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Green space and physical activity: An observational study using Health Survey for England data

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ABSTRACT

Past studies have suggested that a link between health outcomes and green space is due to increased levels of physical activity of individuals living in areas with more green space. We found a positive association between green space and physical activity levels. The odds of achieving the recommended amount of physical activity was 1.27 (95% CI: 1.13–1.44) for people living in the greenest quintile in England compared to those living in the least green quintile, after controlling for individual and environmental factors. However, no association was found between green space and types of physical activity normally associated with green space. An association was found with other types of physical activity (gardening and do-it-yourself, and occupational physical activity). These findings suggest that although there is a positive association between physical activity and green space it may not be explained by individuals using green space for recreation.

1. Introduction

The high levels of physical inactivity in high-income countries (Centers for Disease Control and Prevention 2010; World Health Organisation, 2010; Donaldson, 2010) are of concern due to the contribution of physical inactivity to the development of many major health problems, including cardiovascular disease, cancer and obesity. Traditional efforts to improve physical activity, through health education and social marketing have had limited effects. Increasingly efforts to increase physical activity follow a settings approach, which considers the role of the environment in determining health behaviours such as physical activity (Rhodes and Nasuti, 2011).

Central to the settings approach is the socio-ecological framework (Sallis and Owen, 2002) that emphasises the interaction of multiple social and environmental influences on an individual's behaviour. Green space may be one such environmental influence promoting physical activity by offering a safe, accessible and attractive place for exercise, such as walking, running, cycling or playing ball games. It is hypothesised that those who have access to more green space in their local environment might be expected to achieve higher levels of physical activity.

Several observational studies have sought to establish whether a relationship between green space and physical activity exists. However, work in this area is young and far from conclusive (Lachowycz and Jones, 2011). While some authors have found a positive association between measures of, or access to, green space and physical activity (Epstein et al., 2006; Giles-Corti and Donovan, 2002; Roemmich et al., 2006; Coombes et al., 2010; Gomez et al., 2010; Sugiyama et al., 2010), the associations are often weak, and are contradicted by other studies that have failed to find an association (Maas et al., 2008; Foster et al., 2009; Witten et al., 2008; Giles-Corti et al., 2005; Hillsdon et al., 2006).

As many of the studies have been small and have studied the association of green space with physical activity on a local scale (within a region or city) it remains unclear whether the lack of an association is due to lack of statistical power or insufficient heterogeneity of green space in a local area. Conversely the past positive findings might be due to chance or explained by confounding between green space and other factors associated with physical activity such as socio-economic status or better access to leisure facilities. Differences in study design and settings may also contribute to the different findings in the literature, and these remain hard to explore with the limited number of studies undertaken. For example some studies have examined different categories of physical activity: overall physical activity, walking, or physical activity solely undertaken in green space.

So despite the strong underlying theory and some supportive observational evidence, there is still some uncertainty about whether there is a causal relationship between green space and

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physical activity. The question of an association between green space and physical activity across England is of particular interest because of conflicting results from two studies, using data from across the whole of England, investigating the association between green space and different health outcomes.

One group discovered an inverse association between overall and cardiovascular mortality and green space (Mitchel, 2008). They hypothesised that the association was due to increased levels of physical activity among people living in greener areas. However a second found that those living in the greenest areas were more likely to be obese (Cummins and Fagg, 2011), suggesting that green space may be less important for promoting physical activity than previously thought. In support of this, we also note that the majority of adult physical activity occurs at home, on the way to work, or at work, with a relatively small proportion being recreational (Belanger et al., 2011), which might suggest that associations with overall physical activity will be weak. Neither Mitchel nor Cummins looked directly at the association between green space and physical activity but both speculated on its potential importance in explaining the relationship between green space and health.

In the present study we build on these previous studies by investigating the association between green space in the local environment and physical activity in England. We use a national cross-sectional survey, the Health Survey of England, and link it to a national survey of environment type, the generalised land use database, that includes a measure of green space.

In this work we examine the association of green space on overall physical activity levels in a large socially and environmentally heterogenous population. We also consider the association of green space on category specific types of physical activity.

2. Method

2.1. Study design

The study is a cross-sectional observational study. We used data from the annual HSE (2002–2004) linked to area measures of green space taken from the generalised land use database 2001. We constructed a series of multivariate models using logistic regression to test for associations between self-reported physical activity levels for populations living in areas of England characterised by different levels of green space, with adjustment for confounding factors.

Our primary aim was to test for an association between green space in the local environment and overall physical activity levels, after controlling for confounding variables. In the presence of such a relationship, our secondary aim was to test for an association between green space in the local environment and particular sub-categories of physical activity that can be undertaken in green space, as well as other types of physical activity.

