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Elizabeth A. Richardson* and Richard Mitchell

*Corresponding Author

Dr Elizabeth A. Richardson
School of Geosciences
University of Edinburgh
Drummond Street
Edinburgh, UK
EH8 9XP

e.richardson@ed.ac.uk
Tel: 0131 650 2800
Fax: 0131 650 2524

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ABSTRACT

Natural environments, or 'green spaces', have been associated with a wide range of health benefits. Gender differences in neighbourhood effects on health have been found in a number of studies, although these have not been explored in relation to green space. We conducted the first UK-wide study of the relationship between urban green space and health, and the first such study to investigate gender differences in this relationship. An ecological approach was used. Two land use datasets were used to create a proportional green space measure (% by area) at the UK Census Area Statistic ward scale. Our sample consisted of 6432 urban wards, with a total population of 28.6 million adults aged 16 to 64 years in 2001. We selected health outcomes that were plausibly related to green space (cardiovascular disease mortality, respiratory disease mortality and self-reported limiting long-term illness) and another that was expected to be unrelated (lung cancer mortality). Negative binomial regression models examined associations between urban green space and these health outcomes, after controlling for relevant confounders. Gender differences in these associations were observed and tested. Male cardiovascular disease and respiratory disease mortality rates decreased with increasing green space, but no significant associations were found for women. No protective associations were observed between green space and lung cancer mortality or self-reported limiting long-term illness for either men or women. Possible explanations for the observed gender differences in the green space and health relationship are gender differences in perceptions and usage of urban green spaces. We conclude that it is important not to assume uniform health benefits of urban green space for all population subgroups. Additionally, urban green space measures that capture quality as well as quantity could be more suited to studying green space and health relationships for women.

INTRODUCTION

Natural or green environments positively influence people's self-perceived health (de Vries, Verheij, Groenewegen, & Spreeuwenberg, 2003; Maas, Verheij, Groenewegen, de Vries, & Spreeuwenberg, 2006; Mitchell & Popham, 2007; Sugiyama, Leslie, Giles-Corti, & Owen, 2008), blood pressure (Hartig, Evans, Jamner, Davis, & Gärling, 2003), levels of overweight and obesity (Ellaway, Macintyre, & Bonnefoy, 2005), longevity (Takano, Nakamura, & Watanabe, 2002) and risks of all-cause and circulatory disease mortality (Mitchell & Popham, 2008). Possible causative mechanisms behind the green space and health relationship include the psychologically and physiologically restorative effects of nature (Hartig, Evans, Jamner et al., 2003; Pretty, Peacock, Sellens, & Griffin, 2005), the facilitation of social contacts (Maas, van Dillen, Verheij, & Groenewegen, 2009) and the provision of opportunities for physical activity (Humpel, Owen, & Leslie, 2002; Kaczynski & Henderson, 2007), though not all studies find associations between green space and physical activity (Hillsdon, Jones, Panter, & Foster, 2006; Maas, Verheij, Spreeuwenberg, & Groenewegen, 2008). Visual access to green space may, in itself, provide a salutogenic effect (Ulrich, 1984).

There has been little exploration of whether the associations between green space and health vary between different types of people. One study from the Netherlands suggested that the health of young people, the elderly, housewives and those with low socioeconomic status benefited more from residential green space than other groups (de Vries, Verheij, Groenewegen et al., 2003; Maas, Verheij, Groenewegen et al., 2006). This was attributed to the greater amount of time these groups spent in their residential area and thus their greater exposure to green spaces.

There is a larger body of work exploring the influences of other aspects of residential environment on health and this has found that effects may vary by residents' gender, age or socioeconomic status (Stafford, Cummins, Macintyre, Ellaway, & Marmot, 2005). In particular, gender differences in neighbourhood effects on health have been found in a number of studies. Stafford, Cummins, Macintyre, Ellaway, & Marmot (2005) found that various social and physical characteristics of the neighbourhood were more strongly associated with women's health than with men's. They suggest that the residential environment may be more important for women's health, perhaps because women have greater exposure to their neighbourhood environment, or are more vulnerable to its effects.

Other studies suggest that neighbourhood social environment in particular is more important for women's health than men's (Kavanagh, Bentley, Turrell, Broom, & Subramanian, 2006; Molinari, Ahern, & Hendryx, 1998; Poortinga, Dunstan, & Fone, 2007), whilst its physical environment may be more important for men's health (Molinari, Ahern, & Hendryx, 1998). As men and women benefit from their residential area in different ways, further investigation of gender differences in neighbourhood effects is warranted (Poortinga, Dunstan, & Fone, 2007).

