Effect of exposure to natural environment on health inequalities: an observational population study

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Summary

Background Studies have shown that exposure to the natural environment, or so-called green space, has an independent effect on health and health-related behaviours. We postulated that income-related inequality in health would be less pronounced in populations with greater exposure to green space, since access to such areas can modify pathways through which low socioeconomic position can lead to disease.

Methods We classified the population of England at younger than retirement age (n=40 813 236) into groups on the basis of income deprivation and exposure to green space. We obtained individual mortality records (n=366 348) to establish whether the association between income deprivation, all-cause mortality, and cause-specific mortality (circulatory disease, lung cancer, and intentional self-harm) in 2001–05, varied by exposure to green space measured in 2001, with control for potential confounding factors. We used stratified models to identify the nature of this variation.

Findings The association between income deprivation and mortality differed significantly across the groups of exposure to green space for mortality from all causes ($p<0·0001$) and circulatory disease ($p=0·0212$), but not from lung cancer or intentional self-harm. Health inequalities related to income deprivation in all-cause mortality and mortality from circulatory diseases were lower in populations living in the greenest areas. The incidence rate ratio (IRR) for all-cause mortality for the most income deprived quartile compared with the least deprived was 1·93 (95% CI 1·86–2·01) in the least green areas, whereas it was 1·43 (1·34–1·53) in the most green. For circulatory diseases, the IRR was 2·19 (2·04–2·34) in the least green areas and 1·54 (1·38–1·73) in the most green. There was no effect for causes of death unlikely to be affected by green space, such as lung cancer and intentional self-harm.

Interpretation Populations that are exposed to the greenest environments also have lowest levels of health inequality related to income deprivation. Physical environments that promote good health might be important to reduce socioeconomic health inequalities.

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Introduction

The persistence and growth of socioeconomic health inequalities continues to command the attention of researchers, clinicians, and politicians.[1–4] Several studies have investigated how socioeconomic inequalities in health vary between societies, to try to establish what types of social and economic policies might reduce health inequalities.[5–8] Elsewhere in public-health research, interest is growing in how social and physical environments might interact to affect health, both in a salutogenic (ie, health improving) and pathogenic sense.[9,10] In this Article, we combine these strands of research.

How natural environments, or so-called green spaces, might affect health and health-related behaviour has received substantial attention from a range of disciplines, including epidemiology and psychology.[11–18] Green spaces are defined as "open, undeveloped land with natural vegetation"[19] and include parks, forests, playing fields, and river corridors, for example. Evidence suggests that contact with such environments has independent salutogenic effects[20]—eg, green spaces independently promote physical activity.[17,21] Importantly, physical activity in such environments might have greater psychological and physiological benefits than might physical activity in other settings.[22,23] However, the effect of green space is not solely based on promotion or enhancement of physical activity. Several studies have shown that contact (either by presence or visual) with green spaces can be psychologically and physiologically restorative, reducing blood pressure and stress levels,[13,22] and possibly promoting faster healing in patients after surgical intervention.[24]

Although many studies show that natural environments enhance health or encourage healthy behaviours, and a few examine variation in these effects by socioeconomic status,[11,15,18] the potential for access to green environments to affect socioeconomic inequality in health within populations has, as far as we are aware, received no attention.

We postulated that socioeconomic inequalities in health will be less pronounced in people with greater exposure to green space than in those with less exposure. The reason for this hypothesis is that some pathways, through which lower socioeconomic position might lead to worse health, are potentially modified by exposure to green space. We know, for example, that people with low socioeconomic status are less likely to exercise[25] than are those with high socioeconomic status, partly because the environments in which they live are less conducive to it.[26] Indeed, evidence for the relations between socioeconomic status and green space suggests that, although more deprived populations might be less likely to have access to such areas (by virtue of residential location or transportation disadvantage), socioeconomic position itself does not independently affect use of green space if it is readily available.[18] Thus, disadvantaged populations that do have access to green space might be expected to accrue health benefits from using it (perhaps to a greater extent than any physical activity in other settings),[22,23] and therefore potentially enjoy better health than might those of a similar level of deprivation, but without access to green space.

Another pathway through which green space might be associated with lower inequality involves the physiological responses to the stress of poverty, which are implicated in increased risk of various diseases, notably heart disease.[27–30] If, as already noted, contact with natural environments is associated with reductions in stress, blood pressure, and promotion of healing,[13,22,31] more deprived populations with access to green space might plausibly have some protection from the biological effects of their poverty-related stress, decreasing their mortality rates compared with those without access to green space. Thus we would expect inequalities in health to be reduced for populations who are exposed to green space in terms of causes of death for which there is a causal pathway on which green space might plausibly exert an effect.

