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Research Paper

The impact of urbanisation on nature dose and the implications for human health

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ABSTRACT

The last 100 years have seen a huge change in the global structure of the human population, with the majority of people now living in urban rather than rural environments. An assumed consequence is that people will have fewer experiences of nature, and this could have important consequences given the myriad health benefits that they can gain from such experiences. Alternatively, as experiences of nature become rarer, people might be more likely actively to seek them out, mitigating the negative effects of urbanisation. In this study, we used data for 3000 survey respondents from across the UK, and a nature-dose framework, to determine whether (a) increasing urbanisation is associated with a decrease in the frequency, duration and intensity of nature dose; and (b) differences in nature exposure associated with urbanisation impact on four population health outcomes (depression, self-reported health, social cohesion and physical activity). We found negative exponential relationships between nature dose and the degree of urbanisation. The frequency and duration of dose decreased from rural to suburban environments, followed by little change with further increases in urbanisation. There were weak but positive associations between frequency and duration of dose across all four health domains, while different dimensions of dose showed more positive associations with specific health domains in towns and cities. We show that people in urban areas with a low nature dose tend to have worse health across multiple domains, but have the potential for the greatest gains from spending longer in nature, or living in green areas.

1. Introduction

The global urban population has risen dramatically over the last 100 years, with rural-to-urban migration responsible for the majority of this growth (United Nations, 2014). This shift is predicted to continue, with 60% of people estimated to be residing in cities by 2030 (United Nations, 2014). The move from rural to urban environments affects people's lives in many ways. Some of these effects are positive, with urbanisation supporting, for example, economic growth and development along with a range of beneficial social outcomes (Dye, 2008). At the same time, cities are crowded, polluted and more stressful than rural areas (Dye, 2008), and the competition for space means there is little room for nature. This, in combination with increasingly busy modern lifestyles, may be leading to a decline in experiences of the natural world (Hartig & Kahn, 2016; Soga & Gaston, 2016).

Any decline in experiences of nature associated with an urbanising population could lead to a reduced knowledge of, and support for, environmental issues (Miller, 2005; Pyle, 1978; Soga & Gaston, 2016). Arguably more pressingly, urbanisation is now considered one of the most important health challenges of the 21st q (World Health Organization, 2015), being associated with an increase in chronic and non-communicable conditions such as obesity, stress, poor mental health and a decline in physical activity (Dye, 2008). The decline in experiences of nature could be a direct contributor to these issues given the breadth of health and wellbeing outcomes that have been associated with nature exposure. This includes reduced all-cause mortality and mortality from cardiovascular diseases (Donovan et al., 2013; Mitchell & Popham, 2008), improved healing times (Ulrich, 1984), reduced respiratory illness and allergies (Hanski et al., 2012; Lovasi, Quinn, Neckerman, Perzanowski, & Rundle, 2008), improved self-reported

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well-being and a reduced risk of poor mental health (Cox et al., 2017b; Dallimer et al., 2012; Fuller, Irvine, Devine-Wright, Warren, & Gaston, 2007), and improved cognitive ability (Berman, Jonides, & Kaplan, 2008; Han, 2009). Understanding how experiences of nature change with urbanisation, and how this affects health and well-being, is a critical knowledge gap that will assist in planning for an increasingly urban future.

A widely held assumption is that population movement from rural to urban landscapes will inevitably result in a decline in experiences of nature (Turner, Nakamura, & Dinetti, 2004; Zhang, Goodale, & Chen, 2014). However, this may not necessarily be the case. In the UK, for example, 87% of households have access to a domestic garden (Davies, Fuller, Loram, Irvine, Sims, & Gaston, 2009), and policy recommends that every home should be within 300 m of an accessible natural green space (Natural England, 2008). This might suggest that most people should be able to maintain some exposure to nature. However, the social landscape of urban environments is infinitely complex. Exposure to nature has an important behavioural component with people choosing how often and how long they interact with the natural world (Shanahan, Fuller, Bush, Lin, & Gaston, 2015b). A number of studies have now demonstrated that access to nature alone is insufficient to determine or predict its use - instead, factors such as feelings of connectedness to nature or socio-demographics are much stronger indicators (e.g. Lin, Fuller, Bush, Gaston, & Shanahan, 2014; Shanahan et al., 2017; Shanahan, Lin, Bush, Gaston, & Fuller, 2014). Understanding the differences in nature experiences between rural and urban populations will be a key step in unpicking exactly how urbanisation affects experiences of nature.

A nature-dose framework distinguishes three dimensions of nature exposure, namely its frequency (how often), duration (how long) and intensity (how much; Shanahan et al., 2015a). Each element of exposure is likely to be mechanistically tied to different types of health and wellbeing outcomes. For example, spending time in your garden just once per week is associated with reduced levels of depression (Cox et al., 2017a), and similarly visiting a public park for just 30 min a week is linked with reduced levels of depression and of high blood pressure (Shanahan et al., 2016). The mechanistic pathway to these outcomes may be associated with attention restoration, where mental fatigue is relieved by undemanding nature experiences. Higher levels of vegetation around the home has also been associated with better mental health (Cox et al., 2017b); this may be driven by greater incidental exposure on a day-to-day basis. Intuitively, incidental nature exposure will be greater in rural areas because of the greater variability of and access to greenspaces. While this has been attributed, in part at least, to explaining rural-urban differences in health (Maas, Verheij, Groenewegen, de Vries, & Spreeuwenberg, 2006), this premise has not been tested. One possibility for a difference in nature associated health outcomes between rural and urban areas is not the time that people intentionally interact with nature, but that incidental nature exposure is higher in rural areas, and this might influence the health gains across different dimensions of dose.