Gender differences in exposure to or use of green space have been suggested by several studies, although this work leads to contradictory hypotheses about how these differences might manifest themselves in health associations. Women are under-represented in their use of green space, proportionate to their numbers in society (Cohen, McKenzie, Sehgal, Williamson, Golinelli, & Lurie, 2007; Hutchison, 1994; Ward Thompson, Bell, Satsangi, Netto, Morris, Travlou et al., 2003) and are less likely to engage in vigorous physical activity than men whilst in green space (Cohen, McKenzie, Sehgal et al., 2007). Thus we might hypothesise that green space will be more important for men's health than women's. Alternatively, women spend more time in their neighbourhood than men because they are more likely to be supervising children, working part time, conducting domestic work or being primary caregivers (Kavanagh, Bentley, Turrell et al., 2006). We could therefore hypothesise that the neighbourhood environment (including green space availability) will be more important for women's health. This study was prompted by these competing hypotheses and by the lack of existing evidence for gender differences in the relationship between urban green space and health.

The setting for this study was the United Kingdom. Evidence of a positive association between green space and health has been found in England (Mitchell & Popham, 2007, 2008) and Scotland (Ellaway, Macintyre, & Bonnefoy, 2005), but lack of a UK-wide green space measure has precluded investigation of green space and health relationships for the entire UK. The study aims were; to develop a UK-wide small area measure of green space coverage; to use it to examine the associations between health and green space coverage; and to determine if there are gender differences in these associations.

METHODS

Geographical unit of analysis

Our areal units were Census Area Statistics (CAS) wards (2001), the smallest geographical unit for which our health, environment and population measures were available throughout the UK. There are 10654 CAS wards in the UK, but we selected the 6432 wards classified as urban according by the urban-rural classifications of the UK's constituent countries (DEFRA, 2005; NISRA, 2005b; Scottish Executive, 2006; i.e., settlements with populations > 10,000). We restricted our analysis to urban settings for two reasons. First, the dominant types of green space and their accessibility tend to differ between urban and rural areas (Liu, Wilson, Qi, & Ying, 2007; Mitchell & Popham, 2008). Often agricultural land dominates in rural areas for example, and it is known that environmental correlates of health-related behaviour differ between urban and rural areas (Parks, Housemann, & Brownson, 2003). Second, the majority of the population in the UK live in urban areas. Our sample of 6432 wards had a mean population of 6930 in 2001 (standard deviation 4014), and a mean size of 4.6 km^2 (standard deviation 11.3).

Green space measure

Two land use datasets were used to create our green space measure. The Generalised Land Use Database (GLUD, Office of the Deputy Prime Minister, 2001) provided percentage green space per small area. GLUD is derived from the high resolution Master Map product available from the Ordnance Survey (OS). OS Master Map vector data is captured at a scale of 1:1250, hence the GLUD estimates include all vegetated areas larger than 5 m^2 in area (with the exception of domestic gardens), regardless of their accessibility (public or private). However, the GLUD only covers England. The Coordination of Information on the Environment (CORINE) land cover dataset was also obtained (EEA, 2000), as this has UK-wide coverage. Raster pixels (100 m^2) from remotely-sensed satellite imagery are classified into one of 44 land cover categories (e.g., green urban areas, continuous urban fabric, pasture, water bodies). The smallest area of green space mapped in the CORINE dataset was 25 hectares (Büttner, Feranec, & Jaffrain, 2002), hence only large green spaces were represented.

CORINE (UK-wide coverage but only sensitive to larger spaces) and GLUD (more sensitive to total green space regardless of space size, but only English coverage) were used together to produce a data set estimating green space within *all* wards in the UK. We created a regression model in which GLUD percentage green space for each English ward was predicted by a combination of its CORINE composition (% green space, % urban fabric, % blue space) and population density (2001 census). The model predicted the GLUD values extremely well ($R^2 = 0.95$, $p < 0.001$). Predicted green space values for all wards in the UK were then derived from the model. For English wards we compared model results (see below) obtained when using GLUD as a measure of green space, with those using our derived estimates of green space. Unsurprisingly (given the strength of the predicting regression model), no differences were observed. Due to its origins in the GLUD dataset our derived measure was an estimate of the percentage combined coverage of all green spaces larger than 5 m^2 (excluding domestic gardens) for each ward in the UK. The measure had greater sensitivity to small green spaces than the CORINE dataset, with the benefit that green spaces smaller than 25 ha were included. Green spaces included therefore ranged from transport verges and neighbourhood greens, to parks, playing fields and woodlands.

Health data

We selected three prevalent health outcomes whose aetiology could be plausibly associated with green space availability, based on the assumption that green space effects on health derive from a combination of physical activity promotion and stress reduction. There is clear evidence for the protective effects of physical activity against cardiovascular disease mortality (Nocon, Hiemann, Müller-Riemenschneider, Thalau, Roll, & Willich, 2008), respiratory disease mortality (Garcia-Aymerich, Lange, Benet, Schnohr, & Anto, 2006) and self-reported ill health (Netz, Wu, Becker, & Tenenbaum, 2005). We also selected lung cancer mortality, as a health outcome for which a plausible association with green space is absent or less clear (Tardon, Lee, Delgado-Rodriguez, Dosemeci, Albanes, Hoover et al., 2005).