These ideas prompted us to investigate whether the magnitude of income-related health inequality varies by exposure to green space.

Methods

Study design

We compared income-related health inequality in populations living in areas of England that are characterised by differing amounts of green space, with adjustment for other potentially confounding characteristics of the areas. We selected causes of death with contrasting causes to improve testing of our hypotheses and guard against residual confounding. This study was undertaken in July–August, 2008.

Data

We obtained data describing the quantity of green space in an area from the generalised land use database (GLUD) 2001.[32] The GLUD classifies land use in England into nine categories, one of which is called green space. This category includes parks, other open spaces, and agricultural land, but excludes domestic gardens. Classification is accurate to 10 m². Areas of green space with coverage of less than 5 m² are ignored in this dataset—eg, single or small clumps of trees on a street would not be included. We used lower level super output areas (LSOA) as our geographical units and calculated the percentage of each LSOA's land area that was classified as green space. An LSOA is a geographic unit that is used for reporting small area statistics in England. The 32 482 LSOAs have a minimum population of 1000, a mean population of 1500, and an average physical area of 4 km². We classified the English population into five exposure groups, on the basis of the proportion (quintile) of green space in their LSOA of residence. Thus, every exposure group contained about 20% of the study population (table).

For **super output areas**, see http://www.statistics.gov.uk/geography/soa.asp

We obtained anonymised, individual mortality records from the UK Office for National Statistics. The records covered every death registered and matched to an LSOA in England, between 2001 and 2005, and provided the age at death, sex, cause of death (International Classification of Diseases [ICD] 10), and LSOA of residence. We obtained age-group and sex-specific population estimates at LSOA level from the Office for National Statistics. The age groups by which these estimates were structured differed slightly since women retired at 60 years and men at 65 years at the time to which these data refer. We excluded populations who were older than retirement age because inequalities in mortality tend to be at a maximum in the working-age population. Thus the total study population was 40 813 236, with 366 348 deaths.

In addition to all-cause mortality, we purposefully selected three other causes of death for study. We examined deaths from circulatory diseases (ICD-10 codes I00–I99, n=90 433), partly because they have striking socioeconomic inequalities, but primarily because some important associated risk factors (sedentary lifestyle and psychosocial stress) can be particularly ameliorated by green environments. We also selected two other causes of death that have substantial socioeconomic inequalities but different risk factors and aetiologies. Inequalities in death from lung cancer (ICD-10 code C34, n=25 742) are mainly driven by smoking and are fairly weakly related to physical activity.[33] Deaths from intentional self-harm (ICD-10 codes X60–X84, n=12 308) also have causes that differ greatly from circulatory disease and lung cancer.

Data for population income were not routinely available. Instead, we followed the work of other investigators[34] and used the income deprivation domain of the 2004 English index of multiple deprivation (EIMD). This index represented the proportion of low-income families in an area, and was the best available income-related measure. We used it to classify each LSOA, and hence its resident population, into an income-deprivation quartile (table).

We used other domains of the EIMD to adjust for area characteristics that were plausibly associated with mortality; deprivation in education, skills, and training; and deprivation in the living environment (including measures of air pollution). We controlled for living environment because greener places could also be those in which levels of other pollutants or environmental hazards are lower. We also controlled for population density and for the degree of urbanity[35] to allow for potential differences in types of green space and accessibility between more and less urban areas.

Statistical analysis

We first examined associations between exposure to green space and income deprivation to establish whether

	Groups of exposure to green space					Total
	1 (least exposed)	2	3	4	5 (most exposed)	
Income-deprivation group 1 (least deprived)	1 497 663	1 512 733	1 756 134	2 503 755	3 716 717	10 987 002
Income-deprivation group 2	1 757 904	1 617 400	1 720 964	2 080 000	2 891 637	10 067 905
Income-deprivation group 3	2 291 828	2 033 620	2 025 834	1 821 320	1 161 087	9 333 689
Income-deprivation group 4 (most deprived)	2 797 692	2 983 898	2 591 694	1 654 367	396 989	10 424 640
Total	8 345 088	8 147 653	8 094 629	8 059 446	8 166 435	40 813 236

