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

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Abstract

BACKGROUND

The persistence and growth of socio-economic inequalities in health continues to command attention. Studies demonstrate that exposure to natural environment, or 'green space' has an independent influence on health and health-related behaviours. Our hypothesis was that income-related inequality in health would be less marked among populations with greater exposure to green space because it has the potential to modify pathways via which lower socio-economic position can lead to disease.

METHODS

The population of England at below retirement age (*n*=40,813,236) was classified into area-based income deprivation and green space exposure groups. We determined whether the association between income deprivation, all-cause and cause specific mortality (circulatory disease, lung cancer and intentional self harm) 2001-2005, varied by green space exposure measured in 2001, controlling for potential confounders. Stratified models then determined the nature of this variation.

FINDINGS

The association between income deprivation and mortality differed significantly across the green space exposure groups for mortality from all causes ($p < 0.0001$) and circulatory disease ($p = 0.0212$), but not from lung cancer or intentional self harm. Income deprivation related health inequalities in all-cause mortality and mortality from circulatory diseases were lower among populations resident in the most green areas. The incidence rate ratio (IRR) for all cause mortality for the most income deprived quartile compared to the least deprived was 1.93 (95% CI 1.86-2.01) in least green areas while 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. The absence of an effect for causes of death with aetiologies unlikely to be influenced by green space supports our hypothesis.

INTERPRETATION

Populations exposed to greener environments also enjoy lower levels of income deprivation related health inequality. Physical environments which promote good health may be important in the fight to reduce socio-economic health inequalities.

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

BACKGROUND

The persistence and growth of socio-economic health inequalities continues to command the attention of researchers, clinicians and politicians (1-4). Several studies have explored how socio-economic inequalities in health vary from society to society, as a means of trying to establish what kinds of social and economic policies might lead to smaller health inequalities(5-8). Elsewhere in public health research, there is growing interest in how social and physical environments may interact to affect health, both in a salutogenic (i.e. health improving) and pathogenic sense (see (9;10) for example). In this paper, we combine these strands of research to explore how socio-economic inequalities in health differ among those exposed to contrasting physical environments.

The role which natural environments, or 'green spaces' may play in influencing health and health-related behaviour has received considerable 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, for example, parks, forests, playing fields and river corridors. There is a considerable amount of evidence that contact with such environments has independent salutogenic effects (20). Green spaces independently promote physical activity for example (17;21). Importantly, physical activity in such environments may have greater psychological and physiological benefits than physical activity in other settings (22;23). However, the influence of green space is not solely based on promotion or enhancement of physical activity. A number of studies have shown that contact (either by presence or visual) with green spaces may be psychologically and physiologically 'restorative', reducing blood pressure and stress levels (13;22), and may promote faster healing in patients post-surgical intervention (24).

Whilst many studies demonstrate that natural environments enhance health or encourage healthy behaviours, and a few examine variation in these effects by socio-economic status (11;15;18), the potential role for access to green environments to influence socio-economic *inequality* in health at a population level has, as far as we are aware, received no attention.

Our hypothesis was that socio-economic inequalities in health will be less marked among people with greater exposure to green space. The reason for this hypothesis is that some significant pathways through which lower socio-economic position may lead to worse health are potentially modified by exposure to green space. We know, for example, that those in lower socio-economic positions are less likely to exercise (25) and this is partly because the environments in which they live are less conducive to it (26). Indeed, evidence for the relationships between socio-economic status and green space suggests that, whilst more deprived populations may be less likely to have access to it (by virtue of residential location or transportation disadvantage), socio-economic position itself does not independently influence use of green space if it is readily available (18). Thus, relatively disadvantaged populations that do have access to green space might be expected to accrue health benefits from using it (perhaps to a greater degree than any physical activity in other settings (22;23)), and therefore potentially enjoy better health relative to 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 concerns the physiological responses to the stress of poverty which are implicated in elevated 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, reducing their mortality rates relative to those without access to green space. It therefore follows that we would expect inequalities in health to be lower for populations exposed to green space in causes of death for which there is an aetiological pathway on which green space might plausibly exert influence.

These ideas prompted our research question;

“Does the magnitude of income-related health inequality vary by exposure to green space?”

