottom-down interventions to reduce health inequalities have largely failed. Thus, a strong case can be made for providing communities with environments which support them to be active, as this has potential health benefits for the whole population and could also particularly support the most disadvantaged and thus help reduce health inequalities. An advantage of good quality greenspace is that they are often flexible and can provide a free range of facilities for different groups, such as dog walkers, joggers, bird watchers and children wanting to play. This is in contrast to more specific sports provision, which may serve only a small sector of the community (Townshend, 2012).

Methodological and theoretical implications

It is hoped that this thesis makes several key contributions to methodological and theoretical advancement in the field of greenspace and health research. The development of an evidence-based theoretical framework, which documents the conceptual processes between access to greenspace and health outcomes, will hopefully serve as a future resource for other researchers and could help facilitate a step change in how well studies consider and specify the causal pathways being tested. In particular, there is greater need to consider moderating and mediating factors, as the vast majority of the reviewed research did not document the specific processes and factors being tested and instead was based on fairly loosely defined concepts.

The test for mediation in chapter six is one of the first analyses to empirically test what causal pathways might be operating in the relationship between greenspace access and health outcomes. Due to the cross sectional nature of the data, this analysis was, by necessity, rather exploratory in nature as it would not be possible to confirm or rule out that mediation was operating. However, from a methodological perspective, it represents an improvement on merely describing relationships. The finding that recreational walking does not appear to be mediating associations with mortality could be tested more robustly in the future using longitudinal data if and when available. Similar approaches have been used for other health topics. For example, a recent study examined whether small area-level smoking indicators explain deprivation inequalities across Scotland (Popham, 2011). Such examples demonstrate the methodological potential to link available data at small-area levels and begin to test some of the documented relationships between place and health for which the casual mechanisms are poorly understood.

The use of combined GPS-accelerometer methods to simultaneously measure the location and intensity of physical activity is a relatively novel method and the use of it in this thesis represents one of only a few applications to date. Overlay of the GPS data with detailed land use mapping data for children in the PEACH study demonstrated that GPS coordinates could be collected at sufficient accuracy to allocate detailed land use exposures to individuals according to the locations in which they have recorded GPS time. The major advantage that GPS data offers is the ability to objectively measure the locations where people are active (Krenn et al., 2011), rather than being reliant on collecting this information through self-reported questionnaires e.g. a question in a survey such as “have you been physically active within a green space within the last 7 days?”. Outcome data collected from such surveys may suffer from response bias whereby respondents inaccurately recall their true behaviour. This causes bias in the analysis if, for example, people are more likely exaggerate the amount of physical activity they do in greenspace if they live nearer to it (perhaps because they are more aware of the park being there). In consequence, effect sizes may be over-estimated. In addition to reducing response bias, the use of GPS-accelerometers allows collection of much richer and more detailed data (measuring exactly how physically active people are at each location) than would be feasible to expect someone to recall.

Given that use of GPS in this way is an innovative and developing approach, there are still limitations and uncertainties in the methods used. There is not yet consensus about how to deal with signal drop out or 'drift' (Duncan et al., 2009) or how best to generate routes of travel, for example to analyse journeys to and from greenspace. A more fundamental limitation raised in a recent paper by Chaix et al. (2013) is the potential pitfall of selective mobility bias whereby the GPS locations visited are used to generate measures of environmental exposure, for example using the route walked by an individual to compute how accessible greenspace is to them. Given that the individual has chosen to walk this particular route, perhaps specifically choosing to go near or through greenspace, it could be a circular argument to test if their physical activity in greenspace varies according to how accessible it is to them from this route walked. Chaix et al suggests that careless use of GPS data could be "one step backward rather than one step forward" for assessment of causality. The authors go on to propose some strategies to help overcome this source of confounding, which include filtering of the data to generate measures of spatial accessibility from "anchor points" which exclude locations specifically visited for purposes related to the outcome being investigated.

The issues raised by Chaix et al serve as a useful caution to researchers to ensure that GPS data are used appropriately. The analysis of the PEACH data presented in chapters four and five used the GPS data to measure outcomes (how much activity occurred within greenspace) but not to generate exposure measures (access to greenspace), as these were based on the neighbourhood surrounding where the children lived. Therefore, this analysis was not affected by selective mobility bias, as acknowledged by Chaix et al in their review of the published work based on chapter four. Future work using the PEACH data could potentially derive additional measures of accessibility which take into account the different environments which children move around in, for example looking at the routes between home and school. Such work would require consideration of the issues raised by Chaix et al to determine how best to process the data without introducing mobility bias. More fundamentally, GPS data offer enormous potential to enable a far richer understanding of the multiple environments within which people operate and thus generate more sophisticated metrics of exposure not constrained by the assumption that only the immediate vicinity of people's home environment is important. As with many new methods or technologies, it may take some time and debate before consensus emerges as to how its potential can best be realised.

Another key area of methodological contribution was in the approaches used to measure access to greenspace. The literature review found that studies were heterogeneous in the measures used, with the most common approaches being distance to nearest greenspace or percentage of greenness within a certain distance or area. A minority of studies incorporated measures of quality or available facilities and a few used a gravity model approach which modelled access based on the number and size of park areas available. A risk of this heterogeneity is that different methodological approaches could affect the ensuing results, as demonstrated in a recent comparison of alternative greenspace measures in Cardiff, Wales (Higgs et al., 2012). Access measures at different scales or which capture different aspects of the environment potentially limits comparability of findings across settings (Pearce and Maddison, 2011).

Given that previous research had indicated that the distance at which greenspace is measured can affect relationships with health outcomes (Maas et al., 2009b), three metrics of greenspace access were used for the analysis of the Active People Participants across England (within MSOA, within 5k and within 10k). There was no significant trend for the within MSOA measure for total walking and associations between greenspace access and recreational walking were stronger for the 5k and 10k measures than the within MSOA measure. These results therefore suggest the importance of measuring greenspace access at a scale which is appropriate for the research question being tested. Given that some MSOAs are small, particularly in urban areas, it makes sense that residents may use a larger area for walking. Measuring greenspace just within an MSOA is a poor measure of greenspace access for residents of a MSOA which covers one housing estate but is immediately adjacent to a public park.

The study of children in Bristol also used three alternative measures of greenspace, based on distance, area and a gravity model, representing commonly used approaches. The results do show some differences according to the measures used and across the different types of greenspace, thus indicating that the most appropriate measure of accessibility may depend on the type of greenspace. For example, children's use of a play space with facilities may be most influenced by length of walking distance to the space whereas the total size of available space might be more important for informal park types used for jogging and walking.

Strengths and weaknesses

The individual chapters each include a discussion of their strengths and weaknesses. This subsequent discussion is therefore concerned with summarising the overriding strengths of the thesis as a whole and the broader weaknesses and challenges which faced the programme of work undertaken and which are relevant to the wider topic of research.

The major strengths of the work presented in this thesis include development of a novel theoretical framework which for the first time illustrated the theoretical relationship between access to greenspace and health outcomes, and a review of published work which was systematic, broad in focus and included assessment of methodological quality. For the empirical analysis of the PEACH data, the use of GPS-accelerometer methods provided an objective measure of both location and intensity of physical activity, thus using a more specific and valid outcome measure than has been used by the vast majority of existing research. The greenspace measures used for the PEACH participants were based on detailed and well characterised mapping data which included information about type of greenspace. For the England wide study of adults, availability of the Active People Survey linked to small areas codes allowed a comprehensive analysis with good heterogeneity in greenspace exposure and deprivation. Other strengths include relatively large sample sizes for both analyses – the PEACH study is one of the largest samples of GPS-accelerometer data collected to date and the Active People Survey is the largest survey of physical activity ever conducted in Europe – and the use for both studies of objectively derived measures of greenspace produced at small area level.

The limitations of the thesis reflect some of the key challenges which face researchers attempting to understand the relationships between greenspaces and health. One significant limitation identified in the systematic review was reliance on cross sectional methods and this limitation also applies to the analysis then undertaken. Cross sectional study designs are a major impediment to investigating causality. In particular, there is the risk of indirect or direct self selection effects. Indirect selection occurs when people with certain characteristics, such as a high income, choose (or can afford) to live in greener environments. These indirect effects have been controlled for statistically in the analysis through adjustment for SES variables. However, there remains the possibility that residual confounding could explain some of the observed associations, for example by unmeasured variation in socioeconomic factors, by other lifestyle variables such as smoking or by other environmental factors such as air pollution (Villeneuve et al., 2012). Properties located next to greenspace or with views of nature may be the most desirable and expensive to live in or attract a certain demographic of people, but these localised and subtle differences may not be adequately captured by generic measures of deprivation used.

Direct selection occurs when people who are physically active or healthier choose to live in greener areas i.e. the bias in selection is associated with the outcome variable being studied. For example, older people in good health move out of urban areas into greener areas upon retirement whereas less healthy people remain living in cities. This "healthy mover" bias could lead to an over-estimate of the health effects of green environments. Bias in the opposite direction is also possible if people in poorer health choose to live in a green area, perhaps to use it as a source of restoration. Whilst population mobility in general is related to socio-demographic characteristics such as age, income and education, it is not possible to measure and adjust accurately for direct selection using cross sectional study designs. Some authors have argued that direct selection effects have potential to cause significant bias in studies examining the effect of the environment on health (e.g. Boone-Heinonen et al., 2009, Bentham 1998*)*, potentially obscuring real environmental causes or producing spurious associations. However, evidence from longitudinal studies indicates that direct selection effects are not responsible for measured effects of the environment and may even bias associations toward the null rather than act as a positive confounder (Verheij et al., 1998; Boone-Heinonen et al., 2010). No study has yet explicitly tested the role of direct selection as a bias in studies examining greenspace and health outcomes, but Giles Corti et al's recent analysis of RESIDE, a 5-year longitudinal study of people moving into new housing developments in Perth, Australia, found no evidence that self-selection related to choice of residential location was associated with changes in walking upon relocation to a new neighbourhood (Giles Corti et al. 2012).

The analysis in this thesis uses objective measures of access to greenspace. One of the inclusion criteria for the literature review in chapter two was that access measures were derived by GIS or produced using trained auditors with a consistent assessment tool. The greenspace access measures used in the subsequent analytical chapters were generated in GIS. The main advantage of using objective measures is avoiding potential bias introduced by subjective (self assessed) indicators of greenspace accessibility. As represented by the theoretical framework in chapter three, perception of greenspace access is an important mediator in the pathway between objective access and the potential health benefits i.e. two people may have the same objectively measured access but their perceptions of how good their access is will determine how much they use the space and how much health benefit it confers to them. It is plausible that these differences in perception may be associated with the outcome being studied and thus could bias the results. For example, people with more positive perceptions of their environment may also be those who over-report their participation in physical activity.

Other positive implications of constraining the focus to objective measures of greenspace access is that the methods can easily be translated by other practitioners and the approach used can be replicated across different study areas, thus improving generalisabilty and comparison. However, a limitation of not using subjective measures is that the potential importance of perceptions of greenspace as a mediator could not be explored. In fact, the social meaning attached to greenspace may well be a far more important driver of health than merely having physical access (Macintyre et al., 2008). Studies have found there can be very poor agreement between objective and subjective measures of greenspace (e.g. Lackey and Kaczynski, 2009, Macintyre et al., 2008, Kirtland et al., 2003). A further limitation of the objective measures of greenspace used is that they did not capture any markers of quality and this is a limitation of the vast majority of published work. Subjective measures access may be better at capturing quality as people will make a value judgement about the quality of the space when answering how good their access if. However, quality is difficult to measure (Mitchell et al., 2011) and, furthermore, as discussed in chapter three, perceptions of quality are likely to vary by user type and preference.

The framework presented the key mediating and moderating factors which researchers should consider. However, in reality, determining what factors to include in the analysis and specifying how they may relate to each other can be challenging, given the complex web of interrelated factors which is the very principle of social-ecological theory. For example, socio-economic status could in theory act simultaneously as a moderator (if use of greenspace varies by socio-economic group) and a confounder (greener areas are generally more desirable and expensive to live in, plus wealthier people have better health). It is not practical to investigate and unpick these multiple factors and moderator-mediator interactions in every analysis. Therefore, the analysis in this thesis focussed on some identified areas of key interest for which the data available allowed high quality analysis, but there remain lots of unexplored potential and theoretical unknowns.

The “Baron & Kenny” method (Baron and Kenny, 1986) was used to explore if recreational walking mediates relationships between access to greenspace and reduced premature mortality. Along with structural equation models (SEM), which are essentially the same as Baron & Kenny when testing for partial mediation (James et al.,2006), this approach has for a long time been the dominant method used to explore mediation. The validity of this method has recently been criticised, in particular because any residual or hidden confounding between mediator and outcome could bias the results (Emsley et al., 2010). An alternative test for both moderation and mediation, called the ‘causal inference’ approach, is being developed by statisticians. This includes the ability to test for unmeasured confounding and has been demonstrated as a statistically more robust approach when analysing treatment effects in randomised controlled trials (Emsley et al., 2010). There are also related tools under development for various statistical packages to support researchers apply the techniques in their research. It may be superior methods will soon emerge which could be applied in analyses such as that explored in this thesis. However, and importantly, given that one of the main criticisms of the ‘Baron & Kenny’ approach is that it may over-estimate mediation due to unmeasured confounding, over-estimation was certainly not an issue given that no mediation effects were found.

A further challenge is that the effect of any one individual environmental feature, such as greenspace, on health may be small and is likely to interact with a whole web of other factors and so hard to quantify in isolation. It has been documented that, in general, the contribution of environmental variables in explaining levels of physical activity is small and less important than, for example, sociodemographic factors (Jones et al, 2007). Chapter five showed that children with the best access to greenspace were more active within it, but this only represented a few minutes difference in MVPA in absolute terms. The effects of greenspace access on adult’s recreational walking and reduced mortality in chapter six were similarly modest. This does not indicate the results are not of public health significance, as it may well be the case that relatively small changes in physical activity levels could play an important role in the reversal of obesity trends (Jones et al, 2007). Futhermore, an advantage of environmental interventions, such as provision of greenspace, is that it is a population level resource from which the vast majority of the population can benefit from, rather than specific interventions aimed at certain groups. However, it is a challenge for research into environmental influence on health that it is extremely difficult to provide the type of hard evidence comparable with, for example, empirical clinical data used to measure the direct impact of medication, or the effects of smoking on lung cancer. Furthermore, the potential time lag between changes in the environment and long term health outcomes, such as reduced mortality, means that benefits from greenspace take time to become realised.

In this thesis the analysis of the relationships between greenspace access and activity outcomes used regression models to test for associations, with control for key confounding factors. For the analysis of the Active People Survey in chapter six, multilevel regression models were used. Multilevel models are one of the main analytical approaches used to test for effects of places on health as they assess variation at the different levels (at the individual level and at neighbourhood level). However, both normal and multilevel regression models assume simple relationships between variables and therefore do not capture the dynamic links and interactions between individuals and their environments (Auchincloss and Diez Roux, 2008). For example, in addition to selection effects (whereby active or healthy people choose to live near greenspace), people may adapt their behaviours in response to collective behaviours (e.g. seeing other people use greenspace may make an individual more likely to themselves). It has been proposed that computer simulation models (agent based approaches), which allow these dynamic processes to be explicitly tested and modelled, could be used to simulate such interactions and thus model the effects of the environment on physical activity and health. If sufficient data were available to allow such approaches to be developed (the concept is largely theoretical at the moment), examples of their potential application include modelling the effects of greenspace related interventions, such as provision of a new park in a neighbourhood. Samples of GPS-accelerometer data, such as that analysed in this thesis, could also potentially be used to inform parameters within computer models which simulate activity choices and walking behaviours at the micro level. The use of GPS-accelerometers is relatively new, but over time data could potentially be pooled together to give larger samples and provide more robust data to estimates for scenario modelling.

Suggestions for future research

The evidence review and theoretical framework identified several key areas where empirical findings were lacking. The subsequent analysis then aimed to address some of these evidence gaps. Given that research into the relationships between greenspace and health is a relatively new discipline and findings to date are equivocal, there are still many theoretical unknowns and thus lots of areas where more research is needed. In particular, there is a need for evidence from longitudinal studies or natural experiments to supplement and test the findings from cross sectional methods. The mechanisms illustrated in the theoretical framework illustrate a whole myriad of potential research questions, many of which are, as yet, poorly understood. Some suggested priorities for future research are outlined below.

One topic which this thesis did not explore and is a key area for future research is developing understanding of how perceptions of access to greenspace moderate relationships between objectively measured access and physical activity. Studies have shown that there can be poor agreement between objective and subjectively reported access ((e.g. Macintyre et al., 2008; de Jong et al., 2011). How greenspace and the surrounding environment, such as routes to and from it, are perceived are important determinants of how it is used and these perceptions may vary across groups, as represented in the framework. This future research should include perceptions of safety, as evidence indicates a direct link between perceptions of safety and physical activity, at least for certain groups such as older people, women and minority groups (Townshend and Lake, 2009). Qualitative research could help unpick some of these relationships, for example local case studies which use a mixture of qualitative and quantitative techniques (Kessel et al., 2009).