Individual-level mortality records (including age, sex, cause of death and area of residence at death) were obtained from the Office for National Statistics (ONS) for England and Wales, the General Register Office for Scotland (GROS) and the Northern Ireland Statistics and Research Agency (NISRA). These data carried a spatial reference for place of residence at death sufficiently precise to allow matching to CAS ward and hence to an estimate of green space coverage. The mortality records covered a five-year period centred on the 2001 census (1999 to 2003), except for in Scotland where pre-2001 georeferencing issues made the use of

2001 to 2005 data more appropriate. Counts of cardiovascular disease (ICD-9 390-459; ICD-10 I00-I99), respiratory disease (ICD-9 460-519; ICD-10 J00-J99) and lung cancer (ICD-9 162; ICD-10 C33-C34) mortality were generated by age-sex group and CAS ward. A ward-level measure of self-reported morbidity was also used: counts of people reporting having a 'limiting long term illness' at the 2001 UK census.

Ward-level age-group and sex specific population estimates were obtained for 2001 from ONS, NISRA and GROS, and were updated to 2003 (the mid-point of the Scottish mortality data) for Scottish wards using annual small area population estimates from GROS. To focus on premature morbidity and mortality, and reduce the influence of health-related migration in old age, we restricted our sample to adults between the ages of 16 and 64. These are the ages at which social and spatial inequalities in health are maximised. This provided a total population at risk of 28.6 million (in 2001), with 103,711 cardiovascular disease deaths, 26,591 respiratory disease deaths and 30,110 lung cancer deaths over the five year period, and 4.2 million reports of limiting long-term illness in 2001.

Covariate area characteristics

Socioeconomic deprivation is a potential confounding characteristic in any relationship between green space and health. Reliable individual level measures of socioeconomic status for the mortality and LLTI cases were not available. We therefore measured deprivation at ward-level using the Income Deprivation domains from the Indices of Multiple Deprivation calculated for the four nations of the UK (NISRA, 2005a; Noble, Wright, Dibben, Smith, McLennan, Anttila et al., 2004; Scottish Executive, 2004; Welsh Assembly Government, 2005). This measure provided the proportion of the population of an area experiencing income deprivation (i.e., % population that are receiving financial support from the government because they have a low income and additionally are either: unemployed and looking for work; not available for full-time work; 60 or over; or responsible for at least one child). Separate calculation of the domains for the four nations has resulted in some differences: they represent 2001 and 2002 in England and Scotland, 2002 in Wales and 2003 in Northern Ireland; and they include asylum seekers receiving financial support in England and Wales, but not in Scotland or Northern Ireland. As the temporal difference is marginal, and the inclusion/exclusion of asylum seekers reflects the relative numerical importance of these populations in each region, we considered it feasible to combine the domains into a

UK-wide income deprivation measure. Additionally, income deprivation quartiles were used in all analyses, thus limiting the sensitivity of the measure to subtly different methodologies.

It was also important to control for the effects of air pollution. Greener places are likely to have lower pollution levels, due to the indirect effect of reducing the amount of land available to combustion or other pollution-generating processes. By controlling for air pollution levels, we therefore reduced the likelihood that salutogenic impacts of lower air pollution levels became wrongly attributed to higher levels of green space. Particulate matter with a diameter < 10 µm (PM_{10}) is arguably the most commonly used indicator of urban air pollution levels. There is very strong evidence for cardiovascular and respiratory health impacts of exposure to higher levels of PM_{10} (Dockery & Pope, 1994; Kampa & Castanas, 2008). We obtained annual average concentrations at a 1 km grid resolution from AEA Technology for the years 1999 to 2003. The average PM_{10} concentration between 1999 and 2003 was calculated for each ward.

Smoking is a risk factor for all health outcomes examined in this study and is a behaviour which varies both socially and spatially (Twigg, Moon, & Walker, 2004). Smoking is strongly associated with socio-economic deprivation and since access to green space is also negatively associated with socio-economic deprivation (Mitchell & Popham, 2008) smoking was an important potential confounder in this study. Whilst income-deprivation would act as a proxy for community level smoking rate, it was important to examine the potential confounding influence of smoking as far as possible.

Data describing smoking behaviour were not available at the individual or area level across the entire UK. However, synthetic estimates of smoking rates were available for English wards (Twigg, Moon, & Walker, 2004). We therefore repeated our analyses for English wards only (78% of UK wards) including control for area-level smoking rates. This enabled us to assess the impact of omitting measures of smoking on the relationships observed.