In this study, we first explore the differences in exposure to nature between populations of people living in rural to increasingly urbanised environments. Is urbanisation really associated with decreasing nature dose? Second, we examine the differences in health outcomes for these populations, considering exposure to nature as a key potential predictor. Do any apparent differences in exposure to nature associated with urbanisation impact on population health? To address these questions, we used data from c.3000 survey respondents across the UK, measuring the frequency and duration of nature dose as time spent in their garden or public green spaces, and intensity of dose as the quantity of vegetation around the home. We focused on the association of nature with four domains of health for which there are plausible mechanistic pathways linking nature exposure to health, including mental (Berman et al., 2012; Bratman, Hamilton, Hahn, Daily, & Gross, 2015), physical (Salmond et al., 2016; Shanahan et al., 2015b) and social Weinstein et al., 2015) wellbeing, and physical activity (Richardson, Pearce, Mitchell, & Kingham, 2013; for a fuller description of mechanistic pathways see Shanahan et al., 2016).

2. Materials and methods

2.1. Study design

We surveyed 3000 people across the UK, aged 18–70 years to obtain information on health and experiences of nature. This survey was delivered online through a market research company (Surveygoo Ltd) to their existing market research database of potential respondents. The survey was administered over a two-week period in May 2016 as this is a time of reasonably mild (spring) weather when respondents are more likely to engage with nature. For a full copy of the survey see Shanahan et al. (2016). Participants provided written consent at the beginning of the online survey, and were compensated with a nominal fee. The survey was stratified to ensure equal numbers of respondents living in a rural and an urban setting, by first asking 'do you consider your home to be in a rural or urban setting?' Once 1,500 surveys were completed in each category, any further respondents in the same category were unable to continue with the survey. The survey took approximately 20 min to complete, nature dose questions were asked before health questions to avoid any potential priming effects of a person's stated health status on self-reported nature dose (e.g. see Schwarz & Oyserman, 2001). The survey assessed: 1) respondents' weekly doses of nature, 2) their orientation towards nature, 3) measures of health across multiple domains, and 4) socio-demographic information. Respondents were requested to provide a full UK postcode so that their neighbourhood could be characterised (one UK postcode covers approximately 20 households).

2.2. Doses of nature

Each respondent generated three measures of nature dose: frequency and duration (time spent in their garden and public green spaces) and intensity (quantity of neighbourhood vegetation cover). Respondents were told that public green spaces included 'for example, parks, countryside, playgrounds, picnic areas or golf courses'.

Frequency of nature dose was estimated based on the respondents' self-reported frequency of more than ten minutes spent within their garden in the last week, and how frequently they passed through public green spaces. Survey respondents selected the usual frequency of garden use or public green space visitation from: never, less than once a week, once a week, 2–3 days a week, 4–5 days per week, 6–7 days per week. To estimate the number of visits a week the mid-points of selected categories were chosen, with $<$ once per week and never being assigned a score of 0. To estimate the frequency of garden and public green space visits we summed these two scores, to give a numeric scale of 0 to 13 visits a week.

Duration of nature dose was estimated based on self-reported total time spent within their garden and public green spaces within the last week. Survey respondents selected the total time spent in their garden in the last week from the categories of: no time, 1–30 min, 31 min to 1 h, $>$ 1–3 h, $>$ 3–5 h; $>$ 5–7 h, $>$ 7–9 h, $>$ 9 h. Duration of public green space visits was calculated as respondents were asked to name up to seven places they had visited for the longest period in the last week, and select from the following categories how long they spent there: no time, 1–30 min, 31 min to 1 h, $>$ 1–2 h, $>$ 2–3 h; $>$ 3–4 h, $>$ 4 h. To estimate the total duration that respondents intentionally visited green space in the previous week, the mid-points of selected categories were chosen before summing scores to give a numeric scale of 0–41.5 h per week.

Intensity of nature dose was measured as neighbourhood green cover within a 250 m buffer around the centroid of each respondent's postcode. This is the distance that was considered to influence what can be seen or experienced from a person's home on a day-to-day basis. Only those respondents who provided a full UK postcode were included in analyses involving this variable (n = 2920). We utilised the Landsat 8 land cover maps; this dataset includes the Normalised Difference Vegetation Index (NDVI) at a resolution of 30 m from across the UK (Hansen et al., 2013). The NDVI index for each pixel was examined, and a threshold of 0.2 separated vegetated (NDVI ≥ 0.2) from non-vegetated (NDVI < 2) pixels (Liang, 2004). We then calculated nature dose intensity, as the percentage of vegetated pixels within the 250 m buffer.

2.3. Orientation towards nature

Survey participants also completed the Nature Relatedness Scale Nisbet, Zelenski, & Murphy, 2009), which assesses individual differences in connections to nature (Tam, 2013). This scale requires participants to complete a series of questions that assess the affective, cognitive, and experiential relationship individuals have with the natural world (Nisbet et al., 2009). Participants rate 21 statements using a five-point Likert scale ranging from one (strongly disagree) to five (strongly agree). Responses to each of the 21 questions were scored and then the average was calculated according to the system outlined by Nisbet et al. (2009). A higher average score indicates a stronger connection with nature. The scale has been demonstrated to differentiate between known groups of nature enthusiasts and those not active in nature activities, as well as those who do and do not self-identify as environmentalists. It also correlates with environmental attitudes and self-reported behaviour and appears to be relatively stable over time and across situations (Mayer & Frantz, 2004; Nisbet et al., 2009).

