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Neighbourhood Greenspace and Smoking Prevalence: Results from a Nationally Representative Survey in England.

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Conflicts of interest: none.

Abstract

Objective:

The current study investigated whether people are less likely to be smokers when they live in greener neighbourhoods, and whether such an association is attributable to lower rates of ever-smoking and/or higher rates of smoking cessation.

Method:

Using a representative sample of the adult population of England (N = 8059), we investigated the relationships between neighbourhood greenspace and three inter-related smoking outcomes (current smoking, ever-smoking and smoking cessation).

Results:

After controlling for a range of individual and area-level covariates, including social economic status, income and education, living in the highest greenspace quartile was associated with a 20% lower prevalence of current smoking, compared to living in the lowest greenspace quartile (*PR* = 0.80, *CI* = 0.67, 0.96, $p < .017$). Neighbourhood greenspace was not significantly associated with ever-smoking. However, amongst ever-smokers, residing in the two highest quartiles of neighbourhood greenspace quartiles (*vs*. 1st quartile) was associated with a 10% and 12% higher prevalence of smoking cessation (*PR = 1.10, CI = 1.02, 1.18, p = .012; PR = 1.12, CI = 1.02, 1.22, p = .016*, respectively). This suggests that the association between greenspace and current smoking is due to a higher likelihood of smoking cessation, rather than lower rates of ever- smoking. The associations between greenspace, current smoking and smoking cessation were similar in magnitude to those of having high (vs. low) household income and were largely unmoderated by socio-economic measures.

Implications:

Our findings advocate the need to protect and invest in local greenspaces, in order to maximise the public health benefits they may afford. Improving access to greenspace may constitute an overlooked public health strategy for reducing smoking prevalence.

Key words:

Greenspace, Nature, Smoking, Smoking Prevalence, Ever Smokers, Smoking Cessation, Health-risk Behaviour

Highlights:

- High greenspace neighbourhoods associated with a lower smoking prevalence
- Neighbourhood greenspace was positively associated with smoking cessation rates
- Greenspace effects similar in magnitude to those of having a high household income

CRediT authorship contribution statement

Leanne Martin: Conceptualization, Methodology, Formal analysis, Writing - Original Draft, Writing - Review & Editing; **Mathew P. White:** Conceptualization, Methodology, Writing - Review & Editing; **Sabine Pahl:** Conceptualization, Methodology, Writing- Review & Editing; **Jon May:** Conceptualization, Writing- Reviewing & Editing; **Benedict W. Wheeler:** Data Curation, Writing- Reviewing & Editing.

1. Introduction

1.1 Social and Spatial Disparities in Smoking Prevalence

As a major determinant of preventable morbidity and mortality worldwide, smoking constitutes a significant public health issue (WHO, 2018). Despite a decline in prevalence within the general population over the last decade (WHO, 2018) smoking is not equally distributed amongst the population but influenced by marked social and spatial gradients (Cavelaars et al., 2000). Socio-economic status, for example, whether measured by education, income or occupational status, is one of the most robust determinants of variations in smoking behaviour (Williams, Priest & Anderson, 2016). The prevalence of current smokers is disproportionately higher amongst lower socio-economic groups (Laaksonen, Rahkonen, Karvonen & Lahelma, 2005) and is a key contributor to socio-economic disparities in health (Lantz et al., 1998). Whilst the individual determinants of smoking are well-established, there is increasing recognition that the environments in which individuals live also influence health behaviour (Pearce, Barnett & Moon, 2012). A number of neighbourhood characteristics have been positively associated with smoking prevalence, including: deprivation (Algren, Bak, Berg-Beckhoff & Andersen, 2015), crime (Caraballo, Rice, Neff & Garrett, 2019) and, crucially for the current study, level of urbanisation (Pearce & Boyle, 2005).

1.2 Urban-Rural Residency and Smoking Prevalence

Several studies have now demonstrated that inhabitants of urban areas are more likely to be current smokers, than those of rural areas (Idris et al., 2007; Kaleta, Makowiec-Dąbrowska, Dziankowska-Zaborszczyk & Fronczak, 2012; Völzke et al.,

2006; Yaya & Bishwajit, 2019). Moreover, the probability of being a current smoker increases with the degree of urbanisation (Idris et al., 2007; Pearce & Boyle, 2005). Evidence that these effects remain after controlling for a range of individual-level socio-demographics (Martinez et al., 2006; Völzke et al., 2006), suggests that area-level variations in smoking behaviour are not simply an artefact of varying socio-economic population compositions, but the result of contextual and environmental factors.