2.2. Data—collection

The HSE is an annual survey of the English population, containing questions on health and health related behaviours, physiological measurements and blood samples. The sample for the survey is drawn from the publicly available Postcode Address File. Each year several thousand addresses, clustered into postcode sectors, are chosen for sampling. The sample is normally designed to be fully representative of England. Interviews are conducted by trained personnel face-to-face. The survey contains demographic information, including income and social class. Each address is categorised as urban or rural based on the interviewer's observation. It consists of a core set of measures that have been largely unchanged since its inception in 1991.

The years of data collection from 2002 to 2004 were chosen for this study as they included a module with questions on physical activity (Joint Health Services Unit, 2003, 2004, 2005). They were chosen for inclusion being close in time to 2001, when the measures of green space were made, and because the questionnaires used in these years were comparable. Sample sizes for these years of data collection were: 18,398 in 2002, 18,553 in 2003 and 17,345 in 2004. A larger than usual sample of young people (aged 0–24 years) were included in 2002 whilst 2004 included a larger sample of ethnic minorities. All individuals completed the physical activity questionnaire in 2003 and 2004, in 2002 only those aged 16–24 years did so.

The survey included a question on intensity and duration of physical activity for each type of physical activity undertaken. Information on all physical activity was sought, including physical activity at work, at home, and recreational activity. From this information an estimate of the frequency, in number of days per week, individuals were achieving of moderate or vigorous intensity of physical and sporting activity of at least 30 min duration was produced.

Green space measures were taken from the generalised land use database (GLUD). The GLUD categorises land use in England into 9 different categories, including green space. Land use was mapped by using digital ordinance survey maps from 2001 (Office for National Statistics, 2001). Green space includes parks, other open spaces, and agricultural land. It excludes domestic gardens. The classification is precise to 10 m^2 with units of less than 5 m^2 being ignored. The GLUD reports land use in geographic units, known as output areas. Output areas are statistical units, with fixed geographic boundaries, used in England. They are defined on the basis of population size. For this work, we chose to use land use reported at middle super-output area (MSOA). This was thought to best represent the local environment readily accessible, by car and foot for an individual, for physical activity.

The mean population of an MSOA is 7200 people, with a minimum population of 5000 people (Office for National Statistics, (2011a, 2011b, 2011c). In an urban area the smaller unit, the LSOA (mean population 1500) was thought to be too small to adequately represent the local environment. In parts of London the population density approaches 5000 per square kilometre. In England there are a total of 6780 MSOAs.

The HSE classifies each person's home as being in an urban or rural area, based on the observation of the interviewer. It is possible for an area to be classified as urban, by the HSE, but have a large proportion of green space, either if it is on the edge of an urban area or near to an area of parkland.

2.3. Data—outcome variable (physical activity)

The primary outcome measure was overall physical activity defined as achieving the UK government recommended amount of physical activity, 5 sessions a week of moderate or vigorous physical activity (MVPA), of at least 30 min duration (the recommendations at the time of the study;Department of Health, 2005). We also examined three different sub-categories of physical activity: sporting activity, walking, and 'green space leisure' physical activity (a derived composite measure of physical activities that may be undertaken in green space). Several previous studies have examined the association between green space and walking (Giles-Corti and Donovan, 2002; Giles-Corti et al., 2005; Foster et al., 2009; Sugiyama, 2010). Previous associations with cycling have been demonstrated (Maas, 2008). It was hypothesised that these secondary measures might provide evidence of a

link between particular types of physical activity and green space, or show a positive association in the absence of a positive association with overall physical activity.

Overall physical activity, sport and walking were directly reported in the HSE, 2002–2004. The composite measure of 'green space leisure' was produced by combining separate measures reported in the HSE, for running, cycling, football/rugby and walking. While this list was not exhaustive, it was felt to contain the major forms of physical activity undertaken in green space. The HSE does not contain information on where physical activity takes place. Consequently the composite measure is not restricted to activity that was undertaken solely in green space. This tests whether the relationship between overall physical activity and green space may be explained by increased levels of these particular types of physical activity amongst individuals living in areas with green space.

Due to the absence of a clear relationship between green space and measures of physical activity more clearly associated with green space, we also seek to test the association with other key domains of physical activity identified from the HSE. These other domains are occupational, housework, and manual work (not undertaken as part of a job). Manual work consisted of gardening or do-it-yourself work (either in the house or garden).

We chose to create a binary variable for all measures of physical activity. Diary recording of physical activity had led to rounding off of reported number of sessions, and ceiling effects. For example the number of sessions of physical activity in a 4 week period was restricted to 0–28. This meant that physical activity could not readily be treated as a continuous variable. Treating physical activity as a categorical variable was not possible as the proportional odds assumption did not hold.