One of the findings from the evidence review was that the majority of greenspace access measures used in existing research were relatively crude and rarely included information about the type of greenspace or features within it. The data used in the PEACH analysis presented in this thesis was one of the first studies to look at different types of greenspace and future research should continue to investigate these relationships. A greater understanding is needed of how different types of green environments relate to health, including formal parks and gardens, wilder strips of land, sports pitches, playing fields so on. It is also important to seek to understand how routes to and from greenspace affect how the space is used. Whilst lack of mapping data has historically prevented such analyses, the recent proliferation of mapping data availability offers an opportunity for future research. For example, online mapping data can be used to remotely assess the quality of parks (Taylor et al., 2011) or the surrounding streetscapes (Rundle et al., 2011) without requiring costly site visits and audits. For more local studies, where detailed characterisation is possible, resources such as the recently developed neighbourhood green space tool (NGST) (Gidlow et al., 2012) supports standardised assessments of greenspace quality. Similar to the approach used in this thesis, future research should encompass a mixture of small area detailed case studies, using accurately measured and well contextualised measures of access, alongside larger scale studies with sufficient power to detect population level health effects.

The literature review and the theoretical framework were deliberately broad in scope and encompassed all age groups, types of greenspace and potential health outcomes. The subsequent analysis presented in chapters four and five focussed on children and their use of urban parks for physical activity. There are elements in the framework which are of particular relevance to this analysis. Relationships between the environment and childrens' activity are substantially moderated by parental attitudes to factors such as safety (Davison and Lawson, 2006). Therefore, a version of the framework specifically tailored for children could highlight the importance of the family unit as a key pathway of moderation and expand on what specific parental characteristics are important in their role of "gatekeeper" to children using greenspace. These elements could be empirically tested in studies, for example the PEACH survey includes questions to the parents about their own lifestyle and perceptions of the local environment. A version of the framework specifically for children could also expand upon the importance of specific type of greenspace to children and capture some of the wider potential outcomes which relate to younger age groups, such as the role of greenspace as a resource for education and development of independence and confidence (Mulvihill et al., 2000). The most important role of greenspace in children's lives is its role as a location for play activities. In addition to being the key way that children gain their physical activity, research suggests that play is fundamental to children's happiness and well-being, and influential in their health and future life chances (Gleave and Cole-Hamilton, 2012). Drawing upon this evidence and incorporating perspectives from multiple disciplines, such as sociology and psychology, the framework could therefore be developed to highlight and explore the important role of greenspace provision as a potential facilitator of children's play.

It is also important to further understand the role of greenspace for specific groups who may have particular potential to benefit from it or upon whom interventions aimed at increasing physical activity should focus because they have particular health needs. For example, whilst a growing body of research, including this thesis, has studied how children use greenspace, there is a paucity of evidence about the relationship between greenspace access and health for older people. Other groups which need greater focus include black and minority ethnic populations and socio-economically disadvantaged groups, given the potential role of greenspace and other built environment features in shaping health inequalities.

There is a need to understand the potential health benefits of greenspace in a wider context of the potential overall benefits of greenery to humans, such as economic and environmental benefits (Cicea and Pazrlogea, 2011). From a policy perspective, evidence of the overall cumulative impact of greenspace would be particularly useful i.e. how much overall health gain do I get for this much greenspace? - ideally with economic valuation of the costs and benefits to give an estimate of potential return on investment in the long term. This principle of quantifying the economic value brought by the existence of green areas fits with approaches such as 'ecosystems services' whereby natural resources are assessed in terms of the benefits they provides to society and economic prosperity. A recent review of ecosystems services for the UK included some health impact costings (Pretty et al. 2011), and this review acknowledged that some of the supporting evidence was lacking or inconclusive. When a larger body of research is available, meta-analysis type approaches should be used to produce summary estimates of health impacts which can be thus provide more robust estimates to support such approaches.

A final suggestion for the direction of future research is to echo the call by Townshend et al (Townshend, 2012) for greater interdisciplinary working across research disciplines with an interest in greenspace, such as landscape, recreation, built environment and health. For example, recreation and leisure researchers may be better placed than epidemiologists to measure the nuances and detail of parks and recreation environments (Kaczynski and Henderson, 2007). Another example is that methodologies used in transportation research could be applied to the GPS-accelerometer data to impute routes travelled (Duncan et al., 2009), including adjustment for errors such as signal drift and missing data, and so allow physical activity on journeys to and from greenspace to be examined. Townshend recognises the risk to interdisciplinary working is greater complexity, and hence cost, making it particularly challenging in a time of reduced funding. More fundamentally, whilst documenting the exact causal mechanisms at work is proving elusive, there remains clear consensus among academics across various disciplines, that greenspaces are a "good thing" for human health and thus worth protecting and maintaining.

Overall conclusion

There is an historic and prevailing view that greenspaces are beneficial to human health. This thesis lends some support to this view, in that analyses showed that children with better access to greenspace were more physically active within it and adults in greener areas reported higher levels of recreational walking. Certain types of urban greenspace, such as formal areas and those with play facilities, were particularly well used by children. These findings emphasise the need for policymakers and planners to create or protect green environments which support physical activity, particularly as activity in natural areas confers additional psychological benefits. The thesis also considers how relationships between greenspaces and health are moderated by factors such as greenspace type, living context and demographic factors. That certain groups, such as socio-economically disadvantaged populations, may benefit more from access to public greenspace suggests that access is more than just a luxury and could help reduce health inequalities. When exploring the links between greenspace and wider health outcomes, such as reduced mortality, findings indicate that use of the space for physical activity is not acting as a mediator in this relationship. Data from experimental or longitudinal studies should further explore this, but the implication is that the association between greenspace and mortality, if causal, may be explained by other mediators, such as psychosocial processes.

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Appendix A: Table of studies included in systematic review

Key to table:

(1) Size of sample included in analysis

(2) Definition: Area %, Percentage of greenspace within defined geographic area (specified in brackets) or certain distance from home location (distance in brackets, where E, Euclidian distance. N, network) Distance, distance to nearest greenspace or measure of presence of count of greenspace(s) within a certain distance of home location (distance in brackets, where E, Euclidian distance. N, network distance). NDVI (Normalized Difference Vegetation Index.

(3) Collection method: S,Subjective. O,Objective. Other definitions specified.

(4) Summary of other variables collected in the study that were used (or potentially used) in the analysis of the association between greenspace and obesity-related health. SES, socio-economic status variable(s), including measures such as income, education and employment.

(5) OR, Odds Ratio. IRR, Incidence Rate Ratio. n/a, No association or effect size not easily calculable from results given in paper.

No	Study location	1st author (date)	Sample size (1)/ Gender/ Age/	Green space measure used/ Definition (2)	Outcome variable (Collection method (3))	Other variables used in study (4)	Significant associations (p<0.05) between green/open space and outcome variables	Meaningful effect size reported (5) (95% confidence intervals in brackets)
1	Australia (Melbourne)	Ball (2007)	N = 1,282 F 18-65 years	Public Open space, walking tracks, coastal/ Area % (neighbourhood)	Episodes of walking >10 min within week (S)	Individual: Age, SES, marital status, children in home, pregnancy, Educational level, self-efficacy, walking enjoyment, social support, club membership, dog ownership, perceived environmental aesthetics Area: Road intersections	Coastal proximity associated with leisure and transportation walking. Walking track length associated with transportation walking only. Public Open Space density not significant.	OR coastal compared non-coastal: 2.74 (2.20-3.28) walking for transport, 1.46 (1.02-1.90) walking for leisure
2	Australia (Perth)	McCormack (2008)	N = 1,394 MF 18-59 years	Parks , Rivers, Beach / Distance (400m, 1400m N)	Frequency and duration of walking in past 2 weeks (S)	Individual: Age, Gender, SES, number of children, employment, car ownership, BMI Area: SES	Presence of parks not associated with walking. Having a beach within1,500 m was positively associated with irregular walking and regular vigorous physical activity	OR beach within 1,500m compared none: 1.93 (1.20-3.13) regular vigorous activity, 1.97 (1.01-3.83) irregular walking
		Giles-Corti (2005)	N = 1,803 MF 18-59 years	Public open space, including quality and amenities/ Distance (Gravity model)	MET counts (S) classified into activity type (recreation, transport) and levels	Individual: Age, Gender, SES, number of children Area: SES, access to recreational facilities	Public open space not associated with overall activity or recommended levels, apart from association between access to large and attractive spaces with high levels of walking	OR Very good access to POS compared no access: 1.5 (1.06-2.13) achieve high walking levels (x6 per week, >180 mins)
		Giles-Corti (2003)	N = 1,803 MF 18-59 years	Public open space, including quality measure/ Distance (gravity model)	MET counts (S) classified into walking at recommended levels	Individual: Age, Gender, SES, number of children, Area: SES, access to recreational facilities	Walking at recommended levels associated with access to public open space, although borderline statistical significance (p=0.048)	OR Top quartile access to POS compared poor access: 1.47 (1.00-2.15)
		Giles-Corti (2002)	N = 1,803 MF 18-59 years	Public open space, beaches/ Distance (gravity model)	MET counts (S) classified into activity type and levels	Individual: Age, Gender, SES, number of children, employment, access to vehicle, perceptions of environment Area: SES, access to recreational facilities	Association between access to POS and walking for transport and at recommended levels. Beach access positively associated with walking for recreation and negatively with transport walking.	OR Top quartile access to POS compared poor access: 1.35 (1.05-1.73) walking for transport.
3	Australia (Queensland)	Duncan (2005)	N = 760 MF	Parkland / Distance (EN)	Minutes of PA (S)	Individual: Age, Gender, SES, Self efficacy, social support,	People who lived further from parkland were more likely to	OR park within 600m compared not: 1.41

			>18 years			Environmental perceptions., Pathway network, distance to other facilities. Number of active people nearby, number of dogs	achieve recommended levels of physical activity.	(1.00-1.97) achieve recommended levels of PA
4	Canada (Calgerry)	Potestio (2009)	N = 6,772 MF 4-5 years	Public parks, school fields and recreation areas / Count (area), Area %, Distance N, Service area	BMI (O)	Individual: Age, Gender Area: SES, ethnicity	Limited evidence of direct relationship between park access and BMI. Marginally significant relationship between moderate number of parks and lower odds of being overweight/obese, although not significant after control for SES.	n/a
5	Canada (London, Ontario)	Tucker (2009)	792 MF 11-13 years	Parks/ Area% (500m E)	MET minutes per day (S)	Individual: Grade, Gender, Ethnicity, SES, member of sports team, family structure, number of people in household, season Area: Recreational opportunities, land use mix.	No association between park coverage and physical activity	n/a
6	Canada (Waterloo, Ontario)	Lackey (2009)	N = 574 MF Adults	Park> 0.5 acre with certain features and used for PA/ Distance (E)	Duration, intensity and location of PA (S)	Individual: Gender, Age, marital status, education, BMI, children in household, gym membership, self-efficacy, perceptions of neighbourhood environment	Objective proximity to parks was associated with greater neighbourhood based activity but not park-based activity. A match in perceived and objective proximity was related to greater park-based physical activity.	OR park within 750m compared not: 1.12 (1.01-1.25) more likely engage in neighbourhood based activity
		Kaczynski (2009)	N = 384 MF Adults	Parks, including size and features/ Distance (1km E)	Duration, intensity and location of PA (S)	Individual: Gender, Age, BMI, injury	Positive relationship between number and total area of parks within 1k and physical activity occurring in neighbourhood and parks. Stronger relationship for women, younger and older groups	OR for each additional park within 1km: 1.17 (1.01-1.34) participate in neighbourhood based activity, 1.15 (1.01-1.28) park-based activity.
		Potwarka (2008)	N = 108 MF 2-17 years	Parks and facilities/ Distance (E) Area% (1km E)	BMI (S)	Individual: Age, Gender, Parent's BMI Area: Neighbourhood of residence	Out of 13 park facilities, only access to a park playground was associated with being healthy weight	n/a
7	England (all)	Mitchell (2009)	Areas = 32 482 MF All ages	Green space / Area% (neighbourhood)	Mortality (circulatory) (O)	Individual: Age, Gender Area: Deprivation, urban-rural, population density	Association between deprivation and circulatory mortality differed by exposure to green space	IRR for circulatory mortality in most green areas 1.54 (1.38-1.73) most deprived compared least, In least green areas 2.19

								(2.04-2.34)
8	England (Bristol)	Jones (2009)	N = 6,821 MF >16 years	Green space / Distance (N)	Participation in sport and moderate physical activity (S)	Individual: Age, Gender, SES, health, Area: Road density, street connectivity, land use, demographic factors	Association between access to green space and visits to green space but not with physical activity levels	n/a
9	England (Norwich)	Foster (2009)	N = 6,214 MF 45-74 years	Public green space >2h inc river paths/ Distance (N)	Walking for recreation (S)	Individual: Age, gender, ethnicity, SES, car ownership, health conditions, travel mode, occupational activity, proximity to recreational facilities Area: SES, traffic volumes, crime rate	No association.	n/a
		Panter (2008)	N = 401 MF >16 years	Parks and green spaces > 2 acres / Distance (N)	Frequency engaged in PA (S)	Individual: Age, Gender, SES, Number of children cared for, dog ownership, Distances to other leisure facilities, enjoyment of exercise	Those who lived in the closest tertile to a parkor greenspace were over twice as likely to report five or more sessions of physical activity, although this observation was of borderline statistical significance and there was no trend. No significant pattern for sessions of aerobic activity or walking.	OR living nearest to park compared farthest: 2.17 (1.0-4.78) five sessions of PA
		Hillsdon (2006)	N = 4,950 MF 45-74 years	Green space (rated for quality)/ Distance (Gravity model)	Total hours of recreational activity per week (S)	Individual: Age, Gender, education, ethnicity, distance to city boundary Area: SES	No association overall. Those with best access to high quality large green spaces reported significantly lower levels of activity compared with those with poor access.	n/a
10	England (Stoke-on-Trent)	Cochrane (2009)	N = 761 MF >16	Recreational green space ≥ 2 hectares/ Distance (200m EN)	MET minutes per week, non-work related (S)	Individual : Age, Gender, Ethnicity, SES, BMI Perceptions, beliefs, social support Area: Access to facilities, land use mix, population density, transport provision, traffic safety and crime, weather	Distance to green space had a negative association with physical activity during sunnier weather and a positive association in wetter weather.	n/a
11	Europe (8 countries)	Ellaway (2005)	N = 6,919 MF Adults	Audit (Visible greenery and vegetation)	Frequent physical activity (S) BMI (S)	Individual: Age, Gender, Ethnicity, SES, dwelling size, household type Area: City of residence	Respondents whose residential environment contains high levels of greenery had higher likelihood (X3) of being physically active and 40% less likely to be obese	OR greenest area compared lease green: 3.3 (2.5-4.5) frequent physical activity, 0.6 (0.5-0.8) overweight/obese
12	New Zealand	Witten (2008)	N = 12,529	Parks and beaches/	Minutes of PA (S)	Individual: Age, Gender,	No association between park access	n/a

			MF 15 + years	Travel time (N)	BMI (S)	Ethnicity, SES, household size Area: SES, urban-rural classification	and PA. Weak association between beach access and physical activity and BMI.	
13	Portugal (Lisbon)	Santana (2009)	N = 7669 MF >18 years	Parks/ Area (neighbourhood)	BMI (S) Vigorous and moderate PA (S)	Individual: Age, gender, marital status, SES, diet, smoking Area: Environment characteristics (housing, SES, urban sprawl, safety, social cohesion, sports facilities, public health services, land use)	No significant associations between green parks and PA	n/a
14	Sweden	Bjork (2007)	N = 24,819 MF 18-80 years	Mean number of natural recreational values (classified as 'serene', 'wild', 'lush', 'spacious', 'culture') / Distance (100m-300m S)	Time spent MVPA per week (S) BMI (S)	Individual: Age, Gender, SES, country of birth, housing type, smoking stauts	Association between number of recreational values within 300m and MVPA. Weak association between increased recreational values and decreased BMI, only significant among tenants (not home-owners) after adjustment for confounders.	OR 4-5 recreational values within 300m compared 0: 1.44 (1.24-1.66) increased time spent on moderate physical activities
15	The Netherlands (6 cities)	De Vries (2007)	N = 422 MF 6-11 years	Audit: Green space and water scored 0 (none)– 4 (many)	Hours per week of MVPA (S)	Individual: Age, Gender, SES, BMI Area: Built environment factors measured with audit	No association between green space and activity	n/a
16	The Netherlands	Maas (2009)	N = 345,143 MF Adults	Green space/ Area % (1km, 3k E)	Disease prevalence (GP recorded) over 12 months	Individual: Gender, age, SES Area: Urbanity	Significant relation between green space and disease prevalence only for green space in 1k radius. Some relationships at 3k for specific disesases. Strongest relationship for ages <12 and 46-65 and lower educated groups	OR having 10% more green space within 1k: 0.97 (0.95-0.99) CHD prevalence, 0.98 (0.97-0.99) diabetes prevalence
		Maas (2008)	N = 4,899 MF >12 years	Green space/ Area% (1k 3k E)	Minutes of activity per week (S) .	Individual: Age, Gender, SES, Health, garden Area: Urbanity	No significant relationship between the percentage of green space and meeting the public health recommendations for physical activity. Negative relationship between access to greenspace and walking or cycling for leisure.	n/a
17	The Netherlands (Maastrict)	Wendel-Vos (2004)	N = 11,541 MF 20-59 years	Green spaces/ Area% (300m 500m E)	Hours per week of activity (S)	Individual: Age, gender, education, health status, SES, BMI	No associations between walking and green space. Bicycling for commuting purposes was associated with area of parks in 300m radius.	n/a
18	The Netherlands	Prins (2009)	N = 654 MF	Parks/ Distance (1500m E)	Engaging in sports or walking/cycling	Individual: Age, gender, country of birth, educational	No association between access to parks and walking or cycling	n/a