1.3 Neighbourhood Greenspace & Smoking Prevalence

A key feature of increasing urbanisation is the loss of natural spaces (Pauleit, Ennos & Golding, 2005) which reduces opportunities to interact with the natural world (Soga & Gaston, 2016). Given the strong negative correlation between urbanicity and neighbourhood greenspace (Maas et al., 2006) urban-rural differences in smoking prevalence may, at least in part, be explained by the availability of local greenspace. Although we are unaware of any studies directly examining this proposition, several strands of evidence support further investigation into this area.

Firstly, using a nationally representative sample from the Netherlands, Maas et al. (2006) found that differences in general health between residents of urban and rural areas were largely explained by the proportion of neighbourhood greenspace. Since smoking behaviours themselves predict health outcomes (Lopez, Mathers, Ezzati, Jamison & Murray, 2006), it follows that urban-rural disparities in smoking prevalence may also be due to variations in neighbourhood greenspace.

Second, alongside the well-established health and wellbeing benefits of nature (Lovell, Depledge & Maxwell, 2018) there is growing recognition that greenspace may influence a variety of human behaviours. Early research by Kuo

and colleagues suggested that living in greener neighbourhoods, even in areas of relative deprivation, was associated with enhanced self-regulatory capacity as evidenced in lower rates of aggression (Kuo & Sullivan., 2002) and impulsivity on the one hand, and a greater ability to delay gratification on the other (Faber Taylor, Kao & Sullivan 2002). Further, a recent systematic review suggests similar patterns are even present in childhood (Moens et al., 2019). Given the importance of self-regulation for smoking (Schmueli & Prochaska, 2009), it therefore seems plausible that smoking uptake and maintenance may be lower in greener areas. Preliminary support for this idea comes from inverse bivariate associations between neighbourhood greenspace and current smoking observed in large scale cross-sectional surveys in Australia (Astell-Burt, Feng & Kolt ,2014) and Belgium (Van Herzele & de Vries, 2012). Further work is now needed in other countries to see how generalisable the effects are, and more investigation into the potential pathways and mechanisms (e.g. is greenspace associated with ever smoking and/or smoking cessation) is warranted.

Although examination of causality is beyond the scope of cross-sectional studies, there are several mechanisms through which neighbourhood greenspace may affect smoking prevalence. Psychological stress is a robust predictor of smoking uptake and cessation (Wellman et al., 2018) and there is now a considerable body of evidence demonstrating that neighbourhood greenspace is associated with reductions in stress (Roe et al., 2013; Van den Berg, Maas, Verheij & Groenewegen, 2010;). Furthermore, exposure to natural environments has been associated with various cognitive processes such as better self-control (Kuo and Faber Taylor, 2004), lower temporal discounting (Berry et al., 2014; 2015; 2020), and reduced craving (Martin, Pahl, White & May, 2019), all factors that independently predict

smoking cessation (Barlow, McKee, Reeves, Galea & Stuckler, 2016; Killen & Fortmann, 1997; Muraven, 2010). Thus, neighbourhood greenspace could influence smoking prevalence through an inter-play of cognitive and affective pathways.

1.2 Distinguishing between ever- smoking and smoking cessation

The prevalence of current smokers within a particular sub-group of the population may be due to the likelihood of individuals starting smoking *and*/*or* cessation rates (DeCicca, Kenkel & Mathios, 2008; Kuipers et al., 2013; Van Loon, Tijhuis, Surtees & Ormel, 2005). Put differently, the prevalence of current smokers at the population level can be expressed as: proportion of current smokers = rate of ever smokers - rate of smoking cessation. Distinguishing between ever-smoking and cessation therefore offers potential conceptual insights into the mechanisms by which area-level characteristics may influence smoking, and so helps to determine the focus of policy and interventions (Nagelhout, et al., 2012). In terms of neighbourhood greenspace, if the inverse bivariate association between neighbourhood greenspace and current smoking observed in prior research are generalisable once relevant socio-demographics are accounted for, then it is both conceptually and practically useful to establish whether this relationship is attributable to lower rates of ever-smoking and/or higher rates of smoking cessation.

1.4 The Current Research

We addressed these underexplored issues by investigating the relationships between neighbourhood greenspace and three interrelated smoking behaviours:

current smoking, ever-smoking and smoking cessation. Specifically, we used data from a nationally representative survey of the adult population of England to address two key questions: 1) whether neighbourhood greenspace was inversely associated with the prevalence of current smoking, after controlling for a range of individual and area level covariates; and if so, 2) was this association attributable to lower rates of ever-smoking and/or higher rates of smoking cessation.

Based on bivariate associations observed in previous research, we predicted an inverse relationship with neighbourhood greenspace and the prevalence of current smoking. Additionally, given that smoking uptake and cessation are affected by stress, we hypothesised that the association between greenspace and current smoking would be attributable to both lower rates of ever-smoking and higher rates of smoking cessation. However, as nature exposure also supports the cognitive processes required for abstinence behaviour (e.g. reduced craving, Martin et al., 2019), we expected the association between greenspace and smoking cessation to be greater in magnitude than that for greenspace and ever-smoking.