To better explore the role of green space in promoting physical activity we applied two cut-offs to each of the sub-categories of physical activity. We applied the same 'high cut-off' (undertaking five or more MVPA sessions of at least 30 min, i.e. achieving the government recommended level of physical activity through this single form of activity) to the three sub-categories of physical activity (more clearly associated with green space) and the other domains of physical activity (reported in the HSE) that we had applied to overall physical activity. This 'high cut-off' might provide better insight about the role of green space in promoting or sustaining physical activity principally among those already achieving a high level of physical activity. Additionally we also used a 'low cut-off' (undertaking at least one or more session of MVPA of at least 30 min duration in the past 4 weeks). This might provide insight about the role of green space in promoting or sustaining physical activity among people who undertake lower levels of physical activity. This 'low cut-off' was applied to overall physical activity and the three sub-categories and the other domains of physical activity.

2.4. Data—independent variables

Green space was treated as a categorical variable. MSOAs were grouped into quintiles of green space based on total population, such that each quintile of green space would contain about 20% of the total population of England. The quintiles of green space were then linked to individual records in the HSE using postcodes, by a third party (National Centre for Social Research) to protect anonymity.

All other covariates were taken from the HSE. The following individual characteristics recorded in the HSE that were hypothesised to be associated with physical activity, and recorded in the survey were included in the models: age, sex, social class of the head of household, equivalised income (continuous variable), household car ownership (yes/no) and ethnicity (white, black, asian, other). Equivalised income is adjusted for the size and composition of the household to better reflect disposable income. Equivalised income was further adjusted for inflation based on the Retail Price Index to mid-2004 prices (Office for National Statistics, 2005).

The following area level characteristics recorded in the HSE that were hypothesised to be associated with physical activity in the local environment were included in the model: area deprivation (quintiles of deprivation based on the index of multiple deprivation at Lower Super-Output Area), and measures of 'social capital' defined in the HSE. The measures of 'social capital' included were perception of vandalism, perception of teenagers hanging around, perception of ease of access to local shops, and perception of quality of local leisure facilities.

2.5. Statistical analysis

Logistic regression was used to test for an association between physical activity and green space (in quintiles). The Wald test was used as a test for any association between green space and physical activity, across the five quintiles of green space. Odds ratios were calculated for each quintile of green space with 95% confidence intervals to show differences in physical activity across quintiles. Quintile one (the quintile with least green space) was treated as the reference quintile. For the primary outcome variable (overall physical activity, achieving recommended amounts), three models were constructed:

model 1— Uncontrolled: univariable analysis for green space and physical activity
model 2— Individual factors: multivariable analysis controlling for all individual factors
model 3— Individual and environment factors: multivariable analysis controlling for individual and all the environmental factors

Model 3 was then repeated for all other outcome variables: sport, 'green space leisure', and walking, using the 'high cut-off and for all four outcome variables when categorised with a 'low cut-off' (no physical activity or some physical activity).

Likelihood ratio tests were calculated to compare the models predictive power. Co-linearity diagnostics were run on variables included in the model. To test if any associations were due to an urban/rural effect (i.e. physical activity being more prevalent among those living in rural areas) the analysis was repeated, restricted to only those who lived in an urban area. Due to limitations on numbers and homogeneity of green space in rural areas, the analysis was not repeated for rural only areas.

We only included subjects who answered the questions on physical activity levels. We excluded children under 16 years of age, as children under 16 years of age completed a different questionnaire on physical activity. Moreover the nature and determinants of physical activity may be different in this younger age group compared to adults. We also excluded members of the armed forces. They are likely to have a high habitual level of exercise, much of which might not take place in the environment where their residence was listed.

Given the initial findings, of an association between green space and overall physical activity and the absence of an association with sub-categories of physical activity most likely to be undertaken in green space, additional analyses were undertaken to address the question of what type of physical activity explains the observed association with the other domains of physical activity identifiable in the HSE. In order to do this model 3 was repeated for the following outcome variables: occupational physical activity, domestic physical activity—housework, and domestic physical activity–manual work,

using the 'high cut-off' and 'low cut-off'. Where an association was observed this analysis was repeated restricting the analysis to urban only areas.

We used Stata version 11.0 for all analyses.

3. Results

A total of 54,296 individuals were sampled in the 3 years of data collection. Before analysis a number of cases were excluded: those adults who were not invited to complete the physical activity questionnaire (6707), those under 16 years of age (16,371), those in the army (194), and those who did not give a valid response about physical activity levels (88). The characteristics of the remaining 31,049 survey respondents (3604 from 2002, 14,783 from 2003, and 12,707 from 2004) included in the analysis are shown in Table 1.

Table 1
Characteristics of subjects included in the analysis from HSE 2002–2004.