	(Rotterdam)		12-15 years		activities (S)	level, Perceived physical environment, Distance to sports facilities, sidewalks, bicycle lanes		
19	USA (all)	Zahran (2008)	Areas = 3,141 MF >16 years	Forests and Parks / Area (County)	Use bicycle or walk to walk (S)	Area: SES, Ethnicity, Natural amenities scale, Civic variables	Proximity to national parks and forests increases the expected count of walk and cycling commuters	Presence of a park or forest increases expected count of bike commuters by 8.7%
20	USA (Los Angeles)	Cohen (2007)	N = 605 MF >18 years	Parks including characterisics/ Distance (E)	Frequency of leisure exercise per week, frequency of visits to parks (S)	Individual: Age, gender, ethnicity, perceptions of parks	Living near park (within 1 mile) associated with increased exercise sessions and visits to parks	OR park within 1 mile compared no park: 4.21 (2.54-7.00) visit park once per week, 1.38 (1.04-1.84) more exercise sessions per week
21	USA (5 states)	Cohen (2006)	N = 1,556 F 11-12 years	Parks including type / Count (0.5,1 mile N), Gravity model	Non-School Metabolic Weighted –MVPA (O)	School: SES Area: Ethnicity, SES, street connectivity	Parks that were closer had a larger and significant effect on nonschool MVPA compared with those that were farther away.	Additional 33 MET-mins of activity (per 6 days) for each extra park within ½ mile and 12 for each park up to 1 mile.
22	USA (Atlanta)	Kerr (2007)	N = 3,161 MF 5-18 years	Recreation/open space land use/ Distance (1k N)	Walked at least once in the last 2 days (S)	Individual: Gender, Ethnicity, SES, Household size, car ownership Area: Road and residential density, land use	Association between having access to at least 1 recreation/open space associated with reported walking. Association stronger for boys and Whites and in households with several cars, 4+ residents and with high incomes.	OR at least 1 recreation/open space comared with none: 2.3 (1.7-3.2) males, 1.7 (1.2-2.4) females walk at least once in 2-day period.
		Frank (2007)	N = 3,161 MF 5-20 years	Recreation and open space/ Distance (1k N) Area% (1k N)	Walked at least once in the last 2 days (S)	Individual: Gender, Ethnicity, Income, Household size, car ownership Area: Road and residential density, land use	Association between having access to recreation/open space and reported walking. Having up to 5 acres of space related but larger spaces not. Number of destinations more important than size.	OR Access to recreation and open space land use compared none: 2.1 (1.7-2.6) walked at least once, 2.1 (1.5-2.9) walked >0.5 mile per day
23	USA (Baltimore)	Ries (2009)	N = 329 MF 14-18 years	Parks/ Distance (1 mile)	Total weekly minutes of MVPA (O)	Individual: Age, Gender, ethnicity, SES, perceived park access and quality, use of parks by friends and family Area: Crime rate	Marginally significant association between park access and PA and between reported park use and PA. Objective park access not associated with reported use.	One park increase availability associated with 1.99 more minutes weekly MVPA
24	USA (Boston)	Cradock (2009)	N = 152 MF 13-14 years	Open space Area % (800m N)	Average vector magnitude, Proportion of MVPA	Individual: Gender, age, ethnicity, BMI	Open space not significantly associated with either physical activity outcome	n/a

					>1000 vector magnitude (O)	Area: Average daily traffic, Housing density, employee density, weather		
25	USA (Buffalo-Niagara Falls)	Epstein (2006)	N = 58 MF 8-15 years	Parks / Area % (0.5mile N)	Change in MVPA counts(O) during change in sedentary behaviour	Individual: Age, Gender, socioeconomic status, BMI, housing type Area: Density, design, land use mix	Living in an area with a large community park was associated with an increase in physical activity when sedentary behaviour decreased	Living in an area with a park >43 hectares compared with no park = +38.9 (29.4-68.3) min of MVPA per day
		Roemmich (2006)	N = 59 MF 4-7 years	Park / Area% (neighbourhood) .	Mean MET counts per minutes (O)	Individual, Gender, Age, Ethnicity, SES, BMI, Television use Area: Housing density, recreational facilities	Greater neighbourhood park and recreation areas were associated with greater physical activity.	Percentage park area accounted for 9% of variance in PA
26	USA (Chicago)	Wen (2009)	N = 3530 & 907 (2 surveys) MF Adults	Park/Distance	Frequency of exercise (S)	Individual: Age, gender, ethnicity, marital status, education, SES Area: SES, social capital, residential density, land use mix, access to facilities	No association.	n/a
27	USA (Indianapolis)	Bell (2008)	N = 3,842 MF 3-16 years	Mean NDVI / Area (1k E)	Change in BMI (O)	Individual: Age, Gender, Ethnicity, SES Area: Housing density, income	Increased green space associated with decreased BMI. Modified by insurance status.	OR greener areas: 0.87 (0.79-0.97) increase BMI
		Liu (2007)	N = 7,334 MF 3-18 years	Mean NDVI/ Area (2Km E)	BMI (S)	Individual: Age, ethnicity, gender Area: SES, Distance to facilities	In higher population density townships, increased amounts of vegetation surrounding a child's residence were associated with less risk of being overweight.	OR for a 0.1 increment in NDVI: 0.899 (SE =1.038) obesity in high density areas
28	USA (King County, Washington)	Moudon (2007)	N = 608 MF Aged >18	Parks /Distance (3k EN)	Total weekly minutes of walking	Individual: Age, SES, household characteristic, behaviour and attitudes, perceptions of environment, distance to facilities	No association, although authors state that additional analysis (not presented) suggested positive relationships between shorter distances to parks and walking to them, although not for overall walking levels.	n/a
		Moudon (2005)	N = 608 MF Aged >18	Parks and trails /Distance (3k EN)	Total weekly minutes of cycling	Individual: Age, Gender, ethnicity, SES, bicycle owenership, car ownership and use, SES, household characteristic, behaviour and attitudes, perceptions of environment.	No association.	n/a

29	USA (Los Angeles and Louisiana)	Scott (2009)	N = 1,815 MF Adults	Parks/ Distance (1 mile E)	Walking frequency per week (S) BMI (S)	Individual: Age, gender, ethnicity, income, car ownership, perceived neighbourhood safety, BMI, distance to markets, neighbourhood design Area: SES	No relationship between park access and walking frequency. Park access was associated with lower BMI among non-hispanic Whites but not among African Americans.	Each additional park within 1 mile: 1% lower BMI for Whites
30	USA (Mexican Americans in Texas)	Gomez (2004)	N = 177 MF 12-13 years	Open play area/ Distance (E)	Activity bouts per week (S)	Individual: Age, Gender, Ethnicity, Perceived barriers Area: SES, Crime	Distance to the nearest open play area was inversely and significantly related to PA for boys. For girls, violent crimes was the only significant factor.	n/a
31	USA (**Massachusetts**	**Oreskovic (2009)**	N =21,008 2-18 years MF	Open space/Area (400m)	BMI (O)	Indivudal: Age, Gender, Ethnicity Are: SES, Built environment characteristics	Amount of open space was inversely associated with BMI, although this was of marginal statistical significance after adjustment for confounders	Highest area of open space : OR 0.93 (0.86-1.00) have BMI > 95th percentile
32	USA (Minnesota)	Forsyth (2007)	N =715 MF Adults	Park / Distance (EN)	MET counts per day (O), PA (S)	Individual: Age, Gender, SES, marital status, home ownership, household size, perceived environment Area: 50 GIS variables	Reported in text that park distance was negatively associated with PA but low values (although significant). Some correlations for other variables but "small and inconclusive".	n/a
33	USA(Minnesota)	Dengel (2009)	N = 188 MF 10-16 years	Parks, recreational trails/ Distance (1600m N) Park and recreation land/ Area % (1600 N)	Metabolic syndrome (MetS) score (O)	Individual: Age, Gender, Pubertal status Area: Population density, Built environment features,	Increase in land use dedicated to parks was negatively associated with MetS, although of marginal statistical significance ($p=0.07$)	n/a
34	USA (North Carolina)	Jilcott (2007)	N = 199 F 40-64 years	Parks / Distance, (1mile 2 mile N)	Average minutes MPVA (O)	Individual: Age, BMI, income, smoking status, health, Perceived proximity to recreational resources. Area: Urbanicty, distance to facilities including gyms and schools	No significant association between objective access to parks and physical activity	n/a
35	USA (Ohio)	Mowen (2007)	N = 1,515 MF 50+ years	Parks/ Distance (E)	Activity levels - sedentary, moderate, active (S)	Individual: SES, Social Support	Significant, but weak, indirect relationships between park proximity, park visitation, daily physical activity, and perceived health (using path analysis)	n/a
36	USA	Nagel (2008)	N = 546	Green and open space/	Weekly walking times	Individual: Age, gender,	Distance to nearest park was	1 unit increase (1

	(Oregon)		MF >65 years	Distance (E)	(S)	ethnicity, SES, health, walking self efficacy Area: SES, perceived neighbourhood problems and walking safety	associated with decreased brisk walking times.	standard deviation of distance to green space) = 5.82 minutes decrease in walking time
		Li (2008)	N = 1,221 MF 50-75 years	Green and open spaces / Area% (neighbourhood)	Minutes of activity per week (S) BMI (O)	Individual: Age, Gender, Ethnicity, SES, alcohol, tobacco and food consumption, health Area: Land use, density of fast food outlets, street connectivity, public transit stations, SES, residential density, ethnicity	Green and open spaces for recreation were associated with more neighbourhood walking and meeting physical activity recommendations. No relationship with BMI.	1 unit increase (1 standard deviation) of green space: OR 1.12 (1.01-1.24) neighbourhood walking, OR 1.06 (1.03-1.10) meet PA recommendations
		Li (2005)	N = 582 MF >65 years	Green and open space/ Area % (neighbourhood)	Activity in neighbourhood (S)	Individual: Age, SES, Perceptions of safety and facilities Area: Number of households, places of employment, street intersections	Area of green and open spaces significantly related to walking activity at the neighbourhood level. 28% of the variation in reported walking activity was attributable to between neighbourhood differences.	n/a
		Fisher (2004)	N = 582 MF >65 years	Parks and trails/ Distance (neighbourhood)	Walking in neighbourhood (S)	Individual: Gender, Age, ethnicity, marital status, ethnicity, health status, walking efficacy, perceptions of safety and neighbourhood Area: SES, Social cohesion, neighbourhood perceptions, age, ethnicity	Parks and trails related to walking at neighbourhood level	n/a
37	USA (Oregon)	Lund (2003)	N = 1,454 MF Adult	Presence of park in neighbourhood	Frequency of walking (S)	Individual: Age, Gender, race, children in household, SES, attitudes to walking, perceptions of neighbourhood, Area: Neighbourhood behaviours, access to retail	Association between transportation walking and having access to both parks and retail.	n/a
38	USA (Pennsylvania)	King (2005)	N = 508 F 52-62	Park, biking or walking trail/ Distance (1500m)	Average steps per day (O)	Individual: Age, ethnicity, marital status, SES, smoking status, BMI, proximity of businesses and facilities Area: SES, housing	No association.	n/a

39	USA (San Diego)	Norman (2006)	N = 789 MF 11-15 years	Parks/ Distance (1 mile N)	Average MVPA METS per day (O) BMI (O)	Individual: Age, Ethnicity Education, residential density, intersection density, retail area, land use. Walkability, private recreation, schools	No association.	n/a
40	USA (South Carolina)	Pate (2008)	N = 1,506 F 17-18 years	Parks/ Distance (0.75mile N)	Number of 30-min blocks of MVPA (S) BMI (O)	Individual: Ethnicity, SES, PA facilities	Number of parks associated with Physical Activity. Interaction with ethnicity.	n/a
41	USA (St Louis and Savannah)	Hoehner (2005)	N = 1,073 MF 18-96 years	Parks and trails Distance (400m E)	Sum of PA over last 7 days (S) – transportation and recreational	Individual: Age, ethnicity, Gender, education, vehicle ownership, perceived social and physical environmental measures, recreational facilities, intersections, bike lanes	People who live closer (<400m) to a park or trail were more likely to use these facilities but no significant association between park access and physical activity, No interactions with gender or income.	n/a
42	USA (Texas)	Jago (2006)	N = 210 M 10-14 years	Parks/ Distance (1mile N)	MET counts (O)	Individual: Ethnicity, SES, BMI, perceived environment, Residential density, crime rate, street characteristics and condition, Distance to facilities.	No association.	n/a
43	USA (Seattle, Washington)	Lee (2006)	N = 438 MF >18 years	Parks and trails/ Distance (E)	Weekly frequencies of walking (S)	Individual: Age, Gender, Ethnicity, Marital Status, Car Ownership, Dog Ownership, Behavioural variables, Attitudes and perceptions of environment, distance to destinations	Park and trail variables did not show a statistically significant association. Utilitarian destinations were more important than recreational ones.	n/a
44	USA (Seattle, Washington)	Tilt (2007)	N = 529 MF Adults	NDVI Parks and community gardens/ Distance (1 mile E)	Frequency of walking trips (S) BMI (O)	Age, Gender, SES, Distance to other facilities (churches, community centres, post offices, shops), Self reported natural features and satisfaction with greenness.	Objective greenness was not significantly correlated with walking, but subjective greenness was. In high NDVI areas was a negative relationship between BMI and objective accessibility, but in low NDVI areas there is a slight positive relationship between BMI and accessibility.	n/a
45	USA (Utah)	Brown (2009)	N = 5,000 MF 25-64	Parks/ Distance (1k N)	BMI (S)	Ind: Gender, Age Area: Land use , walking to work, age of housing, ethnicity, SES, population density, distance to rail and bus stop	No association.	n/a

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Appendix B: Copies of published work

The following papers are published or in press at time of thesis submission (January 2013)

Lachowycz K, Jones AP. Greenspace and obesity: a systematic review of the evidence. Obesity Reviews 2011:12: e183–e189. doi: 10.1111/j.1467-789X.2010.00827.x.

Lachowycz K, Jones AP. Towards a better understanding of the relationship between greenspace and health: Development of a theoretical framework. Landscape and Urban Planning. In press.

Lachowycz K, Jones AP, Page AS, Wheeler BW Cooper AR. What can global positioning systems tell us about the contribution of different types of urban greenspace to children's physical activity? Health & Place: 18 (3),586–594

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Obesity Prevention

Greenspace and obesity: a systematic review of the evidence

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Summary

Greenspace is theoretically a valuable resource for physical activity and hence has potential to contribute to reducing obesity and improving health. This paper reports on a systematic review of quantitative research examining the association between objectively measured access to greenspace and (i) Physical activity, (ii) Weight status and (iii) Health conditions related to elevated weight. Literature searches were conducted in SCOPUS, Medline, Embase and PYSCHINFO. Sixty studies met the inclusion criteria and were assessed for methodological quality and strength of the evidence. The majority (68%) of papers found a positive or weak association between greenspace and obesity-related health indicators, but findings were inconsistent and mixed across studies. Several studies found the relationship varied by factors such as age, socioeconomic status and greenspace measure. Developing a theoretical framework which considers the correlates and interactions between different types of greenspace and health would help study design and interpretation of reported findings, as would improvement in quality and consistency of greenspace access measures. Key areas for future research include investigating if and how people actually use greenspace and improving understanding of the mechanisms through which greenspace can improve health and, in particular, if physical activity is one such mechanism.

Keywords: Environment, greenspace, obesity.

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Introduction

The rise in obesity is well documented (1) and research has recently expanded from a focus on individual determinants of obesity to investigating upstream influences, including how the environment in which people live influences their lifestyle and weight gain. Such socio-ecological approaches consider how individuals interact with their environments. One potentially important factor in a person's living environment is their access to greenspace, as greenspace is theoretically a valuable resource for physical activity (2) and hence could contribute to reducing obesity and improving health.

Recent socio-ecological model based reviews identified greenspace as one of a range of potential environmental determinants of obesity (3–7) and physical activity (8–13). They say little specifically about greenspace but conclude that environmental factors have potential to influence bodyweight, although findings are mixed and associations complex, particularly given inconsistencies in methodological approaches. One systematic review evaluated empirical evidence regarding the association between parks and recreation settings and physical activity (14). However, while there has been a recent proliferation of research in this field and reviews commissioned by Government departments and charitable organizations in the UK (15,16) and elsewhere (17,18), no systematic review has been published in a peer-reviewed journal which specifically evaluates the evidence for a relationship between greenspace and obesity. This paper addresses this by carrying out a systematic literature review of available studies which investigate the relationship between access to greenspace, obesity, and obesity-related health outcomes and behaviours.

Methods

The review focuses on three groups of health markers in relation to greenspace access in the home environment (i) Indicators of physical activity (ii) Weight status and (iii) Health conditions known to be related to elevated weight status. Home environment is defined as the geographic area surrounding the place of residence.

Literature search

A literature search using four electronic databases (SCOPUS, Medline, Embase, PYSCHINFO) was conducted in February 2010. It was limited to peer-reviewed journal articles published between 2000 and 2010, representing a phase of research characterized by a focus on environmental determinants of health (19) and development of objective measures of living environments (20).

Search terms were based on greenspace definitions from planning and health research. Key relevant environmental terms such as 'walkability' were also included to identify papers where greenspace was analysed but not reported in abstract findings. The health search terms covered physical activity (e.g. exercise), weight status (e.g. body mass index [BMI]) and related health outcomes (e.g. diabetes). A full description of terms and search strategy is available in Table S1.