Analyses

We explored the relationship between ward-level urban green space coverage and health outcomes (counts), and whether the associations varied by gender. Over-dispersion of the count data made Poisson models unsuitable (Hilbe, 2007), hence negative binomial regression models were used, with ward population entered as the exposure variable. Green space coverage was operationalised as equal interval groups (four groups: <25%, 25 to <50%, 50 to <75% and 75%+) rather than quantiles, because they represent variations in the 'dose' of green space present in an area rather than variations in the distribution of green space across all UK wards. To be certain this choice did not influence our results, we repeated analyses using quartiles; substantive results did not change. All models were adjusted for age-group, income deprivation quartile, air pollution and country. Age groups used were 16 to 34, 35 to 49, 50 to 59 and 60 to 64, in line with the availability of census LLTI counts. Models were first run separately for men and women, but as this did not constitute a formal test for interaction, whole population models including the interaction term [green space level]*[gender] and main effect terms were then run. The resulting coefficients were tested using a Wald test. All models utilised robust standard errors to allow for spatial clustering (Williams, 2000). Models were run in Stata v.10.

RESULTS

The 6432 urban wards in the study had an average green space coverage of 46.2% (95% confidence interval (CI) 45.7 to 46.8). Table 1 shows the numbers and distribution of men and women in the urban green space exposure groups. As expected, there were no significant differences between men and women in terms of their green space exposure. Although only urban wards were included in the study, about 2.9 million men and women resided in wards with more than 75% green space.

Clear gender differences were observed in the association between urban green space and each health outcome (Table 2). Residence in greener urban wards carried significantly decreased risk of cardiovascular disease and respiratory disease mortality for men, but not for women. For men the risk of cardiovascular and respiratory disease mortality decreased with increasing green space coverage (p trend < 0.001), and was lowest for the greenest wards (cardiovascular disease: incidence rate ratio (IRR) 0.95, 95% CI 0.91 to 0.98; respiratory disease: IRR 0.89, 95% CI 0.83 to 0.96). Thus, men living in the greenest urban wards in the UK had a 5% lower risk of cardiovascular disease mortality and 11% lower risk of respiratory disease mortality than men in the least green wards. In contrast, no association with urban green space was found for female cardiovascular disease and respiratory disease mortality: IRRs were inconsistent in direction (some protective, some detrimental) and gave no indication of dose-response relationships.

When tested formally, a significant interaction effect between urban green space and gender was found for respiratory disease mortality ($\chi^2 = 32.2$, $p < 0.0001$), but not for cardiovascular disease mortality ($\chi^2 = 5.87$, $p = 0.1179$). This gender difference in the relationship between urban green space and respiratory disease mortality is shown graphically in Figure 1. Relative to the reference group (males in low green space wards) all other groups had significantly lower respiratory disease mortality, and women consistently had lower mortality rates than men. The significant interaction occurred because increasing urban green space availability was associated with decreasing respiratory disease mortality for men but not women, and hence the gender gap was markedly reduced in greener wards.

Male lung cancer mortality was not significantly associated with urban green space (Table 2) but for women significantly elevated rates were observed at intermediate levels of urban green space. A significant interaction effect between gender and green space level was found for this relationship ($\chi^2 = 11.18$, $p = 0.0108$).

Self-reported limiting long-term illness (LLTI) was only minimally affected by ward-level urban green space, and again significant effects were only found for females: risk of reporting LLTI was marginally higher in greener wards (Table 2). Given the similar weak directional trends seen for males and females the finding of no significant interaction ($\chi^2 = 1.37$, $p = 0.7127$) was not surprising.

We considered the possibility that the lack of association between green space and cardiovascular disease and respiratory disease mortality for women might reflect the fact that women tend to die from these diseases at older ages than men. We re-ran models for women extending the age range of those included up to 75 but no substantive difference in results was observed.

Models for English wards only, adjusting for smoking rate, largely showed the same substantive results as the main analyses, with slight attenuation of the significant associations between green space and health. The single exception was that the significant positive association between risk of lung cancer death for women and intermediate levels of green space was rendered non-significant on adjustment for smoking. Further analysis showed that smoking rates were significantly higher in wards with intermediate levels of green space ($p < 0.001$). The association between residence in areas with intermediate green space coverage, and higher risk of lung cancer for women (Table 2) is thus probably confounded by smoking behaviour.

Finally, some associations between air pollution and lower risk of mortality or poor health were observed (Table 2), notably for women. This was unexpected and counter-intuitive, and is explored further in the discussion.

DISCUSSION

We developed UK-wide, small area estimates of green space coverage and used them in the first UK-wide study of the relationship between urban green space and health, and to investigate gender differences in this relationship. We found a clear protective association of ward-level urban green space coverage with cardiovascular disease and respiratory disease mortality for men, but not for women. Effect size for men was modest with regard to cardiovascular disease (5% reduction in risk for those in the greenest urban areas), but more substantial for respiratory disease (11% reduction in the greenest urban areas) and there was a dose response relationship in the case of male risk of respiratory disease mortality. In contrast, greener surroundings were not associated with male lung cancer mortality, but were associated with *increased* rates for females, though this is likely explained by confounding with community level smoking rates. Greener surroundings were also associated with a slight increased risk of reporting LLTI for women.