2.4. Health response variables

Respondents provided self-reported information on four health domains.

Mental health (ordinal): A measure of depression was generated based on the depression component of the short version of the Depression, Anxiety and Stress Scale (DASS 21; Lovibond & Lovibond, 1995). On a four-point scale respondents rated the extent to which seven statements applied to them over the previous week. To calculate the degree of severity relative to the wider population, these scores were summed, before banding as normal (score 0–4), mild (score 5–6), moderate (score 7–10), severe (score 11–13), or extremely severe (score 14+).

Physical health (ordinal): Respondents scored their own general health on a five-point scale from very poor to very good (Subramanian, Huikts & Avendano, 2010). This scale is related to morbidity and mortality rates and is a strong predictor of health status and outcomes (Idler & Benyamini, 1997; Mossey & Shapiro, 1982).

Social cohesion (linear): Respondents' perceptions of social cohesion were estimated based on three previously developed scales that measure trust, reciprocal exchange within communities and general community cohesion (Bullen & Onyx, 1998; Sampson, Morenoff, & Earls, 1999; Sampson, Raudenbush, & Earls, 1997). The average score across questions for each scale was calculated, resulting in a continuous score from the highest (4) to lowest (0) perceived social cohesion. The average scores from each scale were then summed to provide a scale from highest (12) to lowest (0).

Positive physical behaviour (linear): Respondents provided a self-reported indication of physical activity, specifically the number of days they exercised for a minimum of 30 min (the duration recommended by the UK government; Department of Health, 2011) during the survey week.

2.5. Socio-demographic information

We collected information about socio-demographic variables that could influence decisions around green space use, including participant's age, gender, personal annual income, their highest qualification, the number of hours worked a week, and the primary language spoken at home. As a potential confounder of recent nature exposure, we asked respondents relatively how much time they spent outdoors in the previous week (see Table S1 for how these variables were classified for analysis). We obtained an estimate of the socio-economic disadvantage of the neighbourhood in which each respondent lived using the Index of Multiple Deprivation (IMD; Sharegeo.ac.uk, data sourced from Data.gov.uk). The IMD is an average of indices for separate domains of deprivation (e.g. income, employment, health deprivation and disability), and is provided at the postcode scale.

2.6. Rurality-urbanity

Two approaches were employed to measure the level of urbanisation surrounding a respondent's home.

Actual rurality-urbanity (linear): We used a vector layer of Edina Digimap (2016), the Ordnance Survey MasterMap Topography Layer (Updated Jan 2016), to calculate the number of building polygons within a 1 km buffer surrounding the centroid of a respondent's postcode. We then summed the area of these polygons, to calculate the percentage building cover within the buffer.

Perceived rurality-urbanity (ordinal): To unpick the perceived rurality or urbanity of the home, beyond the survey stratification of half the respondents living in rural and half in urban areas, respondents were asked 'on a rural to urban scale of 1 to 10, where do you place where you live? (where 1 is an isolated house in the country, 6 might be in the suburbs of a town and 10 is in the middle of a city; Fig. 1)'.

2.7. Analysis

All data extraction and analyses outlined here were performed in QGIS v2.14 (Quantum GIS Development Team., 2016) and in R v3.3 (R Core Team, 2016). First, we explored how each dimension of nature dose varied across the two measures of urbanisation. Of the dependent variables, nature dose frequency was approximately normally distributed (so no transformation was necessary for analyses), whilst nature dose duration was log-transformed and a logit function was applied to the proportion of nature dose intensity so that they were approximately normally distributed. We built Linear Models to examine

Fig. 1. Examples of perceived and actual urbanisation around the home: (A) remote house in country (score 1), building cover < 2%; (B) large village (score 4), building cover c.10%; (C) suburbs (score 7), building cover c.25%; (D) Inner city (score 10), building cover > 41%.

the relationship between each element of nature dose (as response variables) and potential predictors, including a measure of actual and perceived urbanisation, socio-demographic and life circumstance variables (See Table S1 for a full list of how the variables were included in the analysis). We fitted a quadratic function to the actual rurality-urbanity. We used the 'MuMIn' package (Bartoń, 2016) to produce all subsets of models based on the global model and rank them based on AICc. Following Richards (2005) and to be 95% sure that the most parsimonious models were contained within the best supported set, we retained all models where **ΔAICc** < 6. We then calculated averaged parameter estimates and standard errors using model averaging among the retained models (Burnham & Anderson, 2002).

Second, we examined relationships between each health outcome as a response variable and potential predictors, including measures of rurality-urbanity of the home, socio-demographic variables, self-assessment of health, social cohesion and physical activity (where the predictor variable was not also a response variable). We used cumulative link models for depression and self-assessment of health, linear regression for social cohesion and for physical activity (we square root transformed the physical behaviour response to make it approximately normally distributed). The frequency and duration of nature dose were correlated (significant Spearman's rank test correlation of 0.61), so to avoid issues associated with multicollinearity we generated four predictor model sets for each health response: i) rurality-urbanity and socio-economic variables (but excluding measures of nature dose); ii) rurality-urbanity and socio-demographic variables plus frequency of nature dose; iii) rurality-urbanity and socio-demographic variables plus duration of nature dose; iv) rurality-urbanity and socio-demographic variables plus intensity of nature dose. In models ii-iv for each health response we tested for an interaction between each measure of rurality-urbanity and nature dose. If the interaction was not significant it was dropped from the model. We then model averaged as above.