Inclusion criteria

Resulting papers were screened against inclusion criteria outlined in Table 1. The primary author reviewed results of the initial search and selected potentially relevant papers from paper titles. A second stage reviewed abstracts and then full papers to select papers which met the inclusion criteria. A random selection of 20% of papers was screened by another author (A. J.) to confirm they were correctly selected.

Methodological quality assessment

All included studies were assessed for methodological quality by the primary author and an independent reviewer using a 10-item scale (Table S2). Levels of agreement between reviewers were analysed using Cohen's Kappa for multiple raters, with agreement assessed on a dichotomous scale ('Positive'[1] vs. 'negative'[0] and 'insufficiently described'[N]). In the case of disagreement, consensus was reached by discussion. There was no a priori reason for weighting the scores, so studies scored one point for each item and points were summed between 0–10. Studies were classified as high quality if they obtained a score of six or more.

Table 1 Inclusion criteria used to select studies

1	The paper used empirical data to report analysis of obesity-related lifestyle and health outcomes in relation to access to greenspace.
2	The greenspace access measure was generated using objective methods, either by use of a Geographic Information System or an assessment by trained auditors using a consistent tool.
3	Greenspace access was assigned based on location of residence, e.g. (i) Distance to nearest greenspace or count of greenspaces within a certain distance and (ii) Amount of greenspace in the area. Experimental studies which looked at interactions with nature or simulated views of nature were not included.
4	Greenspace access was included as a separate variable within the analysis and results were reported specifically for greenspace, even if this was not the primary aim of the study. This excluded studies which only included greenspace as a potential confounder or as one variable in a composite environmental score.
5	One or more of the outcomes measure used in the study was an indicator of physical activity, weight status or health outcomes shown to be related to obesity. The outcome measure could be either self-reported or objectively measured.
6	There was adequate consideration of and adjustment for confounding factors, defined as including (where appropriate) adjustment for age, sex and a marker of socioeconomic status at a minimum.

Strength of the evidence

A formal meta-analysis approach was judged inappropriate because of heterogeneity of the greenspace access measures and outcomes. Studies were thus summarised according to greenspace and health measures, confounding factors, findings, and effect sizes (See Table S2), with the terms 'association' and 'relationship' used to describe a statistical, rather than necessarily causal, relationship. Each study was assigned by the primary author and independent reviewer to one of four levels describing the relationship between greenspace and health (i) Positive; (ii) Equivocal (weak/mixed); (iii) No relationship and (iv) Negative, with 'positive' defined as health promoting (e.g. increased walking) and 'negative' defined as health demoting (e.g. increased BMI). When summarizing findings, papers reporting results from the same study were covered individually.

Results

The database search produced 2473 hits in SCOPUS and 601 in the Ovid databases. Screening by the primary author

Table 2 Count of papers by strength of the relationship between greenspace and obesity-related health indicators, by outcome measured and population age group

Outcome	Relationship between greenspace and health			
	Positive	Equivocal	None	Negative
Physical activity				
Objective	3 (3C)	2 (1C,1A)	4 (3C,1A)	0
Subjective	17 (3C,10A,4O)	11 (2C,8A,1O)	11 (2C,9A)	2 (2A)
Weight status				
Objective	2 (2C)	3 (2C 1A)	2 (1C,1A)	0
Subjective	1 (1A)	3 (1C,2A)	2 (2A)	0
Obesity-related health outcomes	2 (2A)	1 (1C)	0	0

A, adult (aged > 16/18 or all ages); C, child/teen (aged < 16/18); O, older people (aged > 50/60/65).

identified 219 papers in SCOPUS and 118 in Ovid databases of potential relevance (including duplicates across databases). Review of these papers against inclusion criteria produced a final list of 60 papers. A summary, ordered by location, is available (Table S3).

Papers failed the inclusion criteria for the following reasons: Not statistical analysis of obesity-related health markers in relation to greenspace (132 papers), greenspace not objectively measured or not based on residential location (63), results not specifically presented for greenspace (74), health marker not related to obesity (6) or insufficient adjustment for confounders (2).

Table 2 gives a count of papers according to strength of evidence and grouped by health outcome and study age-group.

Greenspace access measures

Studies were heterogeneous in the approaches and measures used. The most common measure was distance to nearest greenspace or count within a certain distance of home (27 studies), using either straight-line/Euclidean distances (13), network distances (14) or both (5). A further 15 studies calculated the percentage of greenspace within a certain distance or area. Two used an audit of greenness by trained assessors (21,22) and one derived scores of 'recreational value' for different greenspace types (23). Fifteen studies used multiple measures or more sophisticated approaches, including measures based on gravity models (24–27), quality of greenspace (24,27), type of greenspace (27–29), facilities available (30–32) and park service areas (33). A few studies focussed on greenspaces above a particular size (30,34–36) while one removed large parks (33).

Methodological quality assessment

There was 89.2% agreement on the 600 items scored during the quality assessment (kappa statistic 0.78, $P < 001$; substantial agreement) and full consensus was reached after discussion. Overall, 20 papers (33.3%) were rated as high methodological quality. The items where the majority of studies were judged negatively were: potential inclusion bias (77% of papers), use of subjective outcome measure (70%), no consideration of type or quality of greenspace (73%), no measure of greenspace use (83%) and testing of multiple variables (72%).

Greenspace and physical activity

The search identified 50 studies examining the relationship between greenspace and physical activity. The majority (41) used self-reported measures, nine used accelerometers. These studies were conducted in USA (28), England (6), Australia (7), the Netherlands (4), Canada (2), New Zealand (1), Portugal (1), Sweden (1) and Europe-wide (1).

Twenty studies (40%) reported a positive association between greenspace and physical activity. They included six among children/teenagers (21,29,37–41), within which there was some evidence of interactions with sex (37) and ethnicity (37,41). Fourteen studies reported evidence of a relationship among adults (22–24,26,30,32,42–45), including four looking at older people living in Oregon (46–49). There were 28 studies which found no evidence of a relationship (15 studies) or results were weak or mixed (13). Two studies found negative relationships (50,51) and some negative findings were found in two studies for those with access to high quality large greenspaces (27) and in sunnier weather (36).

Several studies examined how relationships might vary with the measure of greenspace access. Two Australian studies found no relationship between physical activity and parks, but found an association with distance to coastal environments (52,53). Research in Perth found that accessibly of public open space was not associated with overall activity, but those with very good access to attractive, large spaces were more likely to achieve high levels of walking (24). Jones *et al.*'s study in Bristol measured greenspace type (formal, sports, natural, etc.) but reported no significant relationships with physical activity (28). Cohen *et al.* found that particular park amenities, e.g. shaded areas, were associated with higher activity (29). Two studies (38,42) used both counts of greenspaces and percentage area within various distances and found the number of greenspaces within a certain distance was more important than size in relation to physical activity (38).

Six studies measured the relationship between greenspace access and utilization. Cohen *et al.* found living within 1 mile of a park was positively associated with park use and frequency of leisure exercise (32). Three studies (24,28,45) found that residents living closer to parks visited them more frequently and higher utilization was associated with higher activity levels; however the direct relationship between park access and physical activity was statistically insignificant (28,45) or significant only for those with access to attractive and large spaces (24). Mowen *et al.*'s analysis among older adults found that park visitation frequency mediated the relationship between proximity and daily physical activity (54). A study in Baltimore (55) found no association between park access and use of parks for physical activity but a marginally significant association between access and total physical activity. Five studies surveyed if physical activity actually took place in the local neighbourhood or in greenspace. There was evidence of an association between access to greenspace and activity in the local neighbourhood (30,47–49,56) but Canadian research found mixed evidence for a relationship between access to parks and activity undertaken within them (30,42).

Overall, the evidence for an association between access to greenspace and physical activity is mixed. The majority of studies (66%) found some evidence of a positive association, although only 40% found an association that appeared unambiguous.

Greenspace and weight status

Thirteen studies investigated the relationship with weight status, all using BMI as the marker, with seven using self-/parent-reported BMI and six using objective measures. Studies were from USA (10), Canada (2) and Europe-wide (1).

Three studies (23%) reported a positive (i.e. reduced BMI) relationship between greenspace and BMI. Liu *et al.* found that increased vegetation was associated with reduced weight among young people living in high population densities (57) while Bell *et al.* reported increased greenspace was associated with less weight gain over 2 years (58). Across eight European cities, people were 40% less likely to be obese in the greenest areas (22).

Six studies found mixed or weak evidence of a relationship between greenspace and BMI, and four found none. A study of adults living in Seattle (59) examined both access to communal greenspace and vegetation indexes derived from remote sensing (Normalized Difference vegetation Index [NDVI]), finding a negative relationship between access to greenspaces and BMI in low NDVI (low amounts of natural vegetation) areas, and a slight positive relationship in high NDVI areas. Several studies found slight evidence of a relationship between greenspace and BMI, which was either marginally significant (60), heavily attenuated by adjustment for socioeconomic status (33) or only in some ethnic groups (61). There was also variation by greenspace type, with relationships found only for access to beaches in New Zealand (62) and park playgrounds among children in Canada (31).

Overall, the majority of studies found some evidence of a relationship with BMI, or report mixed results across subgroups and according to the greenspace measure used.

Greenspace and obesity-related health outcomes

Just three studies examined the association between greenspace and markers of obesity-related health outcomes. Maas *et al.*'s study in the Netherlands found a lower prevalence of diseases in areas with more greenspace, including coronary heart disease and diabetes (63). An England-wide study found an association between greenspace exposure and lower premature mortality from circulatory disease (64). A study of adolescents in Minnesota measured metabolic syndrome scores (MetS), a cluster of risk factors associated with cardiovascular disease and diabetes, finding lower scores in greener areas although this result was marginally significant (65).

Effect size

Nineteen studies presented results as odds ratios of the binary health marker, mostly using least access to greenspace as the reference group. A European-wide study calculated that adults in the highest quintile of greenery were more than three times likely to report they were physically active (OR 3.32, 2.46–4.50) compared with those in least green areas (22). Most studies had more modest estimates of effect. Some reported different effect sizes for subgroups, e.g. boys aged 5–18 in Atlanta (37) were 2.3 (1.7–3.2) times more likely to have walked recently if they had access to at least one greenspace, whereas the odds ratios for girls was 1.7 (1.2–2.4).

Discussion

This is a relatively new field of research and only 60 papers were identified by this review, of which almost half (28) were published in the last 2 years (2008 and 2009). Around two-thirds (33 out of 50 papers) found a positive relationship or some weak or mixed evidence of an association between greenspace and physical activity, 9 out of 13 reported a positive or equivocal relationship with BMI and three papers found some association with obesity-related health outcomes. However, around a third of studies found no relationship, two found a negative relationship and results were equivocal across many papers.

Given the large-range factors which affect weight status and potential time-lags between exposure and change in bodyweight, the lack of a strong association with weight outcomes found in these cross-sectional studies is unsurprising. Several studies found evidence that relationships varied by factors such as age and socioeconomic status and also by the measure of greenspace used. Improvement in the theoretical understanding of the mechanisms through which greenspace may influence health would help study design and interpretation of reported findings. Advances could include identifying which factors within the social-ecological model of health are specifically important for the relationship between greenspace and obesity. In other words, when, how and for whom is access to greenspace associated with obesity? A recent review of recreation settings and physical activity (14) also notes the need for more specific models and calls for improved measures of greenspace. It is noteworthy that most reviewed studies used crude measures of greenspace, with no consideration of quality or other environmental features. More sophisticated approaches are needed (20), particularly as several studies showed size and attractiveness to be associated with utilization frequency.

All studies were cross-sectional and therefore suffer from widely acknowledged methodological limitations. Most importantly, it is not possible to determine if an observed relationship between greenspace and health is causal. There is the possibility of selection effects where more active people choose to live in greener environments (66). The studies also varied hugely in choice of confounding variables and therefore some positive results could be because of residual confounding. Particularly problematic may be inadequate adjustment for socioeconomic factors given the well documented association between deprivation and obesity (67). Furthermore, greenspace was just one of many exposures being tested in several studies so statistically significant findings were more likely to arise because of multiple tests. The majority of studies (44 out of 60) relied on self-reported physical activity or BMI, which is prone to recall bias. Nevertheless, this did not obviously lead to a bias in results. Few studies measured actual use of greenspace. The employment of new technologies such as global positioning systems to record where people are active will help address this.

This review has a number of strengths and limitations. Weaknesses include that the search was restricted to English-language articles and just four databases were searched, although these were judged to best capture relevant studies. The search focussed on peer-reviewed literature but relevant studies may be reported elsewhere. However, limiting inclusion to peer-reviewed studies ensured a high quality of papers. Several papers were based on related populations and these were counted individually within the summary, which may overestimate counts of particular findings. Strengths include the wide set of search terms used and assessment of study quality.

Conclusion

There is some evidence for an association between greenspace and obesity-related health indicators, but findings were inconsistent and mixed across the studies. Developing a more solid theoretical socio-ecological framework which considers the various correlates and interactions between different types of greenspace and health would help both formulation and interpretation of the body of research.

Conflict of Interest Statement

No conflict of interest was declared.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Table S1. Search terms used in systematic review.
Table S2. Criteria for assessment of methodological quality and strength of the evidence.
Table S3. Studies included in greenspace and obesity systematic review.

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Perspective Essay

Towards a better understanding of the relationship between greenspace and health: Development of a theoretical framework

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HIGHLIGHTS

- We develop a framework which documents relationships between greenspace and health.
- The framework highlights key mediators which underpin the relationship.
- Moderators affect the relationship, such as socio-economic status and greenspace type.
- The framework can be used to inform and improve planning of research studies.

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Social ecology

ABSTRACT

A growing body of evidence investigates whether access to greenspace, such as parks and woodland, is beneficial to well-being. Potential health benefits of greenspace exposure include opportunity for activities within the space and psychological benefits of viewing and interacting with nature. However, empirical research evidence on the effects of greenspace exposure shows mixed findings. Hence we suggest that the key questions of "if, why and how?" greenspace influences health remain largely unanswered. We argue that researchers have inadequately considered the causal pathways which drive the relationship. In particular, an improved understanding is needed of potential mediators and moderators. In this paper we draw on social–ecological theories and a review of the literature to develop a novel theoretical framework which summarises current knowledge about hypothetical causal pathways between access to greenspace and health outcomes. The framework highlights how mediators – such as use of greenspace and perceptions of the living environment – drive associations between access and both physical and psychological health outcomes. We propose key moderators based on evidence that associations between greenspace and health differ by demographic factors such as gender, ethnicity and socio-economic status, living context, greenspace type and climate. We discuss the evidence for how and why these factors act as moderators and consider the implications which arise from this improved understanding of the relationship between greenspace and health. In conclusion, we discuss how the framework can be used to inform planning of research studies, and how it may be developed in the future as more evidence emerges.

1. Introduction

Social–ecological models of health seek to explain how environments in which people live and work offer constraints and opportunities for individuals to engage in health-promoting and demoting behaviours (Sallis, Owen, & Fisher, 2008). One environmental factor that has particular potential to influence health is availability of greenspace. Definitions of what constitutes greenspace are subjective and vary widely, but broadly encompass publicly accessible areas with natural vegetation, such as grass, plants or trees (e.g. CDC, 2009; Kit Campbell Associates, 2001). They include built environment features, such as urban parks, as well as less managed areas, including woodland and nature reserves.

Greenspace is important because of its multifaceted potential to influence health. It can be a resource for physical activity if used for walking, running, cycling and sports, all actions for which health benefits are well established (Manley, 2004). The wider benefits of experiencing 'green' environments are well documented, stemming from the seminal research by Kaplan and Kaplan in the 1980s which outlined the psychological benefits of experiencing nature (Kaplan & Talbot, 1983). Recent research has shown

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that time in natural environments is associated with reduced negative emotions and better energy levels, attention span and feelings of tranquillity compared with being in synthetic settings (Bowler, Buyung-Ali, Knight, & Pullin, 2010). There are also wider non-physical potential benefits of greenspace (Lee & Maheswaran, 2010), such as promoting social cohesion by providing areas for people to participate in group activities (Maas, van Dillen, Verheij, & Groenewegen, 2008).

Given the evidence for the potential health value of greenspace, it follows that there may be health benefits to living and working in neighbourhoods which have good availability of public green areas. Indeed, access to greenery has historically been regarded as important in urban planning, evidenced by examples such as widespread creation of public parks in the UK during the Victorian era (Walker & Duffield, 1983). Recently there has been a re-emergence of the recognition of the importance of greenspaces when planning for healthy communities and a simultaneous proliferation of new studies examining associations between greenspace exposure and health, summarised in a number of systematic reviews (Kaczynski & Henderson, 2007; Lachowycz & Jones, 2011; Lee & Maheswaran, 2010).

Given the theoretical importance of greenspace it is perhaps surprising that, whilst some studies have reported evidence of positive associations between greenspace access and health, others have shown little or no relationship and some have even found negative associations. In a systematic review of 50 quantitative studies examining relationships between greenspace access and physical activity, 20 reported positive associations (higher physical activity with increased greenspace access), 15 were weak or mixed, 2 were negative and 13 found no evidence of any association (Lachowycz & Jones, 2011). Furthermore, several studies found associations only for certain groups, in particular areas or for particular types of greenspace, suggesting relationships are sensitive to specific populations and geographical areas. For example, within studies looking at greenspace access and BMI, Scott et al. found that relationships differed by ethnic group (2009) and others found that associations with BMI are only present for certain types of greenspace (Potwarka, Kaczynski, & Flack, 2008; Witten, Hiscock, Pearce, & Blakely, 2008). The equivocal nature of the research evidence may in part reflect the disparate nature of study designs. This may partially result from the fact that there is no comprehensive evidence-based conceptual framework which documents key theoretical relationships and specifies likely causal mechanisms by which greenspace may influence health. Indeed, the need to generate improved theoretical models is well recognised in literature discussing socio-ecological approaches (Sallis et al., 2008). There is also recognition of the need to identify mediators and moderators, terms which are commonly confused across the literature, particularly in topics such as this where research findings are mixed (Baron & Kenny, 1986; Bauman, Sallis, Dzewaltowski, & Owen, 2002).