METHODS

Study design

We compared income-related health inequality among populations resident in areas of England characterised by relatively higher and lower levels of green space, adjusting for other potentially confounding characteristics of the areas. We selected causes of death with contrasting aetiologies in order to better test our hypotheses and guard against residual confounding.

Data

Data describing the quantity of green space in an area were obtained from the Generalised Land Use Database (GLUD) 2001 (32). The GLUD classifies land use in England into nine categories, one of which is 'green space'. This includes parks, other open spaces and agricultural land, but excludes domestic gardens. Classification is accurate to $10m^2$. Areas of green space with a coverage of less than $5m^2$ are ignored in this data set; single or small clumps of trees on a street would not be included for example. We used Lower Level Super Output Areas (LSOA) as our geographical units and calculated the percentage of each LSOA's land area classified as green space. LSOAs are a geographic unit used for reporting small area statistics in England (http://www.statistics.gov.uk/geography/soa.asp). The 32,482 LSOAs have a minimum population of 1000, a mean population of 1500 and an average physical area of 4 km. We classified the English population into five 'exposure' groups, based on the proportion (quintile) of green space in their LSOA of residence. Thus, each exposure group contained about 20% of the study population (see table 1).

Table 1: Study population size, stratified by green space exposure group and by income deprivation group

	Green space exposure group					
Income deprivation group	1	2	3	4	5	Total
1	1,497,663	1,512,733	1,756,134	2,503,755	3,716,717	10,987,002
2	1,757,904	1,617,400	1,720,964	2,080,000	2,891,637	10,067,905
3	2,291,828	2,033,620	2,025,834	1,821,320	1,161,087	9,333,689
4	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

Anonymised, individual mortality records were obtained from the Office for National Statistics (ONS). The records covered every death registered and matched to an LSOA in England, 2001 – 2005, and provided the age at death, sex, cause of death (ICD10) and LSOA of residence. Age group and sex specific population estimates were obtained at LSOA level from ONS. The age groups by which these estimates were structured were slightly different for men and women in that they reflected different retirement ages (women's being 60 and men's 65). We excluded population older than retirement age because inequalities in mortality tend to be maximised in the working age population. This provided a total study population of 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: I00-I99, *n*=90,433), partly because they have marked socio-economic inequalities, but primarily because some important associated risk factors (sedentary lifestyle and psychosocial stress) may be particularly ameliorated by green environments. To contrast with circulatory disease we selected two other causes of death which also have marked socio-economic inequalities but different risk factors and aetiology. Inequalities in death from lung cancer (C34, *n*=25,742) are largely driven by smoking and relatively weakly related to physical activity (33). Deaths from intentional self harm (X60-X84, *n*=12,308) also have an aetiology which differs greatly from circulatory disease and lung cancer. We anticipated that contrasting results for these different causes of death would help us test our hypothesis and, as we expand upon in the discussion, they were also a guard against residual confounding.

Data on income for the population were not routinely available. Instead, we followed others (34) and utilised the income deprivation domain of the 2004 English Index of Multiple Deprivation (EIMD). This index represented the proportion of the population in an area living in low income families 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 1).

We used other domains of the EIMD to adjust for area characteristics which 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 it is plausible that 'greener' places are also 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 green space types and accessibility, between more and less urban areas.

Analyses

We first examined associations between green space exposure and income deprivation to determine if there was sufficient variation in exposure to green space among the most deprived population to warrant testing our hypothesis. We then established, in a negative binomial regression model (which models the count of deaths), that there was an independent association between green space exposure group and all-cause mortality after control for the confounding factors described above. Population size was included 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 green space exposure group. This was achieved using interaction terms for income deprivation and green space exposure group. The exact nature of significant interactions was subsequently unpacked in a sequence of models stratified by green space exposure group, i.e. the first model explored the association between income deprivation quartile and mortality for those in the lowest green space exposure group, the second model explored the same association for those in the next lowest green space exposure group, 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/rural classification. To be certain our results were not simply reflecting urban / rural differences in lifestyle or other aspects of environment, we re-ran models on urban areas only. Models for lung cancer excluded those aged less than 15 because there were too few deaths at these ages. All models took account of the clustering of observations within areal units via robust estimates of variance (36;37). Stata version 10 was used for the analysis.