Median age (IQR) (n=31,409)	41 (26–58) years
Median equivalised income (IQR) (n=31,409)	£18,722 (10,655–32,500)
Sex (n=31,409)	n (%)
Male	13,800 (44.5)
Female	17,249 (55.5)
Ethnicity (n=30,992)	
White	23,608 (76.2)
Black	2138 (6.9)
Asian	4108 (13.3)
Other	1138 (3.7)
Green space quintile (%) (n=31,409)	
1 (1.27–23.37%)	7319 (23.4)
2 (23.38–37.65%)	6668 (21.5)
3 (37.66–57.18%)	6390 (20.6)
4 (57.25–83.80%)	5553 (17.9)
5 (83.81–98.58%)	5119 (16.5)
Social class of head of household (n=29,735)	
Professional	2028 (6.8)
Managerial	9696 (32.6)
Skilled non-manual	4631 (15.6)
Skilled manual	7372 (24.8)
Semi-skilled manual	4674 (15.7)
Unskilled manual	1334 (4.5)
Access to car (% yes) (n=31,042)	24,207 (78.0)
Physical activity (> 30 min MVPA) (%) (n=31,049)	
5 days per week any physical activity	9121 (29.4)
5 days per week sport	2254 (6.9)
5 days per week 'green space leisure'	
5 days per week walking	2975 (9.6)
2254 (7.2)	
5 days per week occupational	3485 (11.2)
5 days per week housework	875 (2.8)
5 days per week manual work	440 (1.4)
any physical activity	23,193 (74.7)
any sport	11,622 (37.4)
any 'green space leisure'	11,081 (35.7)
any walking	8389 (27.0)
any occupational	4657 (15.0)
any housework	13,796 (44.9)
any manual work	5255 (16.9)
Urban area (%) (n=31,042)	25,243 (81.3)
Deprivation quintile (IMD) (n=25,212)	
1 (most deprived)	7725 (24.9)
2	6629 (21.4)
3	5548 (17.9)
4	5400 (17.4)
5 (least deprived)	5747 (18.5)
Measures of social capital (%)	
Teenagers are a problem here (n=28,355)	9738 (34.3)
Vandalism is a problem here (n=28,347)	8871 (31.3)
Easy access to shops (n=28,378)	26,774 (94.4)
Good leisure facilities (n=28,628)	18,396 (55.7)

IQR=inter-quartile range.
IMD=index of multiple deprivation.

There was wide heterogeneity in green space in the local environment from a low in quintile 1 of 1.3–23.4% of land area being green space to a high in quintile 5 of 83.8–98.6%. Although the sample population was not equally distributed across all quintiles of green space, there was a substantial portion of the sample in each quintile of green space (Table 1). The sample living in quintile one with the least green space, compared to quintile 5, was younger (median 37 vs. 48 years, $p<0.001$), had a lower portion of white people (50.2% vs. 98.3%, $p<0.001$), had a lower median income (£14,918 vs. £22,740, $p<0.001$), was more urban (99.1% vs. 23.0%, $p<0.001$), and lived in a more deprived environment (portion in the most deprived quintile 42.5% vs. 4.1%, $p<0.001$).

A positive association between green space and overall physical activity (achieving the government recommended amount) was observed on univariable analysis (Table 2). The odds ratios for each quintile of green space were comparable in model 1 (univariable) and model 2 (controlling for individual factors). The overall measure of association in model two was not significant ($p=0.06$), although the difference in odds of achieving recommended physical activity in quintile 5 compared to quintile one was significant. Likelihood ratio tests indicated that addition of variables to each subsequent model significantly improved the fit. Co-linearity diagnostics calculated with Stata indicated no major concerns with co-linearity, with no variance inflation factor scores above three, far off the benchmark of 10 at which co-linearity warrants further investigation (Chen et al., 2009).

We found a significant association between green space and physical activity, after controlling for individual and local environmental factors (model 3, $p<0.001$). The odds of achieving

Table 2
Association between green space and physical activity, before and after adjustment for individual and environment factors.

	Model 1	**Model 2**	**Model 3**
		Individual factors	Individual and environment factors
Variables	Green space	Green space	Green space
		Sex	Sex
		Age	Age
		Ethnicity	Ethnicity
		HoH class	HoH class
		Equiv Income (cont)	Equiv Income
		Access to car	Access to car
			Area deprivation
			Vandals a problem
			Teenagers a problem
			Access to shops
			Good leisure facilities
n	31,049	24,099	22,254
Quintile of Green space	OR (95% CI)	OR (95% CI)	OR (95% CI)
1 (1.27–23.37%)	1.00	1.00	1.00
2 (23.38–37.65%)	1.05 (0.97–1.13)	1.02 (0.93–1.11)	1.02 (0.93–1.13)
3 (37.66–57.18%)	1.11 (1.04–1.20)	1.07 (0.97–1.17)	1.08 (0.98–1.19)
4 (57.25–83.80%)	1.09 (1.01–1.18)	1.07 (0.97–1.18)	1.10 (0.99–1.21)
5 (83.81–98.58%)	1.14 (1.06–1.23)	1.15 (1.04–1.27)	1.24 (1.12–1.38)
Wald test	15.1 (0.01)	9.1 (0.06)	19.0 (< 0.001)
Log likelihood	−18792	−13857	−12942

HoH class=Social class of reference person in household; Equiv Income=equivalised income adjusted for inflation; area deprivation is quintile of deprivation based on the index of multiple deprivation for the lower super-output area of residence; cont=continuous variable, all other variables are categorical.

recommended physical activity was 1.24 (95% CI: 1.12–1.38) for people living in the greenest quintile compared to those living in the least green quintile. No association was found between green space and specific measures of physical activity using a 'high cut-off', including sport ($p=0.52$), a composite measure of 'green space leisure' ($p=0.58$), or walking ($p=0.89$;Table 3).