We argue the lack of theoretical models means that research on links between access to greenspace and health is often based on loosely defined theoretical concepts, with little consideration of what particular casual pathways are being tested. An improved understanding of potential mediators, which sit on the causal pathway between greenspace access and health, could assist interpretation of research findings and help future studies test specific pathways of influence. In addition, identification of moderating factors which alter the strength or direction of associations could improve understanding of which groups benefit most from greenspace exposure, enabling planners to better identify when and how greenspace provision may lead to health improvement.

In this paper we present a novel conceptual framework which illustrates the theoretical relationship between access to greenspace and health. The framework documents key hypothesised causal pathways and illustrates potential moderating and mediating factors. The framework is then discussed in relation to available evidence, with a particular focus on factors which studies have identified as potential moderators. In conclusion, we consider future use and development of the framework to assist planning of research studies and target greenspace provision for population health gains.

2. Development of a theoretical framework for greenspace and health

To develop our framework we undertook a comprehensive, although not systematic, review. Using search terms including green space, open space, nature and park (for a full list see Lachowycz & Jones, 2011), we searched relevant databases (SCOPUS, Medline, Embase and PYSCHINFO) to identify quantitative studies which looked at greenspace access in relation to health outcomes, including markers of general health and morbidity, measures of mental health and wellbeing, and physical activity behaviours. We consulted key examples of existing socio-ecological models looking at environmental influences on health and health-related behaviours, including mental health and physical activity (for a summary of models see Sallis et al., 2008). We reviewed available quantitative studies investigating relationships between greenspace access and health, drawing on systematic reviews (Kaczynski & Henderson, 2007; Lachowycz & Jones, 2011; Lee & Maheswaran, 2010), but expanding to include other articles that contained relevant material to the production of our framework. The reference lists of identified studies were also reviewed and we used reverse snowballing to identify more recent publications. We also looked at references within the grey literature, found though searching the internet and checking key websites (e.g. Commission for Architecture and the Built Environment (CABE) and Government sites).

Drawing on the literature, we documented hypothetical causal explanations for how objectively measured greenspace access could lead to health improvement, therefore identifying potential health outcomes and mediators. We then reviewed the studies to identify factors for which evidence exists of them acting as a moderator, i.e. stratification by the variable has resulted in different strengths of relationship between greenspace exposure and the health outcome. In addition, we included some factors not yet empirically tested, but for which we believe there is good theoretical basis to suggest they may act as moderators.

The resultant framework, shown in Fig. 1, illustrates the hypothetical causal pathway between access to greenspace and health outcomes. Along this pathway we illustrate the main tiers of moderating factors, the mechanisms of moderation and the key processes of mediation. We discuss the evidence used to construct the framework below, working in reverse, as this was the order used to construct the framework. We hence first discuss the health outcomes, then the pathways of mediation which result in these outcomes and end with a discussion of the moderating factors and mechanisms of moderation.

2.1. Health outcomes

The potential health outcomes resulting from greenspace exposure are discussed extensively across the literature. Our framework categorises these outcomes into two broad groups: physical and psychological. This dichotomy is commonly used, with physical health benefits generally attributed to physical activities within greenspace, and psychological benefits gained from exposure to nature and social interactions. This dichotomy belies the interaction between physical and mental health outcomes and, therefore, our framework shows them as interacting states and does not

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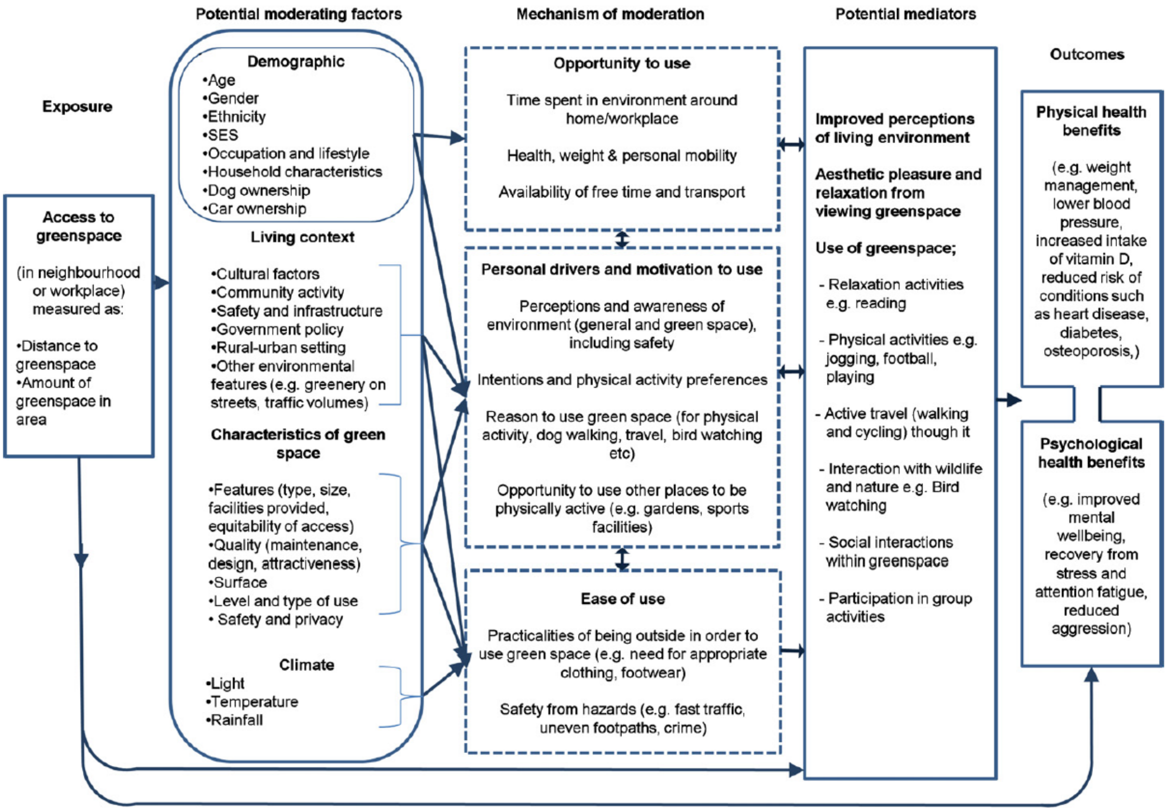

Fig. 1. Socio-ecological framework for the relationship between greenspace access and health.

attempt to link them to specific mediators. For instance, visiting greenspace to interact with nature, or to read a book could have benefits to physical as well as mental health, such as blood pressure reduction (Hartig, Evans, Jamner, Davis, & Garling, 2003), and vitamin D absorption from sunlight exposure (Holick, 2004). There is evidence of the mental health benefits of physical activity (Penedo & Dahn, 2005) and, moreover, evidence of additional benefit from exercise in green environments compared with urban settings (Thompson Coon et al., 2011).

2.2. Potential mediators

To understand how access to greenspace could result in a change in health outcome, we need to consider what underlying mechanisms, or mediators, are driving this change. A core principle of social–ecological models is that features within the physical environment lead to changes in health behaviours and psychological states (Cohen, Scribner, & Farley, 2000). Applying this principle to greenspace access suggests that, for example, living near a park enables individuals to behave or feel differently. These changes in behaviour or mental state are thus the mediators which explain associations between greenspace accessibility and improved health. The fact that a potential health benefit has been demonstrated in a experimental study – for example, that walking in natural areas is associated with lower blood pressure than in more urban settings (Hartig et al., 2003) – does not imply that living near greenspace is associated with lower blood pressure amongst free-living populations. Here, the act of using the greenspace for exercise acts as a mediator between the exposure and the health benefit.

Within the framework, we illustrate mediators as three broad groups; improved perceptions of the living environment and satisfaction from "having the park there" (Bedimo-Rung, Mowen, & Cohen, 2005), aesthetic satisfaction and restoration from viewing natural features, and use of the space for relaxation, physical activities, socialisation and to interact with wildlife. These routes of mediation are identified in the literature as potential causal explanations for the health impacts of greenspace and are supported by some evidence, mostly from experimental studies or surveys. However, research thus far has failed to find strong evidence for the role of a behaviour change mechanism – such as using greenspace – in relation to access. That close proximity of greenspace is associated with increased use seems 'common sense', but actual evidence remains elusive (Giles-Corti & Donovan, 2002) and results from quantitative studies which have investigated how access affects use are ambiguous (Lachowycz & Jones, 2011). For example, a study of Danish adults found no evidence that use of greenspace explains associations with BMI or levels of stress (Nielsen & Hansen, 2007).

Research from The Netherlands attempted to disentangle pathways of mediation and found the strongest evidence that social interactions in greenspace drive associations between access and health (Maas, Verheij, Spreeuwenberg, & Groenewegen, 2008). These researchers also found weak evidence for greenspace acting as a buffer from stressful life events (van den Berg, Maas, Verheij, &

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Groenewegen, 2010) but no support for physical activity acting as an underlying mechanism (Maas, Verheij, et al., 2008). Overall, little has been established about how potential mediators operate in practice and for different health outcomes. Whilst an England-wide study found that inequalities in deaths from circulatory disease were reduced in greener areas (Mitchell & Popham, 2008), it is impossible to establish whether this could be due to amelioration of stress or increased physical activity, or indeed a combination of both, or due to another explanation entirely.

2.3. *Potential moderators*

A central principle of social ecological models is that environmental influences on individuals vary by intra-individual and intra-environmental factors (Sallis et al., 2008). For example, individuals with high motivation to be active may react differently to provision of sports facilities within their neighbourhood than those with lower motivation. Therefore, we aimed to identify which particular factors may interact with, and hence moderate, the relationship between greenspace access (our exposure) and change in health state (our outcome). The role of moderators has been discussed in relation to physical activity (Bauman et al., 2002; Michael & Carlson, 2009) and within social psychological research (Baron & Kenny, 1986). Insight into potential moderators can also be drawn from research into leisure behaviours (Godbey, 2009) and factors which determine use of parks (Bedimo-Rung et al., 2005). Crawford, Jackson, and Godbey (1991) conceptualised barriers to participation in recreation and leisure activities as three key types of constraint: interpersonal (e.g. psychological factors), intrapersonal (factors related to others such as family and friends) and structural constraints (e.g. lack of opportunity, time and money). Drawing on all of this evidence, we suggest that moderation occurs by three broad mechanisms:

(1) *Opportunity to use greenspace*: Individuals have constraints which limit their ability to use greenspace independently of how good their physical access is. These constraints include time limitations and physical constraints such as health-limiting factors. Possession of commodities such as private transport may make access easier and this is related to income, although income level per se is arguably not an important factor if public greenspace is free to use.
(2) *Personal motivation and reasons to use greenspace*: Greenspace is one of many potential health promoting resources which individuals can use or choose not to. Motivations to use are influenced by factors such as personal reasons (e.g. walking the dog, bird watching, or cycling through it on route to work), perceptions of the environment, the composition and lifestyle preferences of the family and community, and opportunities to access alternative health promoting resources such as gyms and gardens. The type of greenspace and the facilities available will also affect the attraction for particular groups.
(3) *Ease of use*: Environmental features may influence how practical it is to use greenspace. Extreme weather conditions or lack of light require individuals to overcome practical considerations, such as obtain appropriate clothing. Other environmental factors may influence use, such as speed of traffic or presence of greenery on routes to the park.

These mechanisms are intertwined and hence linked by two-way arrows on the framework. For example, perceptions of the environment will be influenced by how much time is spent at home and ease of use will be influenced by personal drivers and motivations e.g. it requires a personal choice (and financial ability) to purchase appropriate clothing and footwear in order to use greenspace in all weather conditions.

As socio-ecological models of health commonly divide factors influencing health into two main tiers, those relating to the individual and those pertaining to the environment (Sallis et al., 2008), we represent moderators as a tier of individual factors and those relating to the social and physical environment. The social environment factors are those which we suggest are specifically relevant to the use and health value of greenspace. We include two groups of physical environment factors: greenspace characteristics, as these are key antecedents of use (Bedimo-Rung et al., 2005), and climatic factors, which we hypothesise are important drivers of use of the outdoors for leisure and physical activity (Tucker & Gilliland, 2007). We discuss these groups of moderators below, in relation to evidence used to construct the framework.

2.4. *Demographic factors*

Demographic characteristics such as age, ethnicity and socio-economic status are key determinants of physical activity and health and affect participation in outdoor and recreational activity (Kemperman & Timmermans, 2008; Lee, Scott, & Floyd, 2001). Given that these factors influence the opportunity and motivation to use greenspace, they are likely to moderate relationships between access and health. One key mechanism of moderation is time spent at home, as those spending greater amounts of time in the living environment are more reliant on resources within it (de Vries, Verheij, Groenewegen, & Spreeuwenberg, 2003). This could explain studies which have found that younger and older groups are more sensitive to greenspace provision than middle-aged adults (Kaczynski, Potwarka, Smale, & Havitz, 2009; Maas et al., 2009), who are more likely to be at work. Other factors such as physical activity preferences, health, mobility and perceptions of the environment are strongly age-related and therefore the motivations and practicalities of using greenspace and the types of space most attractive to an individual are likely to vary by age. The majority of studies examining greenspace access and health have focussed on adults of working age (Giles-Corti & King, 2009). This is actually the group for which it may be hardest to find associations, given their complex daily activity patterns. There is a paucity of evidence into how older people's health is affected by greenspace provision.

Gender is known to affect health related lifestyles (Bird & Rieker, 2008) and may be especially important for relationships with greenspace accessibility, as there is evidence that sex influences perceptions and use of the environment, as well as physical activity preferences (Stafford, Cummins, Macintyre, Ellaway, & Marmot, 2005). Gender effects may also be age dependent. In youth, boys are known to roam more freely (Brown, Mackett, Gong, Kitazawa, & Paskins, 2008) and several studies support strongest associations between greenspace access and physical activity amongst them (Epstein et al., 2006; Gómez, Johnson, Selva, & Sallis, 2004; Roemmich et al., 2006). Taylor et al. found that views of nature were associated with improved self-discipline, such as the ability to concentrate, for girls only (Taylor, Kuo, & Sullivan, 2002). The authors suggest that boys are less affected by nature in the immediate vicinity of home as they play further away. Whilst empirical data is needed to test this hypothesis it certainly seems that gender differences can begin early in life, perhaps acting through parental attitudes and differences in play behaviours. In adults some evidence suggests that women have stronger relationships between greenspace access and physical activity (Cerin, Leslie, Toit, Owen, & Frank, 2007; Kaczynski et al., 2009), walking (Foster, Hillsdon, & Thorogood, 2004) and self-reported health (Bjork et al., 2008). Maybe this stems from the fact that women have historically spent more time around the home, especially during motherhood (Lee et al., 2001), although it is noteworthy that women appear more influenced than men by safety concerns (Foster et al., 2004) and also the quality and type of available greenspaces (Bedimo-Rung et al.,

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2005; Cohen et al., 2007). How these factors affect their behaviours is not well understood and longitudinal studies are required to disentangle changes through the life-course in causal mechanisms associated with gender.

Ethnicity has been shown to influence perceptions of natural environments (Huston, Evenson, Bors, & Gizlice, 2003), preferences for recreation (Virdin, 1999) and the nature and frequency of use of greenspace (Tinsley, Tinsley, & Croskeys, 2002). Some surveys suggest that Whites view environments more favourably than other groups (Huston et al., 2003) and several studies have found associations between greenspace exposure and improved health are stronger for White groups (Kerr, Frank, Sallis, & Chapman, 2007; Scott, Dubowitz, & Cohen, 2009; Wen, Kandula, & Lauderdale, 2007). Given that ethnicity is strongly related to cultural and socioeconomic factors, it is difficult to disentangle how these various factors interrelate (Franzini et al., 2009). Ethnic differences in environmental influences on health can be due to genuine differences in lifestyle and cultural values, or may arise because groups are, or feel, excluded from certain environments (Lee et al., 2001). Culture-specific research to elucidate the key factors and mechanisms of mediation across different groups would help planners consider how to make greenspace provision more culturally appropriate and specifically targeted to needs of local populations.

A key principle of much public greenspace provision is that it is free to use and particularly of value for groups of lower socioeconomic status (SES), who may not have private gardens or have time or money to travel for physical and stress-relieving activities. Studies commonly adjust for SES as a confounder when investigating associations between greenspace and health, and indeed this is essential given that greener areas tend to be more desirable and expensive to live in. Several studies have found that positive associations between greenspace and health are actually stronger for lower income groups compared with those on higher incomes (Babey, Hastert, Yu, & Brown, 2008; Maas, Verheij, Groenewegen, de Vries, & Spreeuwenberg, 2006; Maas et al., 2009). These findings are significant given evidence that lower SES groups tend to have poorer perceptions of greenspace and use it less, even when access is as good as in more affluent areas (Jones, Brainard, Bateman, & Lovett, 2009; Schipperijn et al., 2010). It is well established that wealthier groups are healthier (Smith, Blane, & Bartley, 1994) and more active (Gidlow, Johnston, Crone, Ellis, & James, 2006) than those on lower incomes – therefore, it may be that having access to greenspace amongst higher SES groups helps maintain, rather than increase, their health. A survey following introduction of walking trials in Missouri found that lower SES groups were less likely to use the trails, but those that did showed increases in overall levels of walking, unlike wealthier trail users who used the trails to maintain their already higher levels of activity (Brownson et al., 2000). This implies that the relative health gain of increasing greenspace provision is greatest for those who need it most. Consequently, greenspace access could potentially reduce deprivation-related health inequalities, as suggested by an England-wide study which found that gradients in deprivation-related premature mortality were reduced in greener areas (Mitchell & Popham, 2008).