Role of the funding source

This research was carried out without direct funding. The design, analysis, interpretation and writing of the report were free from the influence of any funder. RM, as corresponding author had full access to all data in the study. RM and FP both agreed the decision to submit the paper and RM took final responsibility for the submission.

RESULTS

There was an association between green space exposure and income deprivation quartile such that those with greater exposure to green space were more likely to be less deprived (r^2 = -0.28, p<0.0001). However, with such a large study, we still had a substantial population exposed to each possible combination of deprivation and green space. The smallest population group was that living in areas classified as income deprivation quartile 4 (the most deprived) and green space exposure group 5 (the most green). There were 396,989 people in this group.

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

[Figure 1: Incidence rate ratios (with 95% confidence intervals) for all-cause mortality in green space exposure groups, relative to group 1 (least green space exposure)]

We detected significant interaction between income deprivation and green space exposure in the relationship with deaths from all-causes and from circulatory disease, (Wald test on the interaction terms, $p<0.0001$ for all-cause mortality, $p=0.0212$ for deaths from circulatory disease (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 green space exposure groups. The nature of this difference is illustrated in figures 2 and 3.

Figure 2 shows how the association between all-cause mortality and income deprivation quartile, varied across green space exposure group. It shows IRR for areas classified as being in income deprivation quartiles 2 to 4, all relative to income deprivation quartile 1 (the least deprived) fixed at a value of 1.0. The bars are grouped according to population exposure to green space. Figure 3 shows how the association between circulatory disease mortality and income deprivation quartile varied across green space exposure group.

[Figure 2: Incidence rate ratios (with 95% confidence intervals) for all-cause mortality in income deprivation quartiles 2-4, relative to income deprivation quartile 1 (least deprived), stratified by green space exposure group]

[Figure 3: Incidence rate ratios (with 95% confidence intervals) for deaths from circulatory disease in income deprivation quartiles 2-4, relative to income deprivation quartile 1 (least deprived), stratified by green space exposure group.]

In both figures 2 and 3 we see the classic income-related 'gradient' in mortality; populations living in areas of successively worse income deprivation experience higher mortality rates. This gradient was seen within each of the green space exposure groups. However, the steepness of the gradient, and thus the degree of income deprivation related inequality in mortality, was lower for the populations with greater exposure to green space. When we compared the IRR for income deprivation quartile 2 across the green space exposure groups, there was relatively little difference; it was the magnitude of the IRR for income deprivation quartiles 3, and especially 4, which was most markedly reduced among those exposed to more green space.

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

We found no significant interaction between income deprivation and green space exposure in the relationship with deaths from lung cancer (interaction p=0.0996) or intentional self-harm (interaction p=0.1030). This means that the association between income deprivation and mortality did not differ across the green space exposure groups for these causes of death. There was no substantive difference in the pattern of results when excluding rural areas from the analyses. This was unsurprising since our original models controlled for urban/rural classification and the vast majority of the LSOAs in England are classified as urban (data not shown).

DISCUSSION

Key Findings

The key finding is that, in line with our hypothesis, the income deprivation related inequality in all-cause and circulatory disease mortality is lower among populations resident in the most green areas. A secondary finding is an independent association between residence in the most green areas and lower all-cause and circulatory mortality rates.

The literature suggests that green space may influence health by inducing physical activity, by making that physical activity particularly beneficial, and by ameliorating stress-response. Of our 3 cause-specific mortality measures, circulatory disease showed the strongest attenuation of inequality in the greenest areas. Previous research found that coronary heart disease incidence varied by neighbourhood type independent of individual risk factors, supporting the idea that the physical environment of area of residence may be important for circulatory disease risk (38).

Physical inactivity and stress-response are components of the aetiology of circulatory disease (30;39;40) and their reduction may have contributed to the lower inequalities in greener areas. Amelioration of stress via access to green space is also perhaps one means by which smoking rates, and thus lung cancer rates might be reduced in greener areas. However, this seems a rather tenuous pathway and one for which we have no direct evidence. Lung cancer is also only weakly associated with physical activity. The lack of strong pathways by which green space could influence lung cancer probably explains why the association between lung cancer and income deprivation was not significantly different between green space exposure groups. It is also difficult to establish plausible reasons why the income deprivation related inequality in intentional self-harm might be modified by access to green space. We were thus not surprised to see no significant difference in inequalities for deaths from intentional self-harm between green space exposure groups.