Using a 'low cut-off' for physical activity (any MVPA of at least 30 min duration), the amount of green space in the MSOA was not associated with overall physical activity levels ($p=0.34$) nor sport ($p=0.67$;Table 3). An inverse association was observed for 'green space leisure' and for walking (Table 3). The odds of undertaking any walking (for at least 30 min MVPA) for those living in the greenest four quintiles were significantly less than the odds of walking among those living in the least green quintile after adjustment for confounding factors (Table 3).

When the analysis was repeated restricted to those living in urban areas, a similar pattern was found (Table 4). Using a 'high cut-off' (5 sessions per week of 30 min at moderate intensity), the association between green space and overall physical activity remained strong. The effect of living in the greenest quintile compared to the least green quintile appeared greater when restricted to urban only areas ($OR=1.39$, 95% CI: 1.19–1.63) compared to both urban and rural areas ($OR=1.24$, 95% CI: 1.12–1.38). The inverse association for walking, with the 'low-cut off' also persisted, after restricting to urban areas.

The association between green space and different domains of physical activity are shown in Table 5. Strong associations between green space and these types of physical activity, using both a 'high cut-off' and a 'low cut-off' were observed. These associations persisted and a similar pattern was observed when restricting the analysis to urban areas (data not shown).

4. Discussion

Our study found that people living in the greenest areas of England are more likely to achieve recommended amounts of physical activity, both before and after adjustment for individual and environmental variables. No positive association was found with measures of types of physical activity that may be more strongly linked to green space. The association between physical activity and green space was greater when restricted to urban areas, suggesting that it cannot be explained by people living in rural areas being more physically active.

Table 3
Association between green space and physical activity after adjustment for individual and environment variables ($n=22,254$).

Green space quintile	Overall physical activity	Sport	Green space leisure	Walking
High 'cut off' (at least 30 min of MVPA 5 times per week)				
	OR (95% CI)	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**
1 (1.27–23.37%)	1.00	1.00	1.00	1.00
2 (23.38–37.65%)	1.02 (0.93–1.13)	1.09 (0.93–1.29)	0.98 (0.85–1.12)	0.98 (0.84–1.14)
3 (37.66–57.18%)	1.08 (0.98–1.19)	1.12 (0.95–1.33)	1.02 (0.88–1.17)	1.01 (0.86–1.18)
4 (57.25–83.80%)	1.10 (0.99–1.21)	1.00 (0.84–1.21)	0.90 (0.78–1.05)	0.94 (0.79–1.11)
5 (83.81–98.58%)	1.24 (1.12–1.38)	1.03 (0.85–1.25)	0.97 (0.83–1.14)	1.01 (0.85–1.21)
Wald test* (p)	19.0 (<0.001)	3.2 (0.52)	2.8 (0.58)	1.16 (0.89)
Low 'cut off' (any physical activity of MVPA and 30 min duration)				
	OR (95% CI)	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**
1 (1.27–23.37%)	1.00	1.00	1.00	1.00
2 (23.38–37.65%)	0.99 (0.89–1.10)	1.04 (0.96–1.15)	0.94 (0.86–1.03)	0.85 (0.77–0.94)
3 (37.66–57.18%)	1.06 (0.95–1.19)	1.05 (0.96–1.16)	0.91 (0.83–1.00)	0.85 (0.77–0.93)
4 (57.25–83.80%)	1.06 (0.94–1.19)	1.00 (0.91–1.11)	0.86 (0.78–0.95)	0.80 (0.72–0.88)
5 (83.81–98.58%)	1.11 (0.98–1.26)	1.02 (0.92–1.13)	0.95 (0.86–1.05)	0.85 (0.77–0.95)
Wald test* (p)	4.5 (0.34)	2.4 (0.67)	10.0 (0.004)	21.2 (<0.001)

* Wald test is used to test for any association between green space and physical activity; a 'high cut off' is defined as five or more sessions of the stated activity per week of at least 30 min duration of MVPA; a 'low cut off' is defined as doing some sessions of the stated activity of at least 30 min duration of MVPA; individual and environmental variables are detailed in model 3 (Table 2).

Table 4
Association between green space and physical activity after adjustment for individual and environment variables restricted to urban areas ($n=17,676$).