An individual's occupation, lifestyle and that of their family are included in the framework because we hypothesise that these are important influences on both the opportunity and motivations for use of greenspace. People who are rarely at home, are very physically active in their job or are frequently outside and experiencing nature in their occupation may achieve little additional benefit from access to greenspace at home. Household factors such as dog ownership are also important, as owning a dog is associated with elevated physical activity (Cutt, Giles-Corti, Knuiman, & Burke, 2007) and dog walkers are frequent users of greenspace (Schipperijn et al.). Lifestyle and household factors which studies have identified as moderating relationships between greenspace and health include being a housewife (de Vries et al., 2003), living with children (Kaczynski et al., 2009), and, for children, living in apartments (Babey et al., 2008). The lifestyle of the household is an important moderator for children, for whom the parents act as a gatekeeper to their use of the environment (Veitch, Bagley, Ball, & Salmon, 2006). Davison and Lawson (2006) argue that studies erroneously assume direct links between the environment and children's activity, whereas in reality this link is substantially moderated by parental attitudes to factors such as safety.

2.5. Living context

The second group of factors in the framework are those related to living context. These include socio-cultural factors, such as crime rates, government policy and social attitudes, which influence personal drivers and motivation to use greenspace and may affect ease of use. For example, the value of parks as a health promoting resource is diminished if the neighbourhood has high crime rates (perceived or real) which will discourage people from going outside. Since people need to travel through neighbourhoods to reach greenspace, factors such as busy roads or derelict housing may deter use (Bedimo-Rung et al., 2005).

Other social environment factors which are key components of social–ecological models – cultural attitudes, community activity and government policy – are likely to be important, but their effects are much harder to quantify and test. Factors that affect perceptions of the environment and use of greenspace are undoubtedly intertwined with cultural and historical attitudes to use of the outdoors, participation in physical activity and to nature and wildlife. Studies have documented differences between objective and self-reported measures of access, demonstrating how the concept of accessibility is strongly shaped by social and personal variables (Macintyre, Macdonald, & Ellaway, 2008). In fact, the social meaning attached to greenspace and social perceptions of accessibility may be far more important drivers of health than merely having physical access. Social–ecological theories also acknowledge the existence of undefined 'place' effects on health; contextual differences in health between areas which are unexplained by measured variables (Macintyre, Ellaway, & Cummins, 2002). Consequently, determinants of greenspace use and mediating pathways could vary across different contexts and cultures. Therefore, applying conclusions from one study to a population elsewhere requires caution and consideration of what underlying contextual factors may be different.

One living context factor for which research findings are emerging is how the degree of urbanicity – how urban or rural an area is – moderates physical activity (Ewing, Schmid, Killingsworth, Zlot, & Raudenbush, 2003). We suggest it may also moderate the association between greenspace and health. There is evidence that associations between greenspace access and health are stronger in more urban areas (Babey et al., 2008; Liu, Wilson, Qi, & Ying, 2007; Maas, van Dillen, et al., 2008; Nielsen & Hansen, 2007). If true, it could be that rural dwellers are less sensitive to provision of facilities in their local area as they are more used to travelling out of their neighbourhood to use services. An alternative explanation is the methodological problem of measuring greenspace in rural areas; whilst the countryside is, by definition, 'green' and therefore residents can easily obtain psychological benefits of viewing natural scenery, often a key driver for their choice to live there, the surrounding land is often inaccessible to the public, particularly if it is agricultural. Consequently, improved measures of publicly usable greenspace in rural areas are needed to test the degree to which urban–rural factors act as moderators and how pathways of mediation might vary across different contexts.

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2.6. Characteristics of greenspace

The second group of environmental factors in the framework are characteristics of greenspace. We propose these influence an individual's personal motivation and practical opportunities to use greenspaces. Therefore, the effect of distance as a determinant of use and health value will be moderated by the 'attractiveness' of a greenspace for each individual (Giles-Corti & Donovan, 2002). Research has shown that different groups value different characteristics, facilities and activities within greenspace (Cohen et al., 2010; McCormack, Rock, Toohey, & Hignell, 2010). For instance, a jogger may want a large space with quiet paths whereas a family with young children might prefer smaller areas with play, toilets and parking facilities. In addition to using greenspace specifically for leisure purposes, people may choose to traverse through it on route to work or to the shops if, for example, the paths are hard surfaced and well lit. Whilst some evidence suggests that psychological benefits are greatest in areas which contain wildlife and are species rich (Fuller, Irvine, Devine-Wright, Warren, & Gaston, 2007) these areas may be perceived as less safe for children (McCormack et al., 2010). Therefore, whilst there is evidence that factors such as size and attractiveness (Giles-Corti et al., 2005), greenspace type (Coombes, Jones, & Hillsdon, 2010) and amenities (Cohen et al., 2010) affect relationships with health, the particular health value of any type of greenspace is likely to vary according to the user group or specific health outcome being tested.

Simple measures of distance to parks cannot adequately capture these complexities and therefore it is unsurprising that many studies fail to find relationships between access and health. In particular, information about quality and type of greenspace is rarely available. Use of access scores which incorporate factors such as size and attractiveness (Giles-Corti & Donovan, 2002) helps, as does using tools to assess park characteristics, particularly when developed for specific user groups (Floyd, Taylor, & Whitt-Glover, 2009). Bedimo-Rung et al. propose a conceptual model which considers how park characteristics and user requirements modify relationships between park use and health benefits (Bedimo-Rung et al., 2005). Their framework summarises key park characteristics, such as condition, safety and aesthetics, and the authors suggest future studies should test associations between physical activity levels and these characteristics. Ideally, the measure of greenspace used in studies should reflect the specific research question being investigated and with consideration of which causal pathways and mediators in the framework are being tested. This will depend on the population being studied and, importantly, the particular physical or mental health outcome being evaluated.

2.7. Climate

The final group of moderating factors within the framework are climatic factors, as we argue these are specifically important for determining how people use resources in the environment. A study of the relationship between access and physical activity in Stoke, England, found a stronger association between increased greenspace access and increased physical activity in wetter weather (Cochrane et al., 2009). This seems counter-intuitive but the authors speculate that people travel further in dry conditions and therefore local facilities are less important. A systematic review of climate and weather effects on physical activity summarises how weather and day length act as barriers to outdoor activity, particularly among children (Tucker & Gilliland, 2007). The authors suggest that climatic factors are inadequately considered in creation and surveillance of physical activity interventions within the environment. Further research looking at seasonal and climate-related patterns in use of greenspace for physical activity would help improve understanding in this area and provide evidence to plan public areas which are weather-appropriate and maximise their health value throughout the seasons.

3. Discussion

In this paper we present a framework which illustrates the theoretical causal relationship between access to greenspace and health. The framework documents key mediators driving this relationship and proposes key moderating factors which influence the strength of association. We discuss how available evidence informs the framework and highlight areas within the framework which would benefit from further research to develop understanding. We suggest this framework is novel as for the first time it summarises current knowledge about causal pathways between greenspace exposure and health.

Research into the potential salutogenic benefits of having access to greenspace is a burgeoning field. Yet the vast majority of this research relies on cross-sectional study designs, for which limitations are well known and, in particular, are weak at testing for causality and identifying mediators. Therefore, despite good theoretical bases for how greenspace could influence health, evidence of mediators operating in practice remains elusive. The use of longitudinal study designs and 'natural experiments' where, for example, greenspace is provided in an area which previously had none and change in behaviour is measured will help us better understand behaviours associated with access to greenspace. Evidence from these studies could strengthen and modify the framework, as our reliance on results from cross-sectional studies in its development is undoubtedly a limitation. Improved study designs would also help establish if there are genuine causative mechanisms at work and rule out selection effects, whether direct (people choose to live near greenspace if they are healthier or physically active) or indirect (people with certain characteristics, such as higher incomes, tend to live in greener areas) (Maas et al., 2009). However, given the practicalities of data collection, it is likely that cross-sectional approaches will continue to dominate research in this field for some time. Therefore, our pragmatic argument is that such studies will be methodologically more robust if greater consideration is given as to what particular causal pathways are being tested and also what moderators may be important.

We hope our framework will stimulate debate amongst researchers in this field. We also hope it will support others to be more precise when specifying the theoretical relationships being tested and describing methods used, as currently terms are often used interchangeably when they mean different things (e.g. 'access' verses 'usage'). A practical future application is to use it when planning research in order to map out particular casual pathways to investigate, and design studies which test which mediators and moderators are operating. For example, the use of global positioning systems (GPS) to measure the location of activity (Lachowycz, Jones, Page, Wheeler, & Cooper, 2012) enables researchers to objectively test if use of greenspace is acting as a mediator in relationships between access and physical activity. Subject to data availability, theories can be empirically tested within the analysis, using statistical techniques to test for moderation and mediation (Baron & Kenny, 1986). We appreciate that this is complex, as a tenet of social–ecological models is that multiple factors interrelate and this can make it difficult to know how to measure or test which particular factors may drive any observed relationships. As we have shown, there is a wide body of literature documenting how preferences for recreation and use of greenspace vary across groups and in different contexts, yet there has been a general failure to consider how factors such as ethnicity, deprivation or age moderate relationships between greenspace and health. Many studies

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commonly adjust for various confounding variables – often with little justification for why they are considered to be confounders – but rarely consider how these factors may also moderate or mediate the associations being tested. Therefore, valuable information about differences in effects across sub-groups is lost. Furthermore, erroneous conclusions may be drawn which are not generalisable to other populations or environments, or studies may fail to find relationships even when they do exist.

Our framework is deliberately broad and encompasses multiple greenspace types and both physical and mental health outcomes. More specific versions could be developed for particular health outcomes or types of greenspace, for example the use of playgrounds by children. One route of mediation not included in the framework is the role of greenspace as a protector from environmental stressors, such as pollution and heat (Bedimo-Rung et al., 2005). This was primarily excluded here due to a paucity of evidence, as no epidemiological studies testing for associations between access and health have looked at this as a mechanism of influence. Secondly, greenspace acting as a protector from stressors is likely to act directly on all those living nearby and thus be less affected by mediating and moderating pathways shown in the framework. As evidence emerges, this route of influence could potentially be incorporated.

The causal pathways represented in the framework are illustrated as predominantly uni-directional, whereas the reality is much more complex. For example, use of greenspace may affect perceptions of the local environment. Multiple mediator–moderator interactions may operate in practice but the figure does not attempt to illustrate specific and detailed connections between factors, as there is not yet robust evidence to inform this. The framework presents all the factors and pathways as if they are of equal importance and in the future measures of strength of effect could be incorporated as better evidence emerges. We have discussed available evidence which supports elements presented in the framework, but we believe there is currently not enough information to generate robust measures of effect size. As more is published, meta-analysis could be used to pool findings and estimate the relative influence of the different moderating factors and quantify the impact of greenspace access on health across different routes of mediation. This could be of particular interest to policymakers, for whom indicators of strength of effect which can be clearly applied to population-level planning are the most useful. For example, understanding that certain population groups have low motivation to use greenspace may require specific interventions such as increased education, or facilitation and provision of particular programmes or facilities. This principle of multi-level interventions, where interventions in the environment are accompanied by group-specific targeting of individuals, is well recognised in social–ecological theory as being the most powerful approach to change behaviour and improve health (Sallis et al., 2008). Research has highlighted inequalities in physical access to greenspace, particularly by socio-economic group (Jones, Hillsdon, & Coombes, 2009; Moore, Diez Roux, Evenson, McGinn, & Brines, 2008). However, producing equitable health benefit from greenspace may not be as simple as just providing equal access to it.

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What can global positioning systems tell us about the contribution of different types of urban greenspace to children's physical activity?

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ABSTRACT

Urban greenspace is hypothesised to be an important location for physical activity in children, but their actual use of the resource to be active is not well known. In this study, global positioning systems (GPS) and accelerometers were used to measure activity within green environments for 902 English children aged 11–12. We summarised activity intensities in different types of greenspace on weekday evenings, weekend days and by season. Around half of outdoor moderate-vigorous activity took place in greenspace at the weekend and use was consistent across seasons. The findings suggest the importance of certain types of greenspace to children's physical activity.

1. Introduction

Physical activity during childhood is associated with improved health, including reduced likelihood of becoming obese (Trost et al., 2001) or developing symptoms of depression (Motl et al., 2004). Activity during childhood also contributes to development of healthy lifestyles later in life (Hallal et al., 2006) and has long term protective health effects, such as establishing healthy bone structure (Karlsson, 2004). Despite these benefits, low and declining levels of physical activity have been reported among children in developed countries (Dollman et al., 2005; Knuth and Hallal, 2009). In England, only 32% of boys and 24% of girls aged 2–15 meet the government's recommendations for physical activity of doing at least one hour of moderate activity per day (NHS Information Centre for Health and Social Care, 2009).

A growing body of evidence demonstrates the potential influence of environmental factors on children's physical activity (Davison and Lawson, 2006; Ferreira et al., 2007). One such environmental factor is greenspace, as areas such as parks, playgrounds and woodland can be used by children for play and leisure time physical activity. Public greenspaces can provide natural play spaces with multifaceted benefits to children as they, for example, provide opportunities to interact with nature, play creatively, socialise with others and develop independence and confidence in being in an outdoors environment (Muñoz, 2009). Given that children have less autonomy in their behaviour choices than older groups (Nutbeam et al., 1989) and that their use of the environment is influenced by parental attitudes (Veitch et al., 2006), the availability of suitable and safe play spaces outdoors may help parents feel more confident to allow their children to be more autonomous and play independently outdoors (Mulvihill et al., 2000). Research shows that children who spend greater amounts of time outdoors have higher levels of physical activity (Cleland et al., 2008) and that outdoor activities such as walking, playing informal ball games and unstructured free play are important contributors to overall energy expenditure (Mackett and Paskins, 2008). Furthermore, in addition to the physical activity benefits of playing in greenspace, a wide body of literature documents the psychological benefits of spending time in natural environments (Taylor and Kuo, 2006).

A recent systematic review identified 14 studies, which have looked specifically at the relationship between access to greenspace and children's physical activity, of which 6 found a positive relationship (Lachowycz and Jones, 2011). Therefore, the emerging evidence in this relatively new research field is equivocal (Kaczynski and Henderson, 2007; Lachowycz and Jones, 2011). One reason for this inconsistency may be that studies are largely reliant on measuring cross-sectional associations between overall levels of physical activity and presence of greenspace within a child's living environment, and are often unable to consider the

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actual locations where physical activity takes place. Therefore, the locations children use for active free-play and physical activity remain largely unknown. One developing approach, which can help address this gap is the use of global positioning systems (GPS) to measure how children move around within environments. GPS devices pick up signals from satellites to record positions on the ground, with an accuracy of a few metres. The recent development of affordable, lightweight and accurate GPS allows these devices to collect location data from large samples of individuals and continuously track their movement through the environment. GPS can be used in combination with accelerometers (devices that detect speeds of body movement and generate intensities of physical activity) to simultaneously measure physical activity and location and thus record the environments where different intensities of physical activity take place (Rodriguez et al., 2005). A recent systematic literature review of applications of GPS to physical activity (Maddison and Mhurchu, 2009) concluded that one major advantage is the ability to collect valuable contextual information, such as the occurrence of activity within specific facilities, and thus improve our understanding about how individuals interact with their environments and use different locations for physical activity.

The first applications of these methods amongst children have recently emerged. Combined GPS-accelerometer methods can be used to objectively measure how different types of greenspace are used by children for play and physical activity. A New Zealand study of 184 children aged 5–10 years found that 1.9% of physical activity occurred in public parks with playgrounds (Quigg et al., 2010). That study did not measure activity within other types of greenspace, such as more natural areas and on playing fields. Jones et al. (2009b) collected GPS and accelerometer data from 100 school children in Norfolk, UK, and found that 7.3% of moderate-vigorous activity bouts occurred in areas defined as parks, 11.8% in grassland, 13.6% in farmland, 3.0% in woodland and 24.0% in gardens (Jones et al., 2009b). That study therefore suggests that different types of green areas, not just those designated as parks, may be important physical activity locations. However, Norfolk is a predominantly rural county and no studies have yet examined the extent to which different types of greenspace are used by children living in urban settings. Given that 82% of people aged less than 20 in the UK live in urban areas (Bayliss and Sly, 2009), it is a major gap in knowledge that so little is understood about how much activity occurs in urban green environments and the extent to which this contributes to overall activity levels. Moreover, we believe there has been no research into how levels of activity within greenspace vary across the week and throughout seasons of the year. This information could inform design of environments, which maximise their health value across different times and weather conditions.

This study uses data from the PEACH (Personal and Environmental Associations with Children's Health) project in Bristol, UK, to examine the use of different types of urban greenspace by children aged 11–12 years. The study uses data collected from the children during their first year at secondary school, as in this phase GPS data was collected during weekday evenings and at the weekend. Prior analysis of data collected from the children a year earlier, in their final year at primary school, found that around 2% of weekday evening time was spent in urban public parks and that activity within these parks was more likely to be of high intensity than activity in other areas, particularly for boys (Wheeler et al., 2010). This study extends this work by measuring the locations of activity during all non-school time, across different types of public parks as well as within other types of greenspace, such as in private gardens and on school playing fields.