It is difficult to disentangle the mechanisms by which green space influences health is most responsible for the impact on mortality from circulatory disease. Whilst the literature on green space and health is perhaps more consistent in demonstrating an amelioration of stress than it is in detecting an independent influence on physical activity levels (20), we are not aware of any studies that have firmly connected the restorative aspects of green environments to reduced risk of death from circulatory disease. In contrast, evidence abounds that physical activity is protective against these deaths (41). More research is needed to unpack the mechanisms by which green environments may influence mortality from circulatory disease.

Strengths and weaknesses

This was a highly powered population level study with a simple approach, using robust health outcomes from reliable data sources. The study was hypothesis driven, and that hypothesis was rooted in findings from a large body of research.

However, the study did have several weaknesses. First, the measure of exposure to green environments was limited. Whilst we knew the proportion of green space in the area of residence of the deceased, we were forced to assume individuals resident in areas with equal proportions of green space actually had equal access to that green space. Had appropriate data been available, an alternative design might have been to use a measure of distance to defined green spaces as a proxy for access, though we would still have had no data on whether populations living closer to a specified green space did actually access it to a greater extent. Furthermore, quality of green space may be a significant determinant of use and activity within it (42) and we had no data on quality. There is currently no national level data set describing the quality of green space to which the population has access in England.

Secondly, these were cross-sectional data. We had no means of knowing the degree to which individuals had access to green environments across their life course. It is also possible that, for some, migration prior to death (to access residential care for example) placed them into a distinctly different environment from that in which their disease was acquired or developed. If such migration varied by income group it could influence our results. As we lack data on migration patterns it was not possible for us to quantify the impact.

Thirdly, and perhaps most important, the measure of green space may be associated with other risk factors for which we have not controlled in our models. One of the difficulties of exploring the influence of physical environments on health is that access to better physical environments is strongly associated with individual level socio-economic position. Residual confounding is therefore a threat to studies of this kind. However, our study was large enough to contrast areas with similar levels of income deprivation but different levels of green space; there were still nearly 400,000 people in our study who lived in an area classified as being in the most green, but most deprived group. We had strict additional control for other markers of socio-economic deprivation and other aspects of natural environment, including air pollution. Some types of green environments may reduce the levels of air pollution to which users are exposed (43), and air pollution is a well-documented contributor to both respiratory and cardiovascular morbidity (44). It is possible that we controlled for one potential pathway by which green spaces influence health and, thus, our results may have been conservative. However, natural environments vary in their capacity to remove air pollution and in the absence of detailed data on both green space type and relative action on air pollution, we were more comfortable with this conservative approach.

By choosing to model different causes of death in which there are established socio-economic inequalities, but for which the aetiologies are different, we have also guarded against the influence of confounding. Had we observed the same variation in income deprivation inequalities across green space exposure groups for all these outcomes, that would have suggested that the green space exposure groups 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 influence of residual cofounding in a study of this kind.

CONCLUSION

In studies which compare income-related gradients between different kinds of societies, much is made of the potential influence of different healthcare and other social welfare systems, or of the relative distribution of income within each society. In this study we have shown marked differences in health inequality between populations exposed to the same welfare state, health service and national level income distribution but who are resident in different types of physical environment.

Evidence abounds that interventions in the physical environment are highly effective at influencing health and health-behaviours. Environmental interventions have, for example, been shown to be more successful in influencing physical activity rates than those based on information or media campaigns (45). However, the notion that different kinds of physical environment might have an influence on health inequalities is novel.

In a recent report (46), Macintyre comments that the interventions most likely to have an impact on population-level health inequalities are those which operate ‘upstream’, including those altering the environment in which people live. In this study we have showed that populations which are exposed to greener environments also enjoy lower levels of income-related health inequality. Conversely, populations exposed to less green environments may be less protected from income deprivation related health inequality and this may have ramifications for countries in which urbanisation remains a strong force. The implications of the study are clear; environments which promote good health, may be key in the fight to reduce health inequalities.

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Contributions and Conflicts of interest

I, Richard Mitchell declare that I participated in the design, analysis and writing of this study and that I have seen and approved the final version.

I, Frank Popham declare that I participated in the design, analysis and writing of this study and that I have seen and approved the final version.