Green space quintile	Overall physical activity	Sport	Green space leisure	Walking
High 'cut off' (at least 30 mins of MVPA 5 times per week)				
	OR (95% CI)	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**
1 (1.27–23.37%)	1.00	1.00	1.00	1.00
2 (23.38–37.65%)	1.01 (0.92–1.11)	1.09 (0.93–1.29)	0.98 (0.85–1.13)	0.98 (0.84–1.15)
3 (37.66–57.18%)	1.10 (1.00–1.21)	1.16 (0.98–1.37)	1.03 (0.89–1.19)	1.01 (0.86–1.20)
4 (57.25–83.80%)	1.07 (0.96–1.19)	1.00 (0.83–1.22)	0.89 (0.76–1.05)	0.91 (0.76–1.10)
5 (83.81–98.58%)	1.39 (1.19–1.64)	0.99 (0.73–1.34)	1.10 (0.87–1.39)	1.24 (0.96–1.61)
Wald test	19.1 (<0.001)	4.2 (0.38)	4.5 (0.34)	5.8 (0.21)
Low 'cut off' (any physical activity of MVPA and 30 min duration)				
	OR (95% CI)	**OR (95% CI)**	**OR (95% CI)**	**OR (95% CI)**
1 (1.27–23.37%)	1.00	1.00	1.00	1.00
2 (23.38–37.65%)	0.99 (0.89–1.11)	1.05 (0.96–1.16)	0.95 (0.86–1.04)	0.86 (0.78–0.94)
3 (37.66–57.18%)	1.07 (0.95–1.20)	1.07 (0.97–1.18)	0.90 (0.82–0.99)	0.84 (0.76–0.93)
4 (57.25–83.80%)	1.04 (0.92–1.18)	0.98 (0.88–1.09)	0.86 (0.77–0.95)	0.79 (0.71–0.88)
5 (83.81–98.58%)	1.04 (0.86–1.26)	1.02 (0.87–1.20)	0.95 (0.81–1.11)	0.87 (0.74–1.02)
Wald test	2.1 (0.72)	3.7 (0.45)	9.6 (0.05)	20.7 (<0.001)

*Wald test is used to test for any association between green space on physical activity; a 'high cut off' is defined as five or more sessions of the stated activity per week of at least 30 min duration of MVPA; a 'low cut off' is defined as doing some sessions of the stated activity of at least 30 min duration MVPA; individual and environmental variables are detailed in model 3 (Table 2).

Table 5
Association between green space and other measures of physical activity after adjustment for individual and environment variables (n=22,254).

Green space quintile	Physical activity at work	Domestic physical activity: housework	Domestic physical activity: gardening and DIY
High 'cut off' (at least 30 min of MVPA 5 times per week)			
	OR (95% CI)	**OR (95% CI)**	**OR (95% CI)**
1 (1.27–23.37%)	1.00	1.00	1.00
2 (23.38–37.65%)	1.07 (0.93–1.23)	1.01 (0.78–1.29)	1.11 (0.74–1.67)
3 (37.66–57.18%)	1.12 (0.97–1.30)	1.09 (0.84–1.40)	0.99 (0.65–1.50)
4 (57.25–83.80%)	1.25 (1.07–1.45)	1.13 (0.86–1.48)	1.00 (0.66–1.52)
5 (83.81–98.58%)	1.37 (1.17–1.61)	1.16 (0.87–1.56)	2.19 (1.48–3.24)
Wald test	19.3 (<0.001)	1.78 (0.78)	36.2 (<0.001)
Low 'cut off' (any physical activity of MVPA and 30 min duration)			
	OR (95% CI)	**OR (95% CI)**	**OR (95% CI)**
1 (1.27–23.37%)	1.00	1.00	1.00
2 (23.38–37.65%)	1.07 (0.96–1.23)	1.11 (1.01–1.21)	1.21 (1.07–1.37)
3 (37.66–57.18%)	1.11 (0.98–1.25)	1.16 (1.07–1.28)	1.25 (1.11–1.42)
4 (57.25–83.80%)	1.28 (1.13–1.46)	1.12 (1.02–1.23)	1.27 (1.13–1.45)
5 (83.81–98.58%)	1.35 (1.18–1.56)	1.14 (1.04–1.27)	1.83 (1.61–2.09)
Wald test	24.7 (<0.001)	13.3 (0.01)	99.6 (<0.001)

*Wald test is used to test for any association between green space on physical activity; a 'high cut off' is defined as five or more sessions of the stated activity per week of at least 30 min duration of MVPA; a 'low cut off' is defined as doing some sessions of the stated activity of at least 30 min duration MVPA; individual and environmental variables are detailed in model 3 (Table 2).