The mechanisms most commonly postulated to underlie the beneficial effects of green space are 1) provision of opportunities for physical activity, 2) recovery from stress and attention fatigue, and 3) facilitation of social contact (Hartig, Mang, & Evans, 1991; Health Council of the Netherlands & RMNO, 2004; Kaplan & Kaplan, 1989). A large number of studies report that cardiovascular mortality risk is significantly reduced for physically active individuals (Nocon, Hiemann, Müller-Riemenschneider et al., 2008). Other work suggests that the development and course of cardiovascular disease may be exacerbated by chronic stress (Taylor, Repetti, & Seeman, 1997), and mediated by social contact and support (Kamarck, Mannuck, & Jennings, 1991; Kaplan, Salonen, Cohen, Brand, Leonard Syme, & Puska, 1988). There is also some evidence that regular physical activity may reduce respiratory disease mortality (Garcia-Aymerich, Lange, Benet et al., 2006; Rockhill, Willett, Manson, Leitzmann, Stampfer, Hunter et al., 2001). Mitchell and Popham (2008) reported a protective association of green space with cardiovascular disease mortality in England, for both sexes combined. It is therefore plausible, at least in terms of aetiology, that our findings represent a beneficial effect of contact with green space on men's respiratory and cardiovascular health.

Previous studies have found self-reported health to be better in greener surroundings (de Vries, Verheij, Groenewegen et al., 2003; Maas, Verheij, Groenewegen et al., 2006; Mitchell & Popham, 2007), hence the absence of a protective association of green space with LLTI in this study was unexpected. As mortality rates for the, often chronic, cardiovascular and respiratory diseases were reduced in greener surroundings, and these causes account for almost 50% of UK deaths annually, it seems contradictory that self-reported health should not follow the same trend. Inspection of the interaction model output indicated that the association we found was being predominantly driven by high LLTI rates in the relatively deprived but greener urban wards (income deprivation quartile 3 and green space ≥ 50%). An informal visual inspection of a map showing the locations of these wards suggested they were mainly located in city suburbs**.** Mitchell & Popham (2007) also found a detrimental association between green space and self-reported health for suburban lower income areas. They postulated that green space in such areas may be of poor quality, and suggested that green space quality as well as quantity may be a significant determinant of health benefits. However, their study, like this one, did not have any data on green space quality and this explanation remains speculative.

Why did we observe gender differences in the associations between urban green space coverage and cardiovascular and respiratory disease mortality when the men and women in these wards were exposed to the same quantity and quality of green space? One possible explanation is that men and women may experience and utilise urban green space in different ways. Women are often under-represented in public parks (Cohen, McKenzie, Sehgal et al., 2007; Hutchison, 1994), and are less likely to engage in vigorous activity while there (Cohen, McKenzie, Sehgal et al., 2007). Certain social, physical and psychological barriers to access and participation have been identified for women, whether real or perceived (Ward Thompson, Bell, Satsangi et al., 2003). O'Brien (2005) reported that women have particularly acute concerns about their personal safety when visiting green spaces on their own. Foster, Hillsdon & Thorogood (2004) found that women were significantly less likely to undertake any walking if they perceived their local environment to have a low level of personal safety, whereas men's walking was not influenced by such concerns. Women report feeling safer in obviously managed areas, and have a significantly higher preference for visible management and law enforcement than males (Ho, Sasidharan, Elmendorf, Willits, Graefe, & Godbey, 2005; O'Brien, 2005; Virden & Walker, 1999). In contrast women feel more uncomfortable in neglected and abused areas, and have a significantly lower preference for remote natural settings than men (O'Brien, 2005; Virden & Walker, 1999).

Such differences could explain our results. We suggest that women's use of urban green space may be influenced by the quality of the green space to a greater degree than men's. While the health benefits of green space for men might be clearly demonstrated using a simple objective measure of green space quantity, as here, we suggest that women's health benefits may be more closely associated with subjective indicators of green space quality and perceived personal safety. In particular, other researchers note that women's perceptions of the social quality of their local environment are strongly associated with their health (Molinari, Ahern, & Hendryx, 1998; Poortinga, Dunstan, & Fone, 2007). Environmental attributes that enhance the opportunities for social contact could therefore be usefully incorporated in future work.

It also seems likely that life stage and family circumstances will impact on the relationship between women and their environment, perhaps rather more than for men. Popham & Mitchell (2006), for example, demonstrated that women's leisure time exercise behaviour was more severely attenuated by having young children than was men's. Although we controlled for age in this study, we did not take account of other family or domestic circumstances. Variation in urban green space and health relationships across the life course will be explored in a subsequent paper.