Since this paper was submitted, Mitchell has begun a new and separate study which is funded by the Forestry Commission (FC) (a publicly funded organisation). The submitted study was not funded by the FC and it did not take place when Mitchell was receiving funds from the FC for any other research.

Popham has no conflicts of interest to declare

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Figures

Figure 1: Incidence rate ratios (with 95% confidence intervals) for all-cause mortality in green space exposure groups, relative to group 1 (least green space exposure)

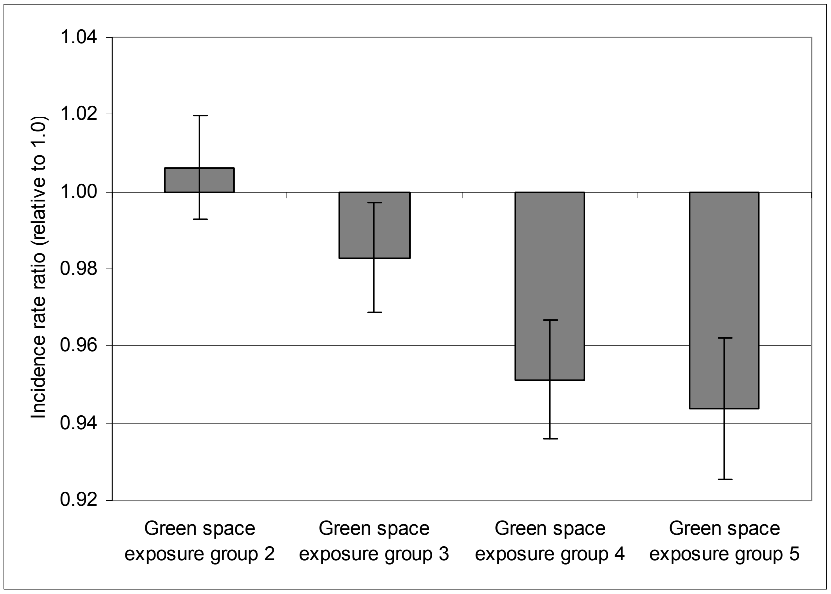

Figure 2: Incidence rate ratios (with 95% confidence intervals) for all-cause mortality in income deprivation quartiles 2-4, relative to income deprivation quartile 1 (least deprived), stratified by green space exposure group

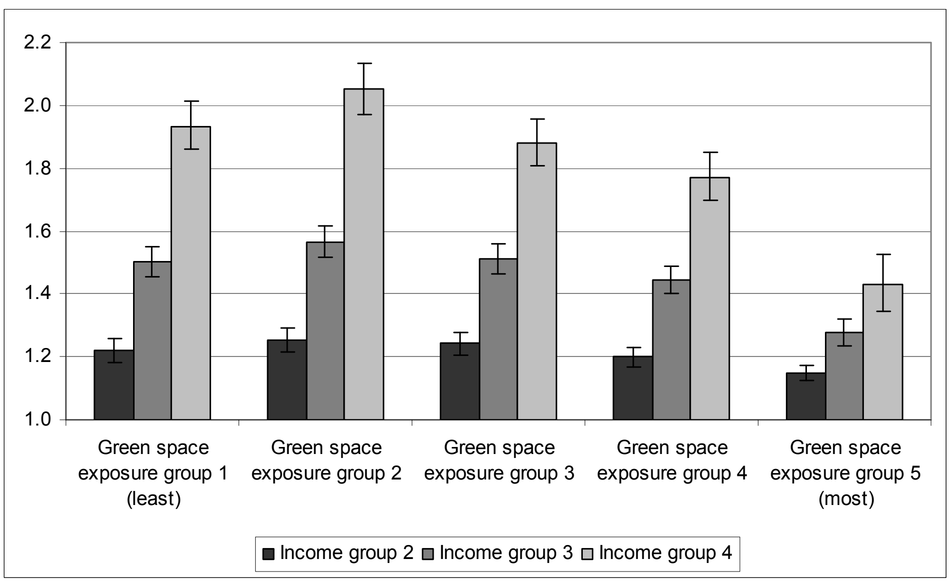

Figure 3: Incidence rate ratios (with 95% confidence intervals) for deaths from circulatory disease in income deprivation quartiles 2-4, relative to income deprivation quartile 1 (least deprived), stratified by green space exposure group.