2.1 Method

2.1 Health Survey for England (HSE) Overview

The HSE is conducted annually in England on behalf of the UK Office for National Statistics to provide information on health, lifestyle factors, and illnesses within the general population. Data is collected throughout the year by trained interviewers using a face-to-face interviewing protocol (Joint Health Surveys Unit, NatCen, 2013). Our analysis of these data is governed by Data Sharing Agreement NIC-09479-J9Z4G with NHS Digital, under approval from the Data Release Panel at Natcen

Social Research. Ethical and data governance information on the HSE is available at https://digital.nhs.uk/data-and-information/areas-of-interest/public-health/health-survey-for-england---health-social-care-and-lifestyles

2.2 Participants

Participants were drawn from the 2012 wave of the HSE because this was the year for which we also had updated measures of neighbourhood greenspace. The sample consisted of 8,291 adults (4,601 females) aged ≥16 years. As part of England's official statistics, the HSE uses a multistage stratified design to achieve a sample representative of the population at both the national and regional level. For current purposes, respondents with missing data for any of the measures used were excluded from the analyses, resulting in a reduced sample of 8,059 (4,462 females).

2.3 Measures

2.3.1 Outcome Variables

Following Kuipers et al., (2013) three interrelated binary smoking indicators were derived from responses to a single item question pertaining to respondents' smoking status: current smoker, ever-smoker, never-smoker. To examine the predictors of smoking prevalence, respondents' smoking status was dichotomised according to whether they were current smokers (*N* = 1,513) *vs*. non-smokers (*N* = 6,546), with the latter category aggregating former regular smokers and never regular smokers. To examine ever smoking, respondents who currently smoked or were former regular smokers were classified as ever-smokers (*N* = 3,628) *vs.* never-smokers (N = 4,431). Finally, to assess predictors of smoking cessation, a binary variable was created categorising the subsample of ever smokers as former (*N* = 2, 115) *vs*.

current smokers, with formers smoker considered to have successfully given up smoking.

2.3.2 Exposure Variables

Neighbourhood greenspace

Neighbourhood greenspace was based on the Lower-layer Super Output Area (LSOAs) in which respondents lived. LSOAs are produced by the Office for National Statistics and represent discrete geographic areas of similar population size. There are 32,484 LSOAs in England (2011 census), each containing approximately 1,500 residents. This information was added by the Health and Social Care Information Centre to the HSE dataset from other sources. Specifically, the percentage of land cover incorporating public greenspace and domestic gardens within each LSOA (at the resolution of $10m^2$) was derived from the Generalised Land Use Database. To enable comparability with previous epidemiological greenspace studies (e.g. Dalton, Wareham, Griffin & Jones, 2016; Liao et al., 2019), our final models expressed greenspace in quartiles, ranging from the lowest level of neighbourhood greenspace (*M* = 5.24%) to the highest (*M* = 86.35%).

2.3.4 Control Variables

Given that our outcome and predictor variables have been previously associated with a range of individual (e.g. socio-economic status, Allen et al., 2017) and area-level confounders (e.g. neighbourhood deprivation, Algren, Bak, Berg-Beckhoff & Andersen, 2015), control variables were created using available data from the HSE

survey, as well as LSOA variables provided by the Health and Social Care Information Centre and included within the multivariate analyses.

Individual-level control variables

Demographic controls included: gender (female, male = reference); age (16-34 = reference, 35-64, 65+); highest educational attainment (no formal education = reference, secondary, tertiary, higher, other); socio-economic classification (routine and manual occupations = reference, intermediate occupations, managerial and professional occupations, other); marital status (married/cohabiting, single/widowed/divorced = reference) and equalised household income (≤ £27, 624 = reference, >£27, 624). In order to keep those who preferred not to state their income in the analysis (*N* = 1,589) we created a third category of 'income undisclosed' for this variable.

Area-level control variables

Respondent LSOA codes were used to derive area-level urbanicity and deprivation indicators. Urbanicity was categorised as: urban *vs.* rural (hamlet/village/town-fringe). The Index of Multiple Deprivation provides a measure of relative disadvantage for each LSOA based on several domains, including: crime, income and employment (Department of Communities and Local Government, 2008). Quintiles of the Index of Multiple Deprivation (IMD) scores were calculated, ranging from the highest level of disadvantage (≥ 34.17= reference) to the lowest (≤8.49).