A contrasting explanation for these gender differences is that they are an artefact of socioeconomic inequalities in mortality being greater for men than for women (Koskinen & Martelin, 1994; Mackenbach, Kunst, Groenhof, Borgan, Costa, Faggiano et al., 1999). If income deprivation is an inadequate or incomplete measure of socioeconomic status, our green space measure may have acted as an additional proxy for this confounder (i.e., more green space ≈ less socioeconomic deprivation). If this were the case, our finding that male cardiovascular and respiratory disease mortality was reduced in greener urban settings could simply reflect the fact that greener areas contain less deprived populations and that men's mortality is more strongly associated with deprivation. We might not have observed a similar association among women if the strength of association between risk of mortality and socioeconomic deprivation is weaker for them.

Our modelling of cause-specific mortality, however, suggested that this was not likely to be the explanation. Socioeconomic inequalities in lung cancer and respiratory disease mortality have been found to be greater for men than women, but for cardiovascular disease the inequalities are greater for women (Koskinen & Martelin, 1994; Mackenbach, Kunst, Groenhof et al., 1999). If green space was acting as a proxy for any residual influence of socioeconomic position, we would have expected a stronger association between green space and cardiovascular disease mortality for women, not the absence we observed. The association between lung cancer mortality and green space was also in the opposite direction to that which would be expected if increasing green space was a proxy for increasing affluence (i.e., detrimental rather than protective).

The observation of some protective effects of air pollution was surprising and is difficult to explain. Annual average concentrations of PM_{10} in our study areas were relatively low (mean 16.1 $\mu g.m^{-3}$), compared with the UK Air Quality Objective concentration set for the protection of human health (40 $\mu g.m^{-3}$). It is possible that the air pollution levels themselves were too low to have much health impact, and that they acted as a proxy for some other feature of residential environment which is salutogenic, particularly for women. PM_{10} levels are correlated with population density for example and it could be that this variable was acting as proxy for service density or even density of social connections.

This issue is an effective illustration of the major weakness in our study; it was ecological. The problems of inference about individual behaviours and health from ecological data are well known and documented (Robinson, 1950). The potential for confounding by unmeasured factors, such as lifestyle, and for exposure misclassification should be borne in mind. Green space coverage is not necessarily equivalent to accessibility, because public and private green spaces were indistinguishable in our dataset (although visual access may be enough to yield health benefits; Ulrich, 1984). It is also not necessarily equivalent to actual use by residents. Our study implicitly assumes that available space was accessed in some way (either visually or physically) and accessed equally because no data were available with which to describe or estimate green space use.

Furthermore, the study assumed that that each ward resident was only exposed to the green space within their particular ward. In reality, individuals may spend varying proportions of their day outside of their ward and those living on the ward's periphery could have greater exposure to green space in adjoining wards than those located more centrally. Accounting for green space in the immediate vicinity of each ward might have improved our area-level measure, but was not possible with the data available.

Our study was cross-sectional and could not prove a causal relationship between exposure to urban green space and better health. However, by including contrasting causes of death which have aetiologies plausibly and not plausibly associated with green space we added some confidence to the hypothesis that urban green space is implicated in lower risk of specific causes of death for men.

The data describing green space coverage were derived from models and whilst we have tested them as best we can, they remain estimates. Furthermore, they represent green space presence in small, arbitrarily defined, spatial areas and might not reflect people's actual access to, or sight of, green space. In the absence of any other representative data which accurately capture realised or even potential access to green spaces, our approach remains the most sophisticated possible when working at an ecological and population level. The production of small area, UK wide estimates of green space represents a significant contribution and a useful new resource for researchers in this field.

Although we acknowledge these methodological weaknesses, the study had several strengths. It was based on a very large sample size which permitted precise estimation of risks associated with relatively unusual combinations of environment circumstances, such as being relatively deprived but living in a greener area. We used high quality, robust and objective measures of both population health and green space coverage, whereas other studies focused on gender differences in neighbourhood effects have relied on self-reported measures of the local environment and/or of health (Molinari, Ahern, & Hendryx, 1998; Poortinga, Dunstan, & Fone, 2007; Stafford, Cummins, Macintyre et al., 2005). These may have been affected by gender differences in reporting. Our study did control for income-deprivation and this will have accounted for a considerable amount of confounding by economic and cultural factors. The study was also the first to cover the entire urban UK, and thus to include the variety of cultures, environments and climates to which the urban population of the UK is exposed. The measure of green space itself was relatively sensitive to smaller and larger spaces and was therefore not biased in characterising exposure. Our exposure measure (which neither contained measures of access to, or behaviour in, green space) was relatively weak and the diseases we worked with are complex and multifactorial. Thus, the detection of any effects of green space coverage on risk of *mortality* is perhaps surprising and very positive.