***Table:* Study population size, stratified by exposure to green space and by income deprivation**

exposure to green space in the most deprived population varied enough to warrant testing our hypothesis. We then established, in a negative binomial regression model (modelling the number of deaths), that there was an independent association between exposure to green space and all-cause mortality after controlling for the confounding factors described above. We included population size as an offset in the models. Poisson models were rejected because of over dispersion. We then explored whether the association between income-deprivation quartile and mortality varied by exposure to green space, which we did using interaction terms for income deprivation and exposure to green space. The exact nature of significant interactions was subsequently unpacked in a sequence of models stratified by group of exposure to green space—ie, the first model explored the association between income-deprivation quartile and mortality for people in the lowest group of exposure to green space, the second model explored the same association for people in the next lowest group of exposure to green space, and so on.

All models were adjusted for age group, sex, deprivation in education, skills and training, deprivation in living environment, population density, and urban or rural classification. To be certain that our results were not simply an indicator of differences in lifestyle in urban or rural setting or other aspects of environment, we re-ran models on urban areas only. Models for lung cancer excluded people aged younger than 15 years because the number of deaths was too few in this age group. All models accounted for the clustering of observations within areal units via robust estimates of variance.[36,37] We used Stata (version 10.1) for our analysis.

Role of the funding source

This study had no direct sponsor. The corresponding author (RM) had full access to all the data. RM and FP both agreed the decision to submit the paper, and RM took final responsibility for the submission.

Results

We noted that people with greater exposure to green space were more likely to be less deprived than were those with little exposure to such areas (r^2=–0·28, p<0·0001). However, with such a large study, we still had a substantial population who were exposed to each possible combination of deprivation and green space. The smallest population group was that living in areas that were classified as the most deprived (income-deprivation quartile 4) and the most green (group 5 of exposure to green space) (table).

Figure 1 shows the independent relation between group of exposure to green space and all-cause mortality, after control for confounding factors and income-deprivation quartile. It shows a clearly lower mortality incidence rate ratio (IRR) for populations in higher groups of exposure to green space (webappendix). Results were much the same for deaths from circulatory disease, but associations were very weak or insignificant for deaths from lung cancer and intentional self-harm (webappendix).

See Online for webappendix

We detected a significant interaction between income deprivation and exposure to green space in the relation with deaths from all causes (p<0·0001) and from circulatory disease (p=0·0212). We used the Wald test for interaction because the more conventional log likelihood ratio test is inappropriate for models with robust standard errors). These results meant that the association between income deprivation and mortality differed significantly across the groups of exposure to green space (figure 2). The IRR for all-cause mortality for the most income-deprived quartile versus the least deprived was 1·93 (95% CI 1·86–2·01) in least green areas, whereas

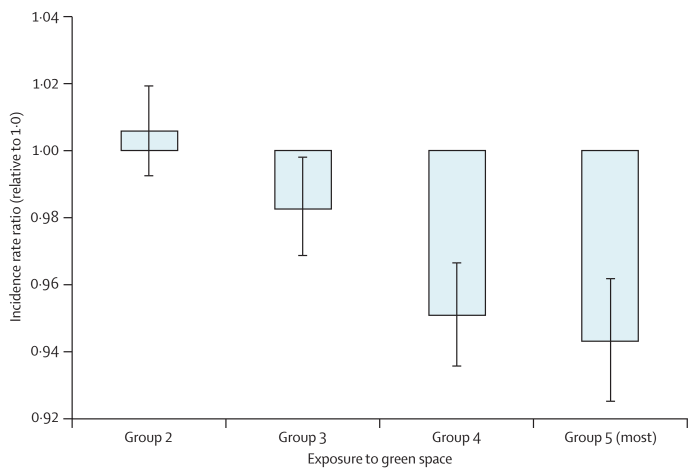

***Figure 1:* Incidence rate ratios for all-cause mortality in groups of exposure to green space, relative to group 1 (least exposure to green space)**
Error bars indicate 95% CIs.