4.1. Comparison with other studies

This study is larger than previous observational studies addressing this question, which we have identified. Other studies have varied in size from 57 (Roemmich, 2006) to 13,927 (Foster et al., 2009). It is one of three studies to address the question on a national scale, the other two, being from New Zealand (n=12,529;Witten et al., 2008) and the Netherlands (n=4889;Maas, 2008). Other studies have used different measures of exposure to green space: distance to park or green space (Foster et al., 2009; Coombes, 2008), travel time to park (Witten et al., 2008) or amount of green space in a fixed radius of home (Maas, 2008). Some studies have also considered the attractiveness or utility of green space (Giles-Corti et al., 2005, Hillsdon, 2006). Most studies, like this one, have looked at the adult population, although some small studies have included only children (Epstein et al., 2006; Roemmich, 2006, 2007; de Vries, 2007)

The findings from these studies are mixed. Unlike our study those that have found a positive association have tended to emphasise attractive green space (Gomez et al., 2010; Sugiyama, 2010), and have had a continuous measure of physical activity using accelerometer data from children (Epstein et al., 2006; Roemmich, 2006, 2007), or have focused on walking (Giles-Corti and Donovan, 2002, Sugiyama, 2010). The large population based studies (greater than 4000 individuals) in contrast to our study have not found an association (Hillsdon, 2006; Maas, 2008; Witten et al., 2008; Foster et al., 2009; Coombes, 2010). We also note that three of these studies were conducted in England, although within a fixed geographical area likely to be more homogenous in terms of green space and other determinants of physical activity (Hillsdon, 2006; Foster et al., 2009; Coombes, 2010). The two other national studies (Maas, 2008) and (Witten et al., 2008) found no association with overall physical activity.

The previous positive association with green space and walking contrasts with our findings, although both these studies were undertaken in Perth, Australia (Giles-Corti and Donovan, 2002; Sugiyama, 2010). This work suggested that it is not access *per se* but access to attractive large open spaces that matters (Giles-Corti et al., 2005). The green space measure in our study does not reflect quality of green space. One study in the UK found no association between proximity to the nearest green space and walking for recreation (Foster et al., 2009). It has been suggested that people living in more urban densely populated (and less green) areas may be more likely to walk for functional purposes, for example to get to the shop (Owen et al., 2004). This might explain the inverse relationship between green space and walking that we found.

The present study is one of three to look at sub-categories of physical activity (other than walking) that may be more tightly associated with green space. Maas found a positive association with cycling and gardening, despite no overall association with physical activity (Maas, 2008). We did not explore the association between cycling in isolation and green space in the UK. The MSOA is a relatively small geographic unit, and most recreational cycling is likely to take place outside this area, with very little functional cycling to local shops or amenities. The latter may be much more common in the Netherlands. Hillsdon found no association between green space and recreational physical activity, similar to our findings (Hillsdon, 2006). Other authors have previously shown an association between green space and gardening (Maas, 2008), but to the best of our knowledge, associations with occupational physical activity or housework have not previously been demonstrated or tested.

Our findings would appear to accord with the national study of all-cause and cardiovascular mortality (Mitchell and Popham, 2008). This study found that those living in the greenest quintile of England (using the generalised landuse database) had lower adjusted mortality. They suggested that this was most likely due to greater physical activity. However our study could not explain the higher odds of being obese or overweight among those living in the greenest quintile of England found in a similar study (Cummins and Fagg).

4.2. Study interpretation: possible mechanisms and implications

In our study, the association between green space and achieving recommended levels of physical activity appears robust. The association persists after adjustment for both individual and environmental variables. It also persists, and is stronger, when restricted to urban areas only. The findings are also consistent with Mitchell's work on cardiovascular mortality that used a similar measure of green space to our study and also looked across England.

However the failure to find an association with measures of physical activity that would take place in green space is troublesome for the hypothesis that green space promotes or supports higher levels of total physical activity. On one hand the absence of an association may suggest that residual confounding, for example due to socio-economic status or access to leisure facilities, is unlikely. On the other hand it suggests that there is some unidentified reason for the higher levels of physical activity among those living in green space, and that it is not due to higher levels of physical activity in green space.

The domain based analysis suggests other possible reasons for this association: notably an association with manual work (gardening or do-it-yourself) and/or occupational physical activity. We note that greener areas in the generalised landuse database also tend to be areas with more garden space relative to domestic building space ($r=0.55$). It therefore seems possible that people who live in greener areas are more likely to have access to a garden, or have a larger garden, such that they might undertake more gardening and do-it-yourself tasks in the garden. The association with occupational physical activity and green space may be due to a different set of jobs being available to people who live in areas with more green space: park maintenance, farming and forestry.

Alternatively the failure to find an association with walking or 'green space leisure' may reflect a failure to look for an effect among the correct activities or in the correct way. Our sub-categories of physical activity may still be poor predictors or measures of green space physical activity. We were also limited by treating physical activity as a binary variable. If green space had an influence on the 'middle range' of physical activity for the sub-categories (rather than at the low or high end) then our study would not be able to detect this. Nonetheless having an influence in the 'middle range' for the sub-categories of physical activity could still be an important determinant of whether somebody achieved overall physical activity levels.

Assuming that the relationship between green space and overall physical activity was due to more activity in green space, reverse causation should be considered as an explanation. Those who like to be physically active choose an environment that is green because it is perceived as important for supporting physical activity. Green space here may have a role in supporting and maintaining physical activity for those individuals when such levels might otherwise decline.