The key aims of the analysis were to establish how much of children's physical activity occurs within different types of urban greenspace and to assess how this activity contributes to total levels of non-school physical activity. The analyses were stratified by activity intensity, with a particular focus on levels of moderate-vigorous activity as this is thought to be particularly beneficial to health (Steele et al., 2009), and the UK government recommends that children are active at this level for at least one hour per day (NHS Information Centre for Health and Social Care, 2009). In order to investigate if patterns of use vary across the week, analyses were carried out separately for weekday evenings, for weekend days and separately for Saturday and Sunday. To investigate if use of greenspace varies across the year, summaries of the amount of moderate-vigorous activity occurring outdoors and within greenspace were produced for each season. The results reveal when greenspace is used by children for play and physical activity and, which particular types are most used by children.

2. Methods

2.1. Data collection

The sample was drawn from the PEACH cohort in Bristol, UK, which originally recruited 1307 children aged 10–11 years from 23 state primary schools. Bristol is the sixth largest city in England, with a population of over 400,000 residents. The city is relatively densely populated and has large socio-economic inequalities, containing areas of considerable affluence and others of significant deprivation (Tallon, 2007). Participants were selected from schools chosen as representative of Bristol according to deprivation and geography. The PEACH methodology is described in detail elsewhere (Page et al., 2009). This study uses data obtained from participants during their first year of secondary school (aged 11–12 years), collected between November 2007 and July 2009. In addition to collection of questionnaire and anthropometry data, participants were asked to wear an accelerometer (Actigraph GT1M) for seven consecutive days, set to record activity counts per 10 s epoch (CPE). Participants were also asked to simultaneously wear a GPS (Garmin Fortrex 201) on four school days between the end of school and bedtime (3 pm–10 pm) and on at least one weekend day between 8 am–10 pm. The GPS was set to record latitude–longitude coordinates (up to 10,000 points) every 10 s to an accuracy of <3 m whenever there is sufficient satellite signal (Garmin, 2006). In order to preserve battery life, participants were asked to switch the GPS on after school or upon waking at the weekend and then to turn off at bedtime. The units were recharged after two days of use by research staff.

Data from the GPS and accelerometers were downloaded to a personal computer and integrated using STATA 10 (Statcorp, 2009), based on date/time fields. This produced an activity count and latitude–longitude coordinate (where recorded) for each 10 s epoch. Any 60-min (or greater) period where accelerometer counts were continuously zero (allowing for up to two minutes of non-zeros per hour) were classified as 'missing', as these were judged to be periods when the accelerometer was recording but not being worn (Troiano et al., 2008). Any epoch record without a location coordinate were coded as 'indoors'. For sequential GPS locations, the speed of travel was calculated based on the change in location on the ground using Pythagoras theorem to calculate the straight-line distance between points and the time between points. Any datapoints with a travel speed above 15 kph were excluded as these were judged to be either journeys in vehicles or erroneous locations caused by deficient signal quality, as GPS receivers are less accurate when the signal is obstructed, for example by heavy tree canopy or dense housing (Maddison and Mhurchu, 2009).

2.2. Linkage with land use mapping data

ArcGIS Geographic Information System (GIS) (ESRI® ArcMap 9.2™) was used to prepare a map of land use across the Bristol Local Authority area. The Ordnance Survey Mastermap (OSMM) topography layer classifies every area within Bristol into one of the following land use types: Buildings, Roads and pavements, Private gardens, Parks, Farmland, Grassland, Woodland and Built surfaces (concreted surfaces such as car parks and pedestrianised thoroughfares). The OSMM is the most comprehensive, detailed and up-to-date digital map available for Great Britain and includes every feature larger than a few metres in size, captured with a positional accuracy scale of 1:1250 in urban areas, meaning that 99% of features are located to within 1 m (Ordnance Survey, 2011). In addition, a map provided by Bristol City Council included information about the type of parks within the Bristol Local Authority area (Jones et al., 2009a), with each park area classified as: Formal (an organised layout and structured path network aiming for aesthetic enjoyment, and generally well maintained), Informal (an informal design with emphasis on informal recreation), Natural (habitats providing access to nature, such as heathland, woodland and wetland), Young People's (areas designed for use by children or teenagers, including those with play and games equipment), and Sports (areas used for organised and competitive sports, such as playing fields and tennis courts) (Bristol City Council, 2008). Areas designated as parks within the OSMM layer were compared with the map of public parks to confirm a match and any discrepancies were checked and recoded as appropriate. Then the two map layers were combined to create one land use map for the whole of Bristol.

Comparison of the Mastermap data with raster maps and satellite imagery showed that the OSMM landuse categories grassland, woodland and farmland encompassed a wide variety of landuse types, including areas such as school grounds, cemeteries, private sports grounds, allotments, footpaths and small patches of scrubland and grassland such as verges and banks. Any grassland, woodland or farmland area, which had been used by a child was visually inspected using maps of Bristol and consultation of online mapping resources in order to determine the specific land use. These areas were then sub-classified into three groups: 1) School grounds: land identified by OSMM as grassland and within an area clearly defined as primary or secondary school, 2) Other greenspace: vegetated areas not defined as public parks, including private sports and recreation facilities, cemeteries, golf courses and gardens of publicly accessible buildings such as universities and hospitals, 3) Green verges: small areas of vegetated land with grass or fragmentary vegetation, such as in the centre of roundabouts and narrow strips or banks of vegetation alongside pavements. These first two classifications were categorised as types of greenspace, whereas green verges were judged unlikely to be specifically used for physical activity due to their small size and fragmentary nature, and were more likely to be walked across whilst traversing roads and paths.

The GPS latitude–longitude coordinates for each 10-s epochs were imported in ArcGIS and plotted as datapoints on a map layer overlaying the land use map. Spatial queries were then conducted to assign these datapoints to a landuse type. Each epoch for which GPS data were available was classified as either greenspace, sub-classified as specific type of park, private garden, school playing field or other greenspace, or other land use, sub-classified as roads and pavements, green verges or built surfaces. Datapoints falling outside Bristol Local Authority area were assigned a category of 'Out of study area'. In order to measure how close the parks were to the children's homes, we calculated the straight-line distance from each child's home (based on their home postcode) to the nearest park boundary for each park type.

2.3. Analytical methods

Data were included from days when the participant registered at least 1 min of GPS time. Children with postcodes outside Bristol Local Authority were excluded, as environmental overlay data were only available for this area. Each 10 s epoch was classified into one of three levels of activity: Sedentary (<100 counts per minute (CPM)), (<17 counts per epoch (CPE)), Light (Between 100-2296 CPM and 17-383 CPE), Moderate–Vigorous activity (MVPA) ($>=2296$ CPM, $>=383$CPE). These cut-points were chosen as a comparison of activity thresholds (Trost et al., 2011) showed that the thresholds produced the most accurate match with energy expenditure for each of the activity levels among children. Each epoch was assigned a season based on the month of data collection. Meteorological seasons were used with Spring defined as March, April and May; Summer as June, July, August; Autumn as September, October, November; and Winter as December, January, February.

Figs. 1 and 2 show examples of the overlay of GPS points on the landuse maps, with GPS points shaded according to the level of activity. Fig. 1 shows an example of GPS points collected during one hour from one child on a weekday evening. Fig. 2 shows an example of one park within Bristol and displays all points within this park collected on weekend days by the eight children who recorded activity within this park. This is a community park in South Bristol, classed as a formal park by Bristol City Council, and also has a children's play area and tennis courts. The two figures illustrate the land classifications used and demonstrate how the GPS coordinates were overlaid with the landuse maps.

Epochs were summarised into total counts per activity level per child per day across all the categories of land use. The data was then expressed as mean minutes (and standard deviations) of activity per child per day across land use types. In addition, total counts of activity for all children were summarised and the percentage of activity within each land use was calculated for each activity level. Analyses were performed separately for weekday evenings, weekend days and for Saturday and Sunday as we hypothesised that play and activity behaviours might vary across the days at the weekend. A summary of moderate-vigorous activity occurring outdoors, within greenspace and within parks was produced for each season. All analyses were conducted using STATA 11.

3. Results

Accelerometer and GPS data were collected from 902 secondary school children. Exclusion criteria removed 9 participants for having non-Bristol postcodes. After deletion of days with <1 min GPS activity, data were available for 614 participants on one or more weekday evening and 301 participants on one or more weekend day. Following deletion of any epochs with a speed greater than 15 kph, a total of 5765 person-hours of data were included in the weekday analysis (average 9.4 h per child) and 3833 person-hours of data were included in the weekend analysis (average 12.7 h per child).

Table 1 summarises demographic, anthropometric and physical activity characteristics of the original sample and those included in the analysis. The sample is relatively deprived based on national deprivation scores, with over a third of children living in areas classified within the 25% most deprived areas in England. Compared with the original sample of 902 participants, those included in the analysis included a higher proportion of females and those of White ethnic group, and were less overweight or obese and had higher moderate-vigorous physical activity. These differences were statistically significant ($p<0.05$) for the weekend sample, but not for the weekday evening participants.

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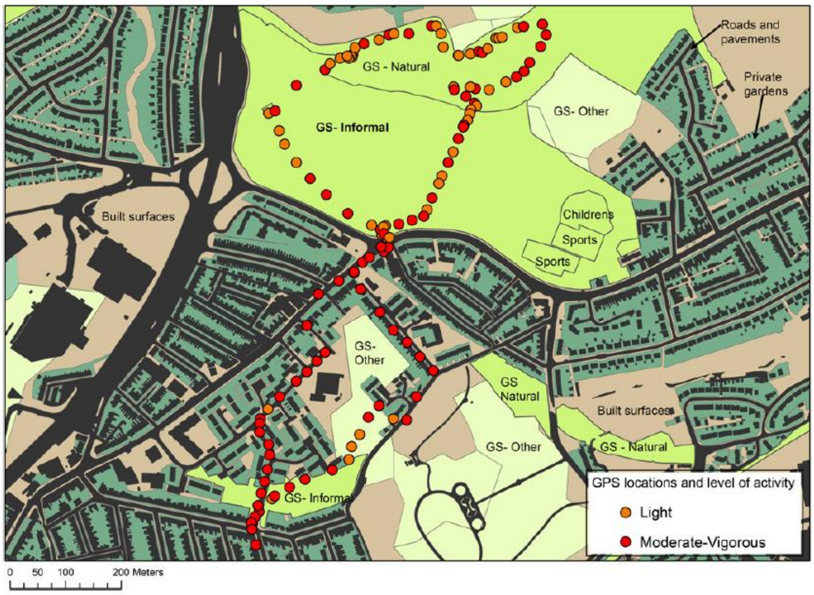

Fig. 1. An example of data collected from one child during one hour on a weekday evening, showing GPS locations and intensity of physical activity. GS=Greenspace. Data Crown Copyright© OrdnanceSurvey. Used under licence.

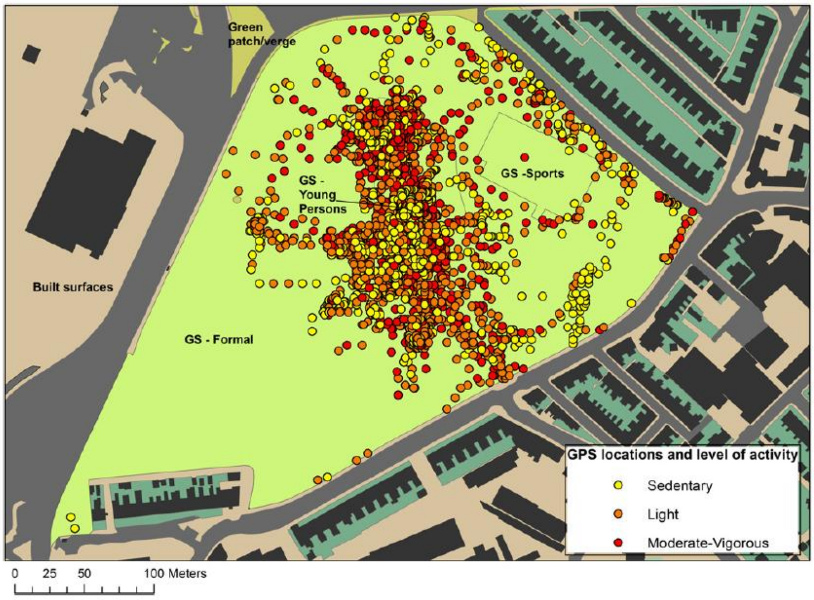

Fig. 2. Example of all GPS data collected within one park at the weekend, showing GPS locations and intensity of physical activity. GS=Greenspace. Data Crown Copyright© OrdnanceSurvey. Used under licence.

There were no significant differences between groups in the average distance to the closest parks for all types.

Table 2 summarises the mean minutes of activity per child per day according to level of activity and stratified by whether the activity was classified as indoors, outdoors and within the study area, or outside the study area. The majority of activity took place indoors, with 26.4% of MVPA occurring outdoors and within Bristol during weekday evenings and 17.6% at the weekend.

Table 3 summarises intensities of activity occurring outdoors and within Bristol by the type of land use within which the activity occurred. Results are expressed as mean times per day and percentages of overall outdoor activity across each intensity level. The average amount of time spent in MVPA per child taking place in greenspace was relatively low (2.4 min per weekday evening and 3.5 min on weekend days), but the contribution of these times to total MVPA was substantial. During weekday

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Table 1
Characteristics of the study sample.

	Total sample $N=902$	Included in analysis of weekday evenings $N=614$	Included in analysis of weekends $N=301$
Age*			
Mean (SD)		12.0 (0.39)	12.1 (0.40)
Gender (%)			
Male	47.5	46.7	39.9
Female	52.5	53.3	60.1
Ethnicity (%)			
White	85.1	86.2	91.7
Asian	3.2	3.3	1.7
Black African	6.4	5.7	2.0
Mixed	4.2	3.7	3.7
Unknown	1.0	1.1	1.0
IMD deprivation (%)			
Most deprived (Quartile 1)	34.5	32.6	31.6
Quartile 2	22.2	22.2	21.3
Quartile 3	28.1	28.8	31.2
Least deprived (Quartile 4)	15.3	16.5	16.0
IOTF weight categories (%)			
Underweight (BMI <18.5)	8.8	9.0	9.3
Healthy weight (18.5 to <25)	68.6	69.2	70.8
Overweight (25 to <30)	17.7	17.4	16.3
Obese (30+)	4.7	4.1	3.0
Unknown	0.2	0.3	0.7
Physical activity: mean counts per minute (SD)			
Weekday evenings 3 pm–10 pm	562.0 (373.5)	572.4 (389.7)	–
Weekend days 8 am–10 pm	453.9 (317.5)	–	512.3 (343.4)
Distance to nearest park: mean metres (SD)			
All types	193.1 (153.8)	192.7 (157.1)	194.3 (156.6)
Formal	239.8 (172.8)	238.0 (176.5)	244.6 (177.2)
Informal	770.8 (604.9)	780.2 (630.3)	796.1 (599.5)
Natural	442.0 (278.8)	451.6 (288.0)	458.6 (286.1)
Sports	651.8 (367.0)	641.5 (379.1)	652.9 (384.3)
Young persons	389.7 (226.9)	391.2 (227.5)	381.4 (224.6)

N=Number of children included in the analysis. IMD=Index of Multiple Deprivation 2007. Lower Super Output Area (LSOA) scores assigned to participants using their home postcode. Quartiles based on ranking of all LSOAs in England. IOTF=International Obesity Task Force. BMI—Body Mass Index (kg/m^2) adjusted for age and sex.

* Mean age of participants on first day they provided GPS/accelerometer data. Therefore, ages not available for children not providing data.

Table 2
Time spent in different activity intensities on weekday evenings and weekend days by location. Values are mean minutes (standard deviation) per day and percentage of total time spent either sedentary or in light or moderate to vigorous physical activity.

Location of activity	Weekday evenings 3 pm–10 pm $N=614$			Weekend days 8 am–10 pm $N=301$		
	Sedentary	Light	Mod–Vig	Sedentary	Light	Mod–Vig
Indoors						
Mean (SD)	195.7 (90.8)	68.2 (38.6)	19.3 (17.2)	363.4 (154.0)	135.5 (70.7)	33.7 (27.9)
Percentage	92.5	87.7	72.6	93.2	89.1	78.7
Outdoors						
Mean (SD)	14.5 (28.8)	9.1 (14.9)	7.0 (1.4)	20.7 (41.3)	13.0 (24.6)	7.5 (17.2)
Percentage	7.0	11.7	26.4	5.3	8.5	17.6
Out of study area						
Mean (SD)	1.1 (17.2)	0.5 (6.0)	0.3 (4.1)	5.7 (30.0)	3.7 (16.1)	1.6 (10.4)
Percentage	0.5	0.6	1.0	1.5	2.5	3.7
Total						
Mean (SD)	211.4 (74.3)	77.9 (27.4)	26.6 (9.3)	389.8 (145.1)	152.2 (75.8)	42.8 (36.1)

evenings, 33.6% of outdoor MVPA was within green environments, with 10.1% in parks and 22.3% in private gardens. Corresponding values for weekends were 46.0%, 29.3%, and 16.1% respectively. The percentage of outdoor MVPA taking place in greenspace overall was higher at the weekend compared with weekday evenings ($p<0.001$) and the percentages of outdoor MPVA occurring within parks were also higher at the weekend for all park types ($p<0.001$) with the exception of sports areas. The percentage of outdoor MVPA taking place in private gardens was higher during weekday evenings than weekend days ($p<0.001$).