3. Results

The proportion of respondents living in each country within the U.K. was comparable with the wider population (Table S2). There was an overrepresentation of female respondents, of respondents earning < £10,399 per year, and of respondents who worked no hours a week (Table S2). Relative to the wider U.K. population there was an under-representation of respondents > 70 years and who considered themselves to be in very good health (Table S2). Across the neighbourhoods of all 3000 survey respondents there was an average vegetation cover of 65.5% (± 25.5% SD), and built cover of 13.2% (± 12.1% SD), with most respondents having access to a private garden (92.3%).

Quadratic regression outperformed higher order polynomial regression in describing the relationship between the three measures of nature dose and actual rural-urbanity. Nature dose frequency and duration were highest in rural areas, before steadily decreasing until urbanisation attained levels typically associated with the suburbs. Further increases in urbanity produced little or no change in nature dose (Table 1; Fig. 2). Nature dose intensity also decreased with increasing urbanisation, but with the relative decrease in dose slowing at higher levels of urbanisation (Table 1; Fig. 2). All three dimensions of nature dose increased with a respondent's age, but decreased with their social deprivation (Table 1). Finally, the frequency and duration of nature dose increased with nature orientation, in people who were retired, and with people who spoke a European language in the home, while dose duration and intensity increased with respondent's income (Table 1).

We found that population levels of depression increased with urbanisation, but so did physical health, while urbanisation did not influence social cohesion or physical behaviour (Table 2). There was a positive relationship between all four health outcomes and frequency and duration of nature dose (Table 2; Fig. 3). Frequent visits to green spaces in the more urbanised population were associated with further improvements to mental health, while the same respondents who spent longer in green spaces saw greater gains to their positive perceptions of social cohesion and positive physical behaviour (Table 2; Fig. 3). Finally, dose intensity was associated with increased positive perceptions of social cohesion, and this effect was more pronounced as urbanisation increased (Table 2; Fig. 3).

Table 1
The relationship between variation in three dimensions of nature dose, two measures of urbanity of the home, and socio-economic and lifestyle predictors. We show model averaged coefficients and standard errors of variables, coefficients of factors are shown relative to a comparative base factor (shown in brackets). The pseudo R^2 is 'McFadden's', boldface indicates statistical significance ($^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$). Education was not included in the top models for dose intensity.

Variables	Frequency	Duration	Intensity
	R^2 = 0.26	**R^2 = 0. 23**	**R^2 = 0.49**
Intercept	0.3 (0.7)	0.1 (0.2)	**3.4 (0.2)*** **
Age	**0.1 (0.03)*** **	**0.03 (0.006)*** **	**0.03 (0.009)*** **
Gender	−0.3 (0.1)*	0.02 (0.03)	−0.02 (0.05)
Income	0.07 (0.03)*	**0.03 (0.006)*** **	**0.03 (0.01)** **
Neighbourhood deprivation	**−0.2 (0.07)*** **	**−0.06 (0.02)*** **	**−0.2 (0.03)*** **
Nature relatedness	**2.0 (0.1)*** **	**0.4 (0.02)*** **	0.04 (0.04)
Language at home (English)			
Language at home (European)	**1.1 (0.3)*** **	**0.1 (0.06)* **	0.05 (0.1)
Language at home (Non-European)	0.1 (0.4)	0.06 (0.08)	0.03 (0.1)
Hours worked per week (No hours)	−0.07 (0.04)	0.005 (0.01)	−0.001 (0.01)
< 16 h	−0.4 (0.2)	**0.2 (0.06)** **	0.2 (0.1)
16–30 h	0.2 (0.2)	**0.1 (0.06)** **	0.2 (0.1)
31–45 h	0.3 (0.3)	0.5 (0.05)	−0.01 (0.08)
> 45 h	0.3 (0.3)	0.5 (0.08)	−0.07 (0.1)
Retired	**0.5 (0.2)* **	**0.2 (0.05) *** **	0.06 (0.09)
Education (No qualifications)			
Level 1	0.7 (0.03)	0.02 (0.08)	–
Level 2	0.5 (0.3)	0.01 (0.08)	–
Level 3	0.1 (0.3)	0.06 (0.07)	–
Level 4	0.2 (0.3)	0.06 (0.07)	–
Measure of urbanisation			
Built cover	**−0.1 (0.02)*** **	**−0.03 (0.004)*** **	**−0.1 (0.007)*** **
Built cover (^2)	**0.001 (0.0003)*** **	**3.4e−4 (6.6e−5)*** **	**0.0008 (0.0001)*** **
Perceived urbanity (score 1)			
Perceived urbanity (score 2)	−0.7 (0.6)	−0.1 (0.1)	−0.4 (0.2)
Perceived urbanity (score 3)	−0.1 (0.5)	−0.2 (0.1)	**−1.2 (0.2)*** **
Perceived urbanity (score 4)	**−2.0 (0.5)*** **	**−0.3 (0.1)** **	**−1.5 (0.2)*** **
Perceived urbanity (score 5)	**−1.9 (0.5) ** **	**−0.3 (0.1)** **	**−1.7 (0.2)*** **
Perceived urbanity (score 6)	**−2.4 (0.5)*** **	**−0.4 (0.1)*** **	**−1.7 (0.2)*** **
Perceived urbanity (score 7)	**−2.4 (0.5)*** **	**−0.4 (0.1)** **	**−1.8 (0.2)*** **
Perceived urbanity (score 8)	**−2.6 (0.6)*** **	**−0.4 (0.1)** **	**−1.9 (0.2)*** **
Perceived urbanity (score 9)	**−2.4 (0.6)*** **	**−0.5 (0.1)*** **	**−2.0 (0.2)*** **
Perceived urbanity (score 10)	**−2.3 (0.6)*** **	**−0.4 (0.1)*** **	**−2.4 (0.2)*** **