If the relationship between green space and physical activity is real and causal, it would have implications for planning policy: preserving, facilitating and encouraging the use of green space in order to promote physical activity. In many western cities that are highly developed with a premium on undeveloped land, radically increasing the amount of green space in cities where most people live would not be possible.

If the underlying relationship between green space and physical activity is not driven by green space activities but by other activities (gardening or occupational work), this would have implications for health improvement campaigns (e.g. messages around gardening) or initiatives to widen access to gardens (e.g. allotments and urban greening, community initiatives turning small patches of urban space into gardens maintained by local people).

Strengths and weaknesses of the study

The strengths of this study include the use of a large data set from a nationwide sample, making it a larger study than others we have identified. The study used an objective validated measure of green space that was taken close in time to the outcome variable. The study also explores the relationship with sub-categories of physical activity that may be more tightly associated with green space. A number of key confounding variables, both individual and environmental, were controlled for.

Weaknesses of this study include this being cross-sectional and using a self-reported measure of physical activity. Nonetheless differential reporting of physical activity by exposure to green space appears unlikely and hence should not bias our result. The measure of physical activity also restricted our analysis to logistic regression, a less powerful technique for exploring the relationship between physical activity and green space.

The measure of green space is crude and may not accurately capture useable green space for individuals in their environment. A perception of useable or 'high-quality' green space may be more important than objective measures of green space for promoting physical activity (Giles-Corti, 2003, 2004). The model accounts for only a small amount of the variance in physical activity. Weather and season have not been controlled for and can affect physical activity (Wolff and Fitzhugh, 2011). Other variables both at an individual level (e.g. desire to undertake exercise) and environmental level (e.g. objective measures of leisure facilities) that will affect physical activity have not been captured in the model.

We chose to examine sub-categories and domains of physical activity to try to explain the positive association between green space and overall physical activity. Greater levels of physical activity among residents in green space areas are thought to be explained by greater levels of physical activity within green space.

Ideally this would be tested by measuring physical activity specifically within green space. The sub-category measures of physical activity we chose were not restricted to exercise that only occurs in green space. They represent only a weak proxy for green space activity. While we feel they represent the most likely activities to be undertaken in green space, they are not the only activities that can occur in green space and these activities can also occur away from green space. For some of these activities (e.g. walking) they may predominantly occur away from green space.

However it may still be informative to look at the association between green space and these sub-categories of activity (e.g. walking). If the greater physical activity among people living in high green space areas is due to more physical activity occuring in green space, it would be expected that at least some of these measures of physical activity (that are undertaken in green space) would show an association with green space. In the absence of an association it might still be possible that green space access promotes that particular type of activity (e.g. access to green space may be important for promoting walking in green space, but overall walking could be lower in people living in green space areas if such areas are less dense prompting people to drive instead of walk as a form of transport), but it would seem unlikely that relationship could fully explain the observed relationship between green space and overall physical activity.

The 'green space leisure' variable is composed of walking, running, cycling and football/rugby. It is heavily weighted towards walking as this activity is much more common, so its association with green space largely follows the same pattern as that observed for walking.

Much sport, particularly in urban areas, takes place away from green space, at specialised facilities and leisure centres. Sport requires high motivation, such that people may be willing to travel to do sport regardless of the local environment. This might suggest that an association between green space and sport would be unlikely.

The domain measures report only a relatively small number of people undertaking these forms of exercise, particularly those to a high level (5 sessions a week at moderate intensity of at least 30 min) were relatively small, so caution should be drawn when considering the extent to which these relationships may explain the broader patterns observed between physical activity and green space in the population. It has not been possible to separate

out gardening from manual work, which is a composite of both gardening and do-it-yourself.

4.3. Unanswered questions and future research

Future research should seek to understand why access to green space has an effect on overall physical activity (achieving recommended guidelines) but fails to have an effect on the types of activity that occur in green space. In particular this should look to validate and explore further the associations observed here between green space and certain domains of physical activity, occupational and manual work (do-it-yourself and gardening). The age, gender and socio-economic balances of this effect should be described.

We suggest that future studies should adopt new technologies that offer the ability to objectively measure, identify type and geographically place physical activity, using a combination of GPS, accelerometers and image capture devices. These should seek to measure how much and what types of physical activities are undertaken in green space; and how this relates to overall physical activity. Longitudinal studies that compare the activity levels, patterns and types of physical activity undertaken, in people who experience a change in green space in their local environment (either because of relocation or due to opening up or closure of areas of local green space), will provide a better test of the hypothesis that green space promotes physical activity. Such studies may also address questions about how activity patterns away from green space, including occupational physical activity or gardening, change when people relocate to greener areas.

5. Conclusion

We found that people living in the greenest areas of England are more likely to achieve recommended amounts of physical activity. It remains unclear whether this is due to increased physical activity in sub-categories of physical activity typically undertaken in green spaces or due to increases in other domains of physical activity (e.g. gardening).

Conflict of interest statement

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