Table 4 details the summary of activity separately for Saturdays and Sundays. The percentage of outdoor MVPA occurring in greenspace was highest on Sundays ($p<0.001$). The use of informal and natural park areas was particularly high on Sundays, with over a quarter of all outdoor MVPA occurring in these areas.

Table 3
Time spent in different activity intensities on weekday evenings and weekend days by location. Values are mean minutes (standard deviation) per day and percentage of outdoor time spent either sedentary or in light or moderate to vigorous physical activity.

Location of activity	Weekday evenings 3 pm–10 pm $N=614$			Weekend days 8 am–10 pm $N=301$		
	Sedentary	Light	Mod–Vig	Sedentary	Light	Mod–Vig
Greenspace (overall)						
Mean (SD)	6.0 (16.1)	3.5 (7.9)	2.4 (4.8)	9.0 (26.9)	6.1 (15.7)	3.5 (9.1)
Percentage	41.1	38.8	33.6	43.7	46.7	46.0
Parks (all types)						
Mean (SD)	1.1 (6.8)	1.2 (7.8)	0.7 (4.7)	3.4 (19.1)	3.5 (16.7)	2.2 (10.5)
Percentage	7.4	12.9	10.1	16.4	26.7	29.3
Formal						
Mean (SD)	0.2 (3.0)	0.3 (4.1)	0.2 (3.3)	0.5 (8.7)	0.7 (8.5)	0.4 (4.3)
Percentage	1.5	3.0	2.7	2.4	5.1	4.8
Informal						
Mean (SD)	0.5 (4.9)	0.4 (4.1)	0.2 (1.6)	1.0 (11.9)	1.1 (7.7)	0.7 (5.0)
Percentage	3.2	4.4	3.2	5.1	8.3	9.9
Natural						
Mean (SD)	0.1 (2.3)	0.1 (1.5)	0.1 (1.1)	0.7 (15.2)	0.6 (8.8)	0.5 (6.6)
Percentage	0.6	0.8	0.8	3.6	4.7	6.1
Sports						
Mean (SD)	0.1 (10.2)	0.1 (10.6)	0.1 (7.4)	0.1 (3.2)	0.1 (1.9)	0.05 (1.2)
Percentage	1.0	1.6	1.5	0.4	0.6	0.6
Young persons						
Mean (SD)	0.2 (4.0)	0.3 (6.6)	0.1 (3.4)	1.0 (19.1)	1.0 (13.9)	0.6 (7.6)
Percentage	1.1	3.3	2.0	5.0	7.9	7.8
Private gardens						
Mean (SD)	4.8 (15.1)	2.2 (4.2)	1.6 (2.8)	5.6 (23.4)	2.5 (7.7)	1.2 (3.2)
Percentage	32.9	24.5	22.3	26.9	19.2	16.1
School grounds						
Mean (SD)	0.1 (5.5)	0.1 (5.2)	0.1 (3.3)	0.1 (2.5)	0.1 (5.1)	0.1 (1.8)
Percentage	0.7	1.3	1.1	0.3	0.7	0.5
Other greenspace						
Mean (SD)	0.01 (0.5)	0.01 (0.5)	0.01 (0.4)	0.03 (1.3)	0.01 (0.4)	0.01 (0.3)
Percentage	0.1	0.1	0.1	0.1	0.1	0.1
Other land use						
Roads/pavements						
Mean (SD)	2.8 (7.2)	2.0 (3.7)	1.9 (3.2)	3.9 (12.5)	2.2 (7.6)	1.6 (6.5)
Percentage	18.9	21.6	26.6	18.9	17.1	20.9
Green verges						
Mean (SD)	0.3 (2.7)	0.2 (2.3)	0.2 (1.8)	0.6 (7.0)	0.5 (5.1)	0.3 (2.7)
Percentage	2.0	2.6	2.9	3.1	3.5	3.8
Built surfaces						
Mean (SD)	5.5 (12.4)	3.4 (6.1)	2.6 (4.4)	7.1 (14.1)	4.2 (9.3)	2.2 (7.1)
Percentage	38.0	37.0	36.9	34.3	32.6	29.3

Table 5 shows the amount of MVPA by season, expressed as mean times of MVPA per day per child and percentages of overall MVPA activity across the seasons for all children. There were no statistically significant differences across the seasons in the average amount of time spent in MVPA per child in total, outdoors, within all types of greenspace, and within greenspaces classified as parks. Whilst the percentage of total MVPA occurring outdoors and within greenspaces overall was similar across seasons during weekday evenings, the percentage of outdoor MVPA occurring in parks was lower in winter and spring compared with summer and autumn ($p < 0.001$). At the weekend, the percentage of MVPA occurring outdoors was highest in the winter and lowest in the summer ($p < 0.001$), although the percentage of outdoors MVPA in greenspace overall and within parks was similar across the year.

4. Discussion

The results show that the amount of activity occurring within greenspace per child is low when expressed as an average daily time, although these figures are broadly in line with a prior study based on the same cohort a year earlier (Wheeler et al., 2010) and also a study of 9–10 year olds in Norfolk (Jones et al., 2009b). However, when expressed as a percentage of total MVPA across all children, time spent in greenspace contributes over a third of all outdoor MVPA occurring during weekday evenings, over 40% on Saturdays and almost 60% on Sundays. This suggests that some children are particularly high users of green environments for play and physical activities and provides some evidence that, at a population level, greenspace use may be an important contributor to overall levels of activity.

The findings show that all types of parks were used by children for sedentary, light and moderate-vigorous activities. It is noteworthy that a high proportion of weekend light and moderate–vigorous activity was within areas specifically designated for use by children or teenagers, in which around 8% of light and moderate–vigorous activity occurred on both Saturdays and Sundays. These areas are few and small (representing $<1\%$ of total park area), but their relatively high usage for activity suggests that provision of facilities specifically targeted at young people is effective and that these facilities are valuable resources for physical activity.

The percentage of weekend outdoor MVPA occurring in greenspace overall and specifically in parks did not differ by season. This is contrary to our prior expectation that greenspace would be

Table 4
Time spent in different activity intensities on Saturdays and Sundays by location: values are mean minutes (standard deviation) per day and percentage of outdoor time spent either sedentary or in light or moderate to vigorous physical activity.

Location of activity	Saturday 8 am–10 pm N=216			Sunday 8 am–10 pm N=177		
	Sedentary	Light	Mod–Vig	Sedentary	Light	Mod–Vig
Greenspace (overall)						
Mean (SD)	7.8 (16.7)	6.5 (15.7)	3.6 (9.0)	10.6 (36.2)	5.5 (15.7)	3.3 (9.2)
Percentage	38.6%	42.9%	40.3%	49.6%	53.4%	56.6%
Parks (all types)						
Mean (SD)	3.2 (16.8)	3.6 (16.7)	2.1 (10.2)	3.6 (22.1)	3.3 (16.8)	2.3 (11.0)
Percentage	15.9%	23.7%	23.8%	17.0%	32.0%	39.4%
Formal						
Mean (SD)	0.7 (10.8)	0.8 (9.6)	0.4 (3.8)	0.3 (3.0)	0.5 (6.3)	0.3 (5.2)
Percentage	3.5%	5.3%	4.5%	1.2%	4.7%	5.3%
Informal						
Mean (SD)	0.9 (6.7)	1.1 (7.0)	0.7 (4.3)	1.3 (16.5)	1.1 (8.7)	0.8 (5.7)
Percentage	4.4%	7.2%	7.5%	5.9%	10.3%	14.4%
Natural						
Mean (SD)	0.3 (3.7)	0.5 (6.9)	0.3 (5.5)	1.3 (22.6)	0.8 (10.9)	0.6 (7.6)
Percentage	1.3%	3.0%	3.5%	6.2%	7.9%	11.0%
Sports						
Mean (SD)	0.1 (1.4)	0.1 (1.8)	0.1 (0.7)	0.1 (4.9)	0.1 (2.0)	0.1 (1.8)
Percentage	0.3%	0.7%	0.5%	0.5%	0.5%	0.9%
Young persons						
Mean (SD)	1.3 (22.6)	1.1 (13.2)	0.7 (7.5)	0.7 (11.6)	0.9 (15.5)	0.5 (8.0)
Percentage	6.5%	7.5%	7.8%	3.3%	8.6%	7.8%
Private gardens						
Mean (SD)	4.4 (11.2)	2.8 (6.8)	1.4 (3.0)	6.9 (33.0)	2.2 (8.7)	1.0 (3.4)
Percentage	22.2%	18.2%	15.9%	32.3%	21.1%	16.5%
School grounds						
Mean (SD)	0.1 (2.9)	0.1 (6.2)	0.1 (2.1)	0.01 (0.6)	0.03 (1.4)	0.03 (1.0)
Percentage	0.4%	0.9%	0.5%	0.1%	0.2%	0.4%
Other greenspace						
Mean (SD)	0.01 (0.2)	0.02 (0.4)	0.01 (0.3)	0.04 (2.1)	0.01 (0.3)	0.01 (0.4)
Percentage	0.1%	0.1%	0.1%	0.2%	0.1%	0.1%
Other land use						
Roads/pavements						
Mean (SD)	4.0 (11.8)	2.9 (9.8)	2.1 (8.3)	3.8 (13.3)	1.4 (3.0)	0.9 (2.7)
Percentage	19.9%	19.2%	23.9%	17.8%	13.4%	15.3%
Green verges						
Mean (SD)	0.8 (6.8)	0 6 (6.3)	0.3 (2.9)	0.4 (7.3)	0.3 (2.6)	0.3 (2.5)
Percentage	4.0%	4.0%	3.5%	2.0%	2.6%	4.3%
Built surfaces						
Mean (SD)	7.5 (12.4)	5.1 (10.3)	2.9 (8.9)	6.6 (16.1)	3.2 (7.8)	1.4
Percentage	37.5%	33.8%	32.3%	30.6%	30.6%	(3.5) 23.8%

Table 5
Time spent in moderate–vigorous activity per season by location: values are mean minutes (standard deviation) per day and percentages of MVPA occurring outdoors, outdoors in greenspaces, and outdoors within parks.

	Weekday evenings 3pm–10pm				Weekend days 8 am–10 pm			
	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter
Number of children	170	147	128	190	102	81	62	56
MVPA—Mean (SD)								
Total	27.7 (22.3)	30.0 (22.4)	25.5 (16.6)	23.8 (20.1)	44.1 (40.0)	39.4 (27.9)	43.0 (28.7)	45.1 (46.1)
Outdoors	7.5 (12.6)	6.2 (10.6)	7.2 (8.9)	7.0 (9.0)	6.6 (13.8)	3.2 (7.2)	11.0 (15.7)	12.2 (28.7)
Within greenspace	2.5 (3.9)	2.5 (3.4)	2.4 (2.5)	1.9 (2.0)	3.3 (8.9)	1.7 (5.4)	4.6 (9.9)	5.0 (11.8)
Within parks	0.6 (4.2)	1.1 (7.7)	0.8 (2.8)	0.5 (3.5)	2.1 (10.0)	1.0 (5.6)	2.7 (11.6)	3.7 (14.1)
Percentage of total MVPA occurring outdoors	27.5	21.1	28.3	29.6	15.7	8.5	26.1	27.8
Percentage of outdoor MVPA in greenspaces (overall)	34.0	41.4	34.6	27.4	52.3	51.9	42.0	40.9
Percentage of outdoor MVPA in parks (all types)	7.7	17.2	11.2	7.0	32.0	30.8	24.5	30.5

used more during warmer weather, and we suggest may partly reflect their use for team sports such as football, which predominately take place in colder seasons. Previous analysis also found evidence of decreased MVPA during longer daylight hours and during British Summer Time (Wheeler et al., 2010). Further research looking at seasonal and climate-related patterns in the use of different environments is needed, potentially linking GPS data with weather variables. This could help plan provision of greenspaces, which are weather-appropriate and maximise their potential use for physical activity across the seasons. The percentage of outdoor MVPA taking place in parks during weekday evenings did vary throughout the year, with a lower percentage of moderate-vigorous activity undertaken within parks in winter and spring. This almost certainly reflects the fact that parks are less suitable for activity on darker evenings and may indicate a need to provide better lighting in them, particularly along pathways and in play areas. Adequate lighting is a key factor for parents when selecting play spaces for children to use (Sallis et al., 1997).

The majority of activity occurred in non-green environments, such as on roads and pavements and concreted surfaces. This illustrates the broad ways in which children gain physical activity outside of school and the need to consider the many environmental contexts, which may be important. In addition to activity within parks, children also made some use of school playing fields, even at the weekend, and other green areas including cemeteries, golf courses and gardens of publicly accessible buildings. Therefore, studies simply looking at access to a public park may miss important contextual factors about other environments, which children may be using. These findings reflect the versatility of children's play and physical activity behaviours and the potential health value of greenspace not formally designated and managed as a public park.

A large proportion of MVPA occurred within private gardens, particularly during weekday evenings, showing the value of private greenspace as a physical activity resource. Evidence suggests that in recent decades children's play behaviour has become less autonomous and increasingly occurs in private gardens and the space surrounding the home, a trend attributed mainly to parental safety concerns (Valentine and McKendrck, 1997). Children are more likely to use parks and play spaces in the neighbourhood if they have a network of other children to play with (Veitch et al., 2006). Our analysis shows how both private and public greenspace are used for activity, with private space used more during the week and public space at weekends, indicating that both types are important resources for physical activity and their combination allows children to gain their activity in different ways across different outdoor settings. This has policy implications for ensuring adequate provision of both private gardens and public greenspace in housing developments in the context of increased higher density housing and the potential loss of greenspace. For example a study in Merseyside, England, found that between 1975 and 2000 land identified as greenspace decreased by 6%, with reduction in private garden space and conversion of public open space into new housing (Pauleit et al., 2005).

Strengths of the study include the use of a large sample of GPS and accelerometer data, meaning that objective methods could be used to measure the intensity and location of physical activity. The mapping data was detailed and well characterised and consequently we believe this is the first study, which has used GPS data to examine activity within different types of greenspace, which also includes information about types of parks. Data was collected throughout the week and across the year, allowing a detailed breakdown of the times when greenspaces are used by children.

In terms of study limitations, Bristol is a relatively deprived and predominantly urban area and, therefore, findings may not be generalisable to other living contexts or other age groups. More rural areas may have different challenges in measuring greenspace, as the need to distinguish inaccessible agricultural land from useable grassland, parks and footpaths will be particularly important. The comparison of included participants with the wider sample showed that children providing GPS data were not representative of the wider PEACH cohort, particularly at the weekend. Excluded participants are those who provided no GPS data, which either means that their GPS receivers were turned off/not worn, or that the children were continually indoors during the data collection period and so not using the outdoors for any activity or play. The comparison of Saturday and Sunday was based on small and different samples as not all participants provided GPS data on both weekend days.

This analysis did not consider how use of greenspace may be affected by how accessible it is to the child (such as how close it is to the child's home) or by demographic factors such as sex, socio-economic factors and other environmental variables, which have been shown to influence children's activity and may affect their use of greenspace, such as road layouts, traffic flows and crime rates. Future research could investigate how these factors moderate the use of greenspace. Whilst inclusion of information about type of parks was a major advantage of this study, no information was available about the quality of park, or the specific facilities available in them, both factors, which may determine use. The availability of detailed online mapping and visualisation tools potentially allow greenspace quality to be assessed remotely (Taylor et al., 2011), and these methods might be used to supplement GIS data in future research.

The linkage of GPS and accelerometer data with land use maps of the environment is a new and developing approach and there are limitations and uncertainties in the methods used. The exclusion of activity occurring outside the study area meant that the use of greenspaces in the surrounding countryside was not considered. This means we have probably underestimated the overall amount of activity within greenspaces. There are also issues with the accuracy of the GPS data (Duncan et al., 2009). GPS signal dropout occurs when the receiver temporarily loses satellite reception and this creates gaps in the data. Nevertheless, based on the identification of periods of missing GPS data lasting 30 s or less, which occurred while child was outdoors, we found that this represented only around 2% of outdoors time in our study. Location data may also be missing during longer dropout periods or due to delays acquiring a sufficient satellite signal upon turning the receiver on (Duncan et al., 2009). However, as our analysis did not require generation of street-level routes, further cleaning or the use of algorithms to impute the missing GPS data was not judged necessary in order to meet the aims of this study.

The removal of any points where participants were travelling >15 kph was an attempt to remove time spent in vehicles and erroneous GPS locations, but consequently may also exclude fast bouts of cycling or running and include time spent in slow traffic. Nevertheless, a sensitivity analysis (results not presented) tested the use of 20 kph as an alternative threshold and found this made no substantive difference to the findings. A further source of potential error is misclassification in the overlay of GPS points with mapping data, particularly across the land use types 'roads and pavements', concreted 'built surfaces' and 'gardens', as these areas are small and often adjacent, thus requiring extremely accurate location data. In particular, the some of the large proportion of activity in gardens may be in part due to misclassification from children who are actually indoors or who are walking past.

5. Conclusion

This study demonstrates a new use of GPS to describe how different types of urban greenspace are used by children and provide an insight into how activity within different types of greenspace varies throughout the week and across the year. Our findings show that whilst children gained the majority of their activity in non green environments, urban greenspaces, both public and private, are valuable resources for children's play and physical activity.

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