4. Discussion

We demonstrate that the environment around the home is an important predictor of nature dose, with people living in more rural areas

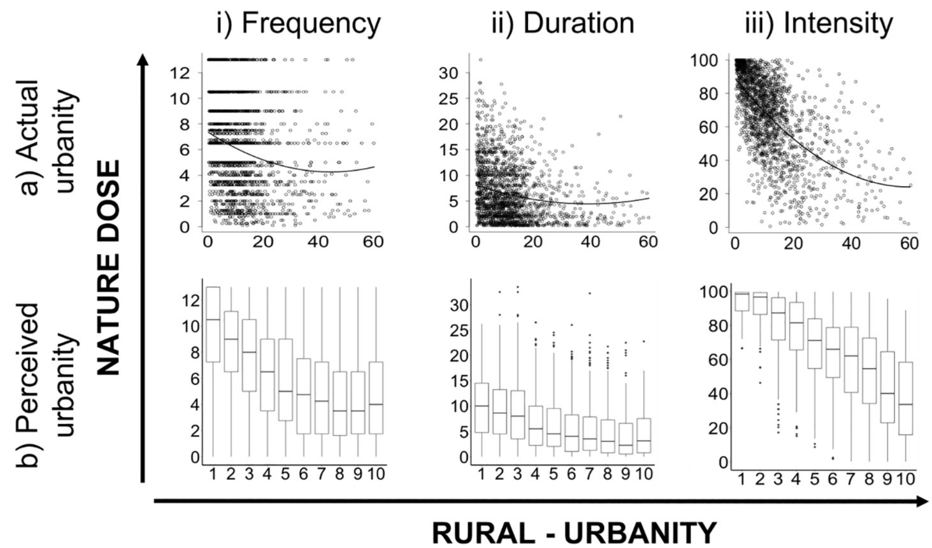

Fig. 2. The relationship between nature dose and two measures of urbanisation, (a) actual urbanity, percentage building cover around the home, (b) perceptions of urbanity, on a scale of 1 (rural) – 10 (inner city). The lines of best fit for actual urbanity control for socio-demographic and lifestyle variables.

tending to have more frequent weekly exposure to nature. Critically, once a certain level of urbanisation is met, there is no further change in nature dose across the population with increased urbanisation. Instead, a person's orientation towards nature was a key driver of the frequency and duration of nature dose, and improvements across three health domains. Second, we present differences in the health gains from dose dependent on the rurality to urbanity of the home. People in heavily built up neighbourhoods with a low nature dose tended to have worse mental health and lower perceptions of social cohesion, while also being less likely to engage in positive physical behaviour. However, these people also had the potential for the greatest gains from either more frequent visits to, or spending longer in, nature respectively. Heavily urbanised areas tend to have reduced levels of vegetation, therefore greening of these neighbourhoods is likely to produce the greatest improvements in people's perceptions of social cohesion.

4.1. Doses of nature around the home

Here we reveal that across all three dimensions of nature dose, namely frequency, duration and intensity, dose is greatest in rural areas. Dose then decreases with increasing housing density and perceptions of urbanisation, until people live in the equivalent of the suburbs of a medium sized town (approximately 20% building cover and a perceived urbanisation score of six). Beyond this level of urbanisation, dose intensity continues to decline, albeit at a slower rate. This did not translate to a parallel decline in the frequency or duration of dose. This downward trend of dose intensity is consistent with that found in other studies, though the nature of the relationship has varied. For example, Shanahan et al. (2017) show a similar curve between green space visitation and measures of tree cover, while Coldwell and Evans (2017) indicate a linear relationship between visitation and urbanisation; such differences could be caused by the use of different measures of urbanisation, and differences in city design. These relationships all suggest a strong behavioural component to engagement with nature. Indeed, an orientation towards nature was the strongest predictor of the frequency and duration of dose, accounting for almost two-thirds of the explained variance in the model ($pR^2 = 0.1$). In urban populations people with an increased nature orientation typically visit public green spaces and their gardens more regularly (Shanahan et al., 2017), travel further to do so (Lin et al., 2014) and are more likely to engage in resource provisioning for garden wildlife (Cox & Gaston, 2016; Cox & Gaston, 2018; Shaw, Miller, & Westcott, 2017). Further, in the second analysis we also found some evidence that an orientation towards nature was a predictor of better mental health, social cohesion and positive physical behaviour. This result held even after accounting for the potentially confounding effects of nature dose (Table 2). This may be an indication of the broader health benefits gained from a deeper connection to the natural world, with nature connectedness being positively associated with life satisfaction and happiness (Capaldi, Dopko, & Zelenski, 2014).

4.2. Urbanisation, nature dose and health

Our study provides further evidence of the health inequities between rural and urban environments in the UK. We found that people in more built up areas were more likely to perceive that they had better physical health, but were increasingly likely to suffer from depression compared with their rural counterparts (Table 2). People in urban areas generally have better access to health care, but are exposed to increased levels of pollution, overcrowding and stress which are known to impact negatively on mental health (e.g. Godfrey & Julien, 2005; Srivastava, 2009). We did not find associations between urbanisation and perceptions of social cohesion, or physical behaviour.