Although we have linked separate pieces of evidence to infer that gender differences in the urban green space and health relationship are likely attributable to women's perceptions about safety risks and their role as childcare-giver, it would be informative if direct evidence could be used to test this hypothesis. Individual level survey data, in which individuals' perceptions of and use of local green space were assessed, could be linked to their health or health behaviours (e.g., self-reported health, obesity, physical activity levels). It would also be useful to explore relationships between other aspects of neighbourhood character, such as crime levels, and gender differences in use of green space. Carrying out a similar study for rural populations would provide an interesting contrast to this urban-based work.

Currently, many agencies are proceeding on the basis that green space has a beneficial relationship with prevalent chronic illnesses such as cardiovascular and respiratory disease, and that improving urban green space availability could have significant benefits for population health. Such agencies include the NHS and the Forestry Commission in the UK. Understanding the specificity of the green space and health relationship for subgroups of the population will be important for ensuring that any health benefits are distributed equitably and that evaluations of any interventions these agencies carry out are designed appropriately. For this purpose, measures of exposure to green space which are sensitive to differences in usage by different subgroups are needed.

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FIGURE

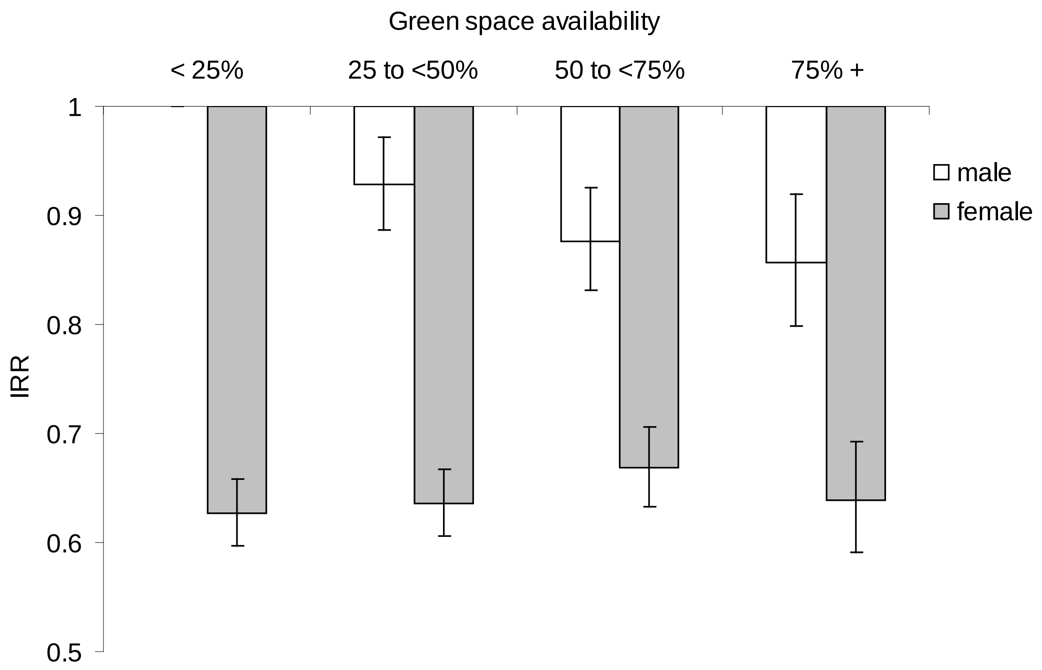

Figure 1. The interaction between gender and urban green space availability, in their relationship with respiratory disease mortality. Incidence rate ratios (IRRs) given relative to the reference group (males in the wards with least green space, IRR = 1.0) and bars indicate 95% confidence intervals. The interaction effect was significant (Wald test χ^2 = 32.2, p < 0.0001).

TABLES

Table 1. Distribution of population (aged 16-64) across urban green space groups

	Proportion of ward area which is green space				
	0-24%	25-49%	50-74%	75+%	Total *n*
Men (*n*)	3,717,054	5,600,755	3,388,490	1,414,096	14,120,395
	26.3%	39.7%	24.0%	10.0%	100.0%
Women (*n*)	3,805,416	5,781,024	3,477,902	1,443,197	14,507,539
	26.2%	39.8%	24.0%	9.9%	100.0%

Table 2. Associations between urban green space availability and health outcomes for adult males and females (incidence rate ratios + 95% confidence intervals), after adjustment for age-group, income deprivation, country and air pollution.