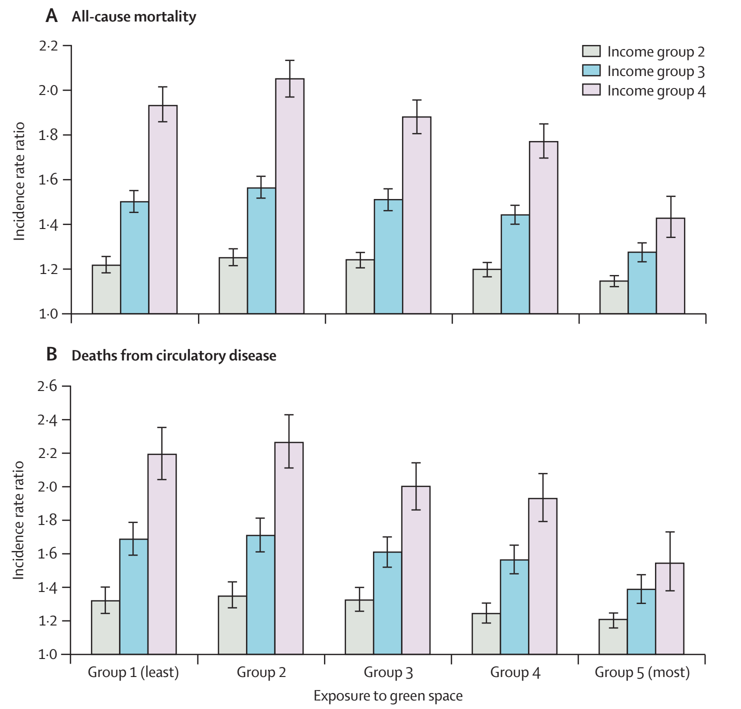

Figure 2: **Incidence rate ratios for all-cause mortality (A) and deaths from circulatory disease (B) in income-deprivation quartiles 2–4, relative to income deprivation quartile 1 (least deprived), stratified by exposure to green space**
Bars are grouped according to population exposure to green space. Error bars indicate 95% CIs.

it was 1·43 (1·34–1·53) in the most green. For circulatory diseases, the IRR was 2·19 (2·04–2·34) in the least green areas and 1·54 (1·38–1·73) in the most green.

Figure 2 shows the classic income-related gradient in mortality; populations living in areas of successively worse income deprivation had increasingly high rates of mortality. We recorded this gradient within each of the groups for exposure to green space. However, the steepness of the gradient, and thus the degree of inequality in mortality related to income deprivation, was lower for the populations with greater exposure to green space than for those with less exposure to such areas. When we compared the IRR for income-deprivation quartile 2 across groups of exposure to green space, we noted little difference; however, the magnitude of the IRR for income-deprivation quartiles 3, and particularly 4, was most reduced in populations who were exposed to more green space (figure 2).

We estimated that the lower inequality in mortality for the population with the highest exposure to green space saved 1328 lives per year in populations classified as in income-deprivation groups 2, 3, and 4 when compared with those in the same income-deprivation groups but in the lowest group of exposure to green space.

We noted no significant interaction between income deprivation and exposure to green space in the relation with deaths from lung cancer (p=0·0996) or intentional self-harm (p=0·1030). Thus the association between income deprivation and mortality did not differ across the groups of exposure to green space for these causes of death (webappendix). We recorded no substantive difference in the pattern of results when we excluded rural areas from our analyses (data not shown). This finding was unsurprising since our original models controlled for urban or rural classification and since almost all the LSOAs in England are classified as urban.

Discussion

Our study has shown that, in line with our hypothesis, the inequality in all-cause and circulatory disease mortality related to income deprivation is lower in populations who live in the greenest areas than in those who have less exposure to green space. We also noted an independent association between residence in the most green areas and decreased rates for all-cause and circulatory mortality.

Published work suggests that green space might affect health by inducing beneficial physical activity, and by ameliorating the response to stress. Of our three cause-specific mortality measures, circulatory disease showed the strongest attenuation of inequality in the greenest areas. Previous research has shown that the incidence of coronary heart disease varied by neighbourhood type and was independent of individual risk factors, lending support to the idea that the physical environment of area of residence could be important for risk of circulatory disease.[38]

Physical inactivity and response to stress are components of the cause of circulatory disease,[30,39,40] and reduction of these factors might have contributed to the lower inequalities that we recorded in greener areas. Amelioration of stress via access to green space is also perhaps one means by which smoking rates, and thus rates of lung cancer, might be reduced in greener areas. However, this pathway seems rather tenuous and we have no direct evidence for it. Lung cancer is also only weakly associated with physical activity. The absence of strong pathways by which green space could affect lung cancer probably explains why the association between lung cancer and income deprivation did not differ significantly between groups of exposure to green space. Plausible reasons for why the inequality in intentional self-harm related to income deprivation might be modified by access to green space are difficult to establish. We were thus not surprised to record no significant difference in inequalities for deaths from intentional self-harm between groups of exposure to green space.