We found that people who choose to spend time in nature more often, and for longer are healthier across multiple dimensions of health. Our results add support to previous studies conducted on urban populations, that explored the relationships between nature dose and health (Cox et al., 2017a; Cox et al., 2017b; Shanahan et al., 2016; Soga, Cox, Yamaura, Gaston, Kurisu, & Hanaki, 2017), but importantly we show that it is also possible to detect these positive associations with health in more rural populations. We found that the benefits to physical health, social cohesion and improved physical behaviour from frequent visits to greenspaces occurred independent of the environment around one's home. This is important for population health, because it indicates that even people with less access to greenspaces can gain similar benefits from regularly spending time in nature, should they choose to do so. As an increasingly urbanised population wrestles with multiple demands on their time, behavioural health interventions are likely to be more successful in promoting short frequent visits to green spaces than longer ones. Importantly, on average respondents in more urbanised areas had poorer mental health than their rural counterparts, while those who visited green spaces more regularly had better mental health. It is therefore conceivable that an increased frequency of dose provides a protective factor against the increased stress and mental fatigue associated with urban living.

We demonstrate that although the duration of dose was positively

Table 2
The relationship between four health outcomes (the response variables), two measures of urbanisation around the home, socio-demographic covariates and nature experience predictor variables. Four models for each response variable are shown: (i) socio-demographics variables only; (ii) socio-demographic variables plus interactions between frequency of nature dose and urbanisation; (iii) socio-demographic variables plus interactions between duration of nature dose and urbanisation; (iv) socio-demographic variables plus interactions between intensity of dose and urbanisation. We show model averaged coefficients and standard errors of variables, coefficients of factors are shown relative to a comparative base factor (shown in brackets). The shown AICc is that of the top model. Boldface indicates statistical significance ($^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$).

Variables	Mental health	Physical health	Social cohesion	Physical behaviour
Model i)	*AICc: 5791.9*	*AICc: 7122.9*	*AICc*: 11777.3	*AICc: 7304.7*
Intercept	–	–	**3.0 (0.5)***	**−0.5 (0.2)**
Actual urbanity	**0.1 (0.04)***	**0.1 (0.04)***	0.03 (0.05)	0.006 (0.009)
Perceived urbanity (score 2)	0.1 (0.4)	0.02 (0.02)	0.2 (0.3)	−0.005 (0.007)
Perceived urbanity (score 3)	−0.4 (0.4)	−0.4 (0.6)	0.3 (0.3)	0.1 (0.1)
Perceived urbanity (score 4)	−0.4 (0.4)	−0.6 (0.6)	0.05 (0.3)	0.04 (0.1)
Perceived urbanity (score 5)	−0.2 (0.4)	0.3 (0.6)	0.2 (0.3)	0.03 (0.1)
Perceived urbanity (score 6)	−0.2 (0.4)	0.1 (0.6)	0.2 (0.3)	0.05 (0.1)
Perceived urbanity (score 7)	−0.1 (0.4)	0.3 (0.6)	−0.3 (0.3)	0.05 (0.1)
Perceived urbanity (score 8)	0.05 (0.4)	−0.1 (0.7)	−0.4 (0.3)	0.08 (0.1)
Perceived urbanity (score 9)	−0.1 (0.4)	0.6 (0.7)	−0.4 (0.3)	0.07 (0.1)
Perceived urbanity (score 10)	−0.6 (0.4)	0.6 (0.8)	−0.1 (0.3)	0.1 (0.1)
Age	**−0.2 (0.02)*****	**−0.1 (0.01)*****	0.03 (0.02)	**−0.04 (0.007)*****
Gender (male)	0.03 (0.08)	**−0.2 (0.08)****	**0.3 (0.1)****	**0.09 (0.04)****
Income	−0.02 (0.0)	**0.07 (0.02)*****	**0.1 (0.1)*****	**0.01 (0.006)***
Nature relatedness	**−0.16 (0.07)***	0.1 (0.06)	**0.6 (0.06)*****	**0.02 (0.007)*****
Neighbourhood deprivation	0.07 (0.04)	**−0.08 (0.04)***	**−0.2 (0.04)*****	0.02 (0.02)
Frequency of 30 min exercise	**0.02 (0.02)*****	**0.2 (0.02)*****	**0.08 (0.02)*****	–
Social cohesion	**−0.08 (0.02)*** 0.04 (0.007)*****	**0.1 (0.02)*****	–	
Relative nature (less time)				
About the same	−0.1 (0.1)	0.2 (0.1)	−0.2 (0.1)	0.06 (0.06)
More time	−0.03 (0.13)	0.2 (0.1)	0.1 (0.1)	0.1 (0.06)
Language at home (English)				
Language at home (European)	−0.12 (0.17)	0.2 (0.1)	0.1 (0.1)	0.1 (0.1)
Language at home (Non-European)	−0.22 (0.22)	0.4 (0.2)	0.2 (0.2)	−0.1 (0.1)
Work hours per week (No hours)				
< 16 h	0.3 (0.2)	**1.0 (0.1)*****	**0.7 (0.1)*****	0.04 (0.07)
16–30 h	−0.1 (0.1)	**0.7 (0.1)*****	**0.3 (0.1)***	0.1 (0.06)
31–45 h	−0.1 (0.1)	**0.8 (0.1)*****	−0.1 (0.1)	0.06 (0.05)
> 45 h	0.2 (0.2)	**0.8 (0.1)*****	−0.1 (0.2)	0.1 (0.1)
Retired	−0.1 (0.1)	0.1 (0.1)		0.1 (0.6)
Education (no qualifications)				
Level 1	–	0.2 (0.2)	**0.4 (0.2)***	0.1 (0.09)
Level 2	–	0.2 (0.2)	**0.7 (0.2)*****	0.04 (0.09)
Level 3	–	0.3 (0.2)	**0.7 (0.2)*****	0.05 (0.08)
Level 4	–	0.3 (0.3)	**0.6 (0.2)****	0.1 (0.09)
Self-assessment health				
Poor	**−0.5 (0.2)***	–	0.4 (0.2)	0.1 (0.09)
Average	**−1.2 (0.2)*****	–	0.2 (0.02)	**0.5 (0.09)*****
Good	**−1.9 (0.2)*****	–	**0.7 (0.2)*****	**0.8 (0.09)*****
Very good	**−2.4 (0.2)*****	–	**1.1 (0.2)*****	**0.9 (0.09)*****
Model ii)	*AICc: 5784.1*	*AICc: 7110.3*	*AICc: 11750.2*	AICc: 7168.0
+ Nature exposure frequency	−0.01 (0.04)	**0.02 (0.01)***	**0.06 (0.01)*****	**0.06 (0.004)*****
+ Actual urbanity * frequency	**−0.08 (0.04)***	–	–	–
+ Perceived urbanity*frequency	–	–	–	–
Model iii)	*AICc: 5785.4*	*AICc: 7105.5*	*AICc: 11740.3*	*AICc: 7188.6*
+ Nature exposure duration	−0.02 (0.08)*-	**0.02 (0.07)****	**0.05 (0.007)*****	**0.01 (0.005)***
+ Actual urbanity * duration	–	–	**0.02 (0.007)****	–
+ Perceived urb. (s8)# * duration				**0.1 (0.05)****
+ Perceived urb. (s9)# * duration				**0.2 (0.05)*****
+ Perceived urb. (s10)# * duration (10)	–	–	–	**0.2 (0.05)*****
Model iv)	*AICc: 5791.9*	*AICc: 7112.1*	*AICc: 11763.0*	*AICc: 7304.7*
+ Nature exposure intensity	−0.07 (0.05)	0.05 (0.05)	0.002 (0.002)	0.0007 (0.0007)
+ Actual urbanity * intensity	–	–	**−0.005 (0.001)*****	–
+ Perceived urbanity * intensity	–	–	–	–