	Cardiovascular disease mortality		**Respiratory disease mortality**	
Variable	Male	Female	Male	Female
Urban green space availability group				
<25%	1.00	1.00	1.00	1.00
25 to <50%	0.97 (0.95 to 0.99)**	1.02 (0.99 to 1.06)	0.94 (0.90 to 0.98)**	1.00 (0.95 to 1.05)
50 to <75%	0.95 (0.93 to 0.98)***	1.01 (0.97 to 1.05)	0.90 (0.85 to 0.95)***	1.03 (0.97 to 1.09)
75%+	0.95 (0.91 to 0.98)**	1.00 (0.95 to 1.06)	0.89 (0.83 to 0.96)**	0.96 (0.88 to 1.05)
Age group				
60 to 64	1.00	1.00	1.00	1.00
50 to 59	0.45 (0.44 to 0.46)***	0.39 (0.38 to 0.40)***	0.36 (0.35 to 0.37)***	0.38 (0.36 to 0.40)***
35 to 49	0.11 (0.10 to 0.11)***	0.10 (0.10 to 0.11)***	0.08 (0.07 to 0.08)***	0.08 (0.08 to 0.08)***
16 to 34	0.01 (0.01 to 0.01)***	0.02 (0.01 to 0.02)***	0.02 (0.02 to 0.02)***	0.02 (0.02 to 0.02)***
Income deprivation quartile				
1	1.00	1.00	1.00	1.00
2	1.34 (1.31 to 1.38)***	1.41 (1.35 to 1.47)***	1.53 (1.43 to 1.63)***	1.52 (1.42 to 1.64)***
3	1.70 (1.66 to 1.75)***	1.87 (1.79 to 1.95)***	2.15 (2.02 to 2.28)***	2.15 (2.00 to 2.31)***
4	2.29 (2.23 to 2.35)***	2.59 (2.49 to 2.70)***	3.29 (3.10 to 3.50)***	3.09 (2.88 to 3.31)***
Country				
England	1.00	1.00	1.00	1.00
N. Ireland	0.89 (0.84 to 0.94)***	0.90 (0.82 to 0.98)*	0.84 (0.74 to 0.95)**	1.06 (0.93 to 1.21)
Scotland	1.18 (1.14 to 1.23)***	1.20 (1.14 to 1.26)***	1.20 (1.11 to 1.30)***	1.08 (0.99 to 1.17)
Wales	0.99 (0.95 to 1.03)	1.02 (0.96 to 1.08)	0.88 (0.80 to 0.97)*	0.92 (0.83 to 1.02)
Air pollution	1.00 (1.00 to 1.01)	1.00 (0.99 to 1.01)	1.02 (1.01 to 1.03)**	0.99 (0.97 to 1.00)*

	Lung cancer mortality		**Limiting long-term illness**	
	Male	Female	Male	Female
Urban green space availability group				
<25%	1.00	1.00	1.00	1.00
25 to <50%	1.02 (0.98 to 1.07)	1.09 (1.03 to 1.15)**	1.00 (0.99 to 1.01)	1.01 (1.00 to 1.02)
50 to <75%	1.01 (0.96 to 1.06)	1.09 (1.02 to 1.15)**	1.01 (1.00 to 1.03)	1.02 (1.01 to 1.03)**
75%+	0.96 (0.90 to 1.02)	1.02 (0.94 to 1.11)	1.01 (1.00 to 1.03)	1.02 (1.00 to 1.04)*
Age group				
60 to 64	1.00	1.00	1.00	1.00
50 to 59	0.39 (0.38 to 0.40)***	0.46 (0.44 to 0.47)***	0.62 (0.62 to 0.62)***	0.76 (0.76 to 0.77)***
35 to 49	0.05 (0.04 to 0.05)***	0.07 (0.07 to 0.08)***	0.34 (0.33 to 0.34)***	0.40 (0.40 to 0.40)***
16 to 34	0.00 (0.00 to 0.00)***	0.00 (0.00 to 0.00)***	0.18 (0.18 to 0.19)***	0.20 (0.20 to 0.20)***
Income deprivation quartile				
1	1.00	1.00	1.00	1.00
2	1.52 (1.44 to 1.60)***	1.41 (1.32 to 1.50)***	1.33 (1.32 to 1.35)***	1.30 (1.28 to 1.31)***
3	1.96 (1.86 to 2.06)***	1.79 (1.68 to 1.91)***	1.71 (1.69 to 1.73)***	1.63 (1.61 to 1.65)***
4	2.73 (2.59 to 2.87)***	2.56 (2.41 to 2.73)***	2.29 (2.26 to 2.32)***	2.12 (2.10 to 2.15)***
Country				
England	1.00	1.00	1.00	1.00
N. Ireland	0.96 (0.87 to 1.07)	0.97 (0.85 to 1.11)	1.11 (1.08 to 1.14)***	1.19 (1.16 to 1.22)***
Scotland	1.32 (1.23 to 1.41)***	1.30 (1.21 to 1.41)***	1.03 (1.01 to 1.05)**	1.08 (1.06 to 1.10)***
Wales	0.90 (0.83 to 0.98)*	0.84 (0.76 to 0.93)**	1.13 (1.11 to 1.15)***	1.15 (1.13 to 1.17)***
Air pollution	1.00 (0.98 to 1.01)	0.97 (0.96 to 0.98)***	0.98 (0.97 to 0.98)***	0.99 (0.99 to 0.99)***

* $0.01 \le p < 0.05$; ** $0.001 \le p < 0.01$; *** $p < 0.001$.