Which mechanism is most responsible for the effect of green space on mortality from circulatory disease is difficult to establish. Although published work on green space and health is perhaps more consistent in showing an amelioration of stress than in detecting an independent effect on levels of physical activity,[20] we are unaware of any studies that have firmly connected the restorative aspects of green environments to reduced risk of death from circulatory disease. By contrast, evidence suggests that physical activity is protective against these deaths.[41] Further research is needed to identify the mechanisms by which green environments might affect mortality from circulatory disease.

We undertook a highly powered population study with a simple approach, using robust health outcomes from reliable data sources. The study was hypothesis driven, and that hypothesis was based on findings from a large amount of research. However, the study did have several weaknesses. First, the measure of exposure to green environments was restricted. Although we knew the proportion of green space in the area of residence of people who had died, we had to assume that individuals living in areas with equal proportions of green space actually had equal access to that green space. Had appropriate data been available, we could have used a measure of distance to defined green spaces as a proxy for access, although we would still have had no data for whether populations living closer to a specified green space did actually access it to a greater extent. Furthermore, quality of green space could be a substantial determinant of use and activity within it,[42] and we had no data for quality. No national dataset describing the quality of green space to which the population has access in England is available.

Second, our data were cross-sectional. We had no means of knowing the extent to which individuals had access to green environments throughout their life. Migration before death (eg, to access residential care) could have placed some people into a distinctly different environment from that in which their disease was acquired or developed. If such migration varied by income group, our results could be affected. Since we have no data for migration patterns, we were unable to quantify the effect of this factor.

Third, and perhaps most importantly, the measure of green space might be associated with other risk factors that we have not controlled for in our models. One of the difficulties of exploring the effect of physical environments on health is that access to good physical environments is strongly associated with the socioeconomic position of individuals. Residual confounding is therefore a threat to studies of this type. However, our study was large enough to contrast areas with similar levels of income deprivation but different amounts of exposure to green space; our study included nearly 400 000 people who lived in an area classified as being in the most green, but most deprived group. We had strict additional control for other indicators of socioeconomic deprivation and other aspects of natural environment, including air pollution. Some types of green environments might reduce the amounts of air pollution to which users are exposed,[43] and air pollution is well known to contribute to both respiratory and cardiovascular morbidity.[44] We might have controlled for one potential pathway by which green spaces affect health and, thus, our results could have been conservative. However, natural environments vary in their capacity to remove air pollution, and in the absence of detailed data for both type of green space and relative action on air pollution, we preferred to use this conservative approach.

Our decision to model different causes of death for which there are established socioeconomic inequalities, but for which the causes are different, kept confounding to a minimum. Had we recorded the same variation in income-deprivation inequalities across groups of exposure to green space for all these outcomes, the results would have suggested that the groups of exposure to green space were really just another way to identify more or less wealthy populations. Our stratified study design, in which exposure to green space varied, offers the best possible protection against the effect of residual confounding in a study of this type.

In conclusion, in studies that compare income-related gradients between different types of societies, much is made of the potential effect of different health-care and other social-welfare systems, or of the relative distribution of income within societies. We have shown substantial differences in health inequality between populations who are exposed to the same welfare state, health service, and national income distribution but who are resident in different types of physical environment.

Evidence suggests that interventions in the physical environment are highly effective at affecting health and health behaviours. Environmental interventions have, for example, been shown to be more successful in affecting rates of physical activity than have those based on information or media campaigns.[45] However, the notion that different types of physical environment might have an effect on health inequalities is novel.

Macintyre[46] comments that the interventions most likely to have an effect on inequalities within populations are those that operate upstream, at a societal or population level, rather than at an individual level. This includes changing the environment in which people live. In this study, we have shown that populations exposed to greener environments also enjoy lower levels of income-related health inequality. Conversely, populations exposed to less green environments could be less protected from health inequality related to income deprivation, which might have ramifications for countries in which urbanisation remains a strong force. The implications of the study are clear: environments that promote good health might be crucial in the fight to reduce health inequalities.

Contributors

RM and FP participated in the design, analysis, and writing of this study and have seen and approved the final version.

Conflict of interest statement

Since this paper was submitted, RM has begun a new and separate study that is funded by the GB Forestry Commission (FC) (a publicly funded organisation). The submitted study was not funded by the FC and it did not take place when RM was receiving funds from the FC for any other research. FP declares that he has no conflict of interest.

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