Only significant factor levels shown, as indicated by the perceived urban score (s; where for example S10 is equivalent to the inner city).

associated with all four health outcomes, across two health domains the benefits from spending longer in nature were greater in the urban population (i.e. increased dose was associated with increased physical activity and perceptions of social cohesion). On average respondents in more urbanised areas who spent no time outdoors had the lowest perceptions of social cohesion, while those who spent nine or more hours in greenspaces had the most favourable perceptions of their community. A potential explanation is that the increased density of people in urban areas means that there is greater potential for positive interactions between neighbours, with greenspaces being locations that

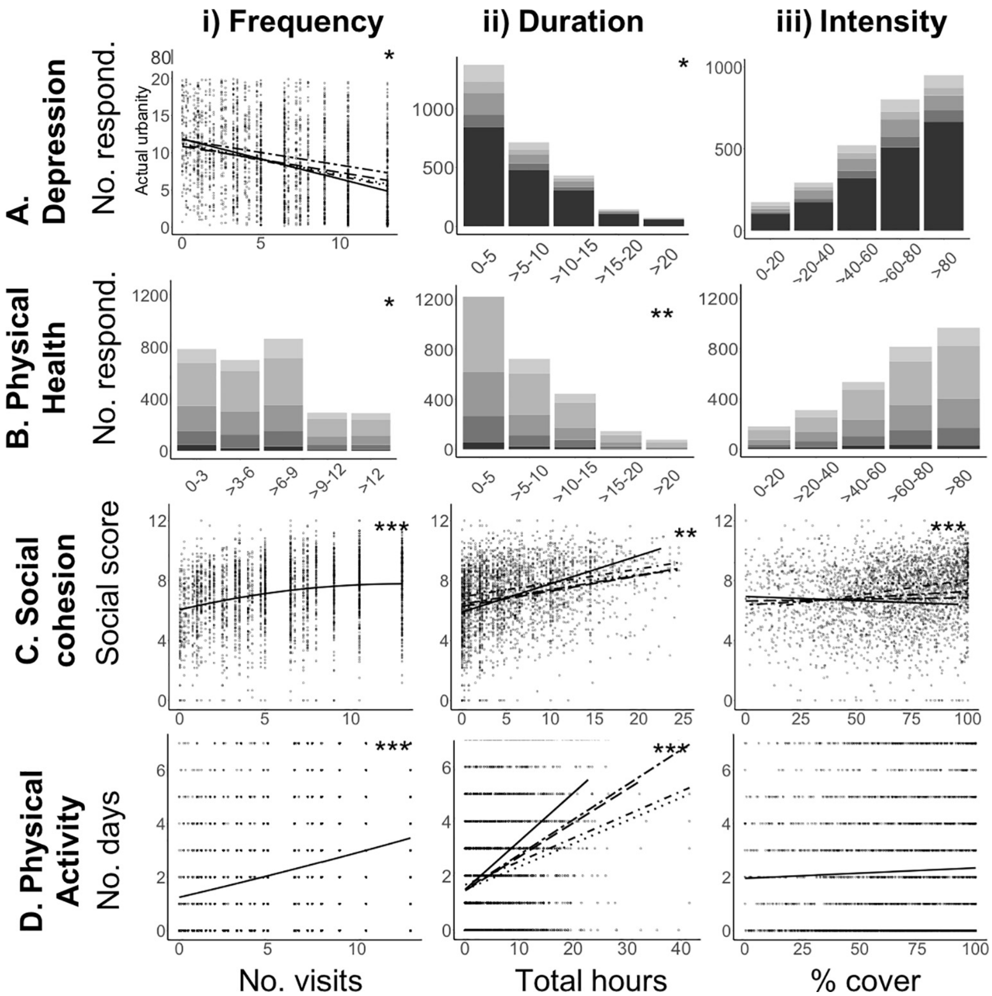

Fig. 3. The relationships between health responses (A–D) and doses of nature, comprising (i) the frequency of visits to gardens and public green spaces; (ii) the total duration of visits to gardens and public green spaces; and (iii) the nature intensity, measured as the quantity of green space within 250 m of the postcode. Ai, iii) Mental health state is shown as: Normal, black; mild, dark grey; moderate, medium grey; severe, light grey; very severe, dark grey. Bi-iii) Perception of physical health is shown as: Very poor, black; poor, dark grey; average, medium grey; good, light grey; very good, pale grey. We show significant interactions between nature dose and perceived or actual urbanity (shown by Fig. Ai: normal, solid line; mild, dashed; moderate, large dash dot; severe, small dash dot; very severe, dot. Fig. Cii; Ciii; Dii: rural, solid line; village, dashed; suburban, large dash dot; urban, small dash dot; inner city, dot. Statistical significance ($^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$).

facilitate these interactions. Finally, respondents in more heavily urbanised areas who exercised more regularly were more likely to do so in greenspaces than those who engaged in similar amounts of exercise in less urbanised areas. This could be due to a possible higher use of other types of exercise location (e.g. indoor gyms, swimming pools, roadways etc) by respondents in less urbanised locations, or through higher levels of exercise associated with work activities.

Finally, we found that people in towns and cities had a better sense of community when there was more greenspace around the home. This may be because of the greater availability of places to socialise, so facilitating community life (Weinstein et al., 2015). We did not find any relationships between dose intensity and the other three health domains, suggesting these health metrics are less related to available nature around the home based on the method of measurement used here. The coarse area-based measure of nature is likely to be at best a limited surrogate for the complex experiences that people have with individual components of nature. Species richness (dose intensity quality) and abundance (dose intensity quantity) will vary significantly between greenspaces and nature experiences, and this is likely to influence any associated health outcomes (e.g. Cox & Gaston, 2015). For example, there is evidence that visiting greenspaces in the countryside provides different wellbeing benefits from those gained from spending time in urban greenspaces (Coldwell & Evans, 2018). Instead a better measure of intensity, but one that would require a completely different methodological approach to the one taken here, would be to measure dose intensity experienced throughout a participant's daily life. Ideally, this approach would account for indirect, incidental and intentional experiences not only around the home, but also when people are moving around the landscape, such as walking to the shops or visiting the countryside. As emerging technologies of personalised activity monitors, such as GPS trackers, eye-tracking glasses and electroencephalography (EEG) continue to advance, these exposures will become increasingly understood.

4.3. Limitations

This study uses a cross-sectional design, which inevitably has both advantages and limitations. The main advantage is that it allows the simultaneous analysis of multiple risk factors. The limitation is that the design cannot definitively establish a cause-effect relationship. However these pathways are becoming increasingly well-developed in other studies (Bratman et al., 2015; Hanski et al., 2012; Shanahan et al., 2015a). This study also relied on self-reported data, which may lead to common method bias. Thus, additional studies using more objective health indicators, such as stress cortisol and heart rate could provide more in-depth understanding. The improvements in model quality (i.e. lower AICc values) with the addition of nature dose variables were low particularly for the mental and physical health responses (see Table 2). This maybe because either the influence of doses of nature on health is small, or because health is a complex issue with multiple drivers and although we controlled for key socio-demographic covariates known to influence health, the impacts of life events are difficult to control for. Further, the benefits of contact with nature may vary across socio-economic groups, cultures and environments (e.g. Mitchell & Popham, 2008). Indeed, because there was an overrepresentation of respondents on low incomes (< £10,399 per year), and of those who work no hours per week, caution must be applied when drawing conclusions applicable to broader populations. The improvement in model quality with the addition of nature variables found here was comparable (e.g. Coldwell & Evans, 2018; Shanahan et al., 2016) or less (e.g. Barton & Pretty, 2010) than that of similar studies. However, given the numerous contributing factors towards health and the economic and social cost of poor health, any detectable effect of nature dose has the potential to lead to significant savings towards the prevention and treatment of ill health.

4.4. Conclusions

We show that people in urban areas had a reduced exposure to nature across three dimensions of nature dose compared to their rural counterparts. However, regardless of opportunity to access greenspaces around the home, people with an increased orientation towards nature typically choose to visit greenspaces more often and for longer. There was also some evidence that those with a greater orientation to nature have better mental health, social cohesion, and physical behaviour, even after accounting for nature dose. This result highlights the importance of supporting the development of a connection to nature across a person's life-course. This study paves the way for future research to establish how behavioural interventions can promote engagement with everyday nature.

Conflict of interests

We have no competing interests to declare.

Ethical clearance

This research was conducted with approval from the Bioscience ethics committee of the University of Exeter (project number 2016/1418). Participants provided written consent at the beginning of the online survey.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.landurbplan.2018.07.013.

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