2.4 Analytical Approach

Analyses were conducted using STATA 16 (StataCorp, College Station, TX). Descriptive statistics for the three outcomes (current smoking, ever-smoking and smoking cessation) as a function of neighbourhood greenspace exposure and covariates are presented in Section 3.1. Multivariate analyses are reported in Section 3.2. Due to their large number, many LSOAs contained only a single respondent, rendering multi-level modelling with area modelled as a level one factor inappropriate (Boyd, White, Bell & Burt, 2018). Therefore, as recommended for prevalent binary outcomes (McNutt, Wu, Xue & Hafner, 2003) modified Poisson regression with robust standard errors were used to estimate prevalence ratios (*PR*) and corresponding 95% confidence intervals (95% *CI*) for the associations between smoking outcomes and neighbourhood greenspace, whilst controlling for individual and area-level covariates. Unadjusted and partially adjusted models (examining area-level predictors only) are reported in Supplementary Materials 1 and 2. The direction of the associations between variables in these models were largely consistent with those observed in final models.

Additionally, to assess the magnitude of the associations for greenspace, we compared their prevalence ratios to those of relevant control variables (Section 3.3). Previous research has noted lower prevalence of smokers amongst individuals who live in the least disadvantaged neighbourhoods, are highly educated, from higher income households and higher socioeconomic groups (Algren, Bak, Berg-Beckhoff & Andersen, 2015; Laaksonen, Rahkonen, Karvonen & Lahelma, 2005). Smoking cessation is also more prevalent within the aforementioned social groups (Chandola, Head & Bartley, 2004; Halonen et al., 2016). Accordingly, neighbourhood deprivation (5^{th} quintile, least disadvantaged *vs*. 1^{st} quintile, most disadvantaged) education (higher education *vs*. no formal education), socio-economic position

(managerial/professional, highest *vs*. routine, lowest) and equivalised income (> £27,624 = reference *vs.* ≤ £27,624, lowest) were selected as comparator variables. Using such benchmarks connects our findings to other disciplines and helps researchers and policymakers assess their relative importance.

Section 3.4 reports a series of robustness checks on our models. Higher proportions of greenspace were evident amongst rural and the less deprived neighbourhoods within our sample (Supplementary Material 3). This is in line with prior research showing better greenspace access among more educated and wealthier groups (Boone et al., 2009; Iverson and Cook, 2000; Shanahan et al., 2014). As these individual and area-level characteristics also influence smoking behaviours (see Section 1.1), it is possible that associations between greenspace and smoking outcomes could be due to social groups who are less likely to smoke, simply residing in greener areas (i.e. multiplicative moderation effects). To test this possibility, we conducted an additional series of Poisson regression models estimating smoking prevalence ratios (*PR*) as a function of neighbourhood greenspace, individual (education, socio-economic group, income) and area-level characteristics (neighbourhood deprivation) and their interaction terms. An additional model was run for urban settings only because the vast majority of rural dwellers were already in the highest quintile of greenspace coverage, rendering interaction terms inappropriate for this variable.

3. Results

3.1 Descriptive Statistics

Descriptive data for the three outcome domains as a function of neighbourhood greenspace and covariates is presented in Table 1. Approximately one fifth of

Table 1: Individual and area-level characteristics by smoking outcome.

	Current Smoker		Ever Smoker		Smoking Cessation	
	No	**Yes**	**No**	**Yes**	**No**	**Yes**
Total N (%)[a]	6546 (81%)	1513 (19%)	4431 (54%)	3628 (45%)	1513 (41%)	2115 (58%)
Neighbourhood greenspace (%)						
1st quartile (M= 5.23, lowest)	1656 (78%)	458 (22%)	1135 (54%)	979 (46%)	458 (47%)	521 (53%)
2nd quartile (M= 24.46)	1525 (80%)	381 (20%)	1068 (56%)	838 (44%)	381 (45%)	457 (55%)
3rd quartile (M= 54.18)	1928 (81%)	445 (19%)	1264 (53%)	1109 (47%)	445 (40%)	664 (60%)
4th quartile (M= 86.35, highest)	1437 (86%)	229 (14%)	964 (58%)	702 (42%)	229 (33%)	473 (67%)
Gender						
Male	2866 (80%)	731 (20%)	1767 (49%)	1830 (51%)	731 (40%)	1099 (60%)
Female	3680 (82%)	782 (18%)	2664 (60%)	1798 (40%)	782 (43%)	1016 (57%)
Age						
16-34	1415 (74%)	489 (26%)	1153 (61%)	751 (39%)	489 (65%)	262 (35%)
35-64	3199 (79%)	832 (21%)	2177 (54%)	1854 (46%)	832 (45%)	1022 (55%)
65+	1932 (91%)	192 (9%)	1101 (52%)	1023 (48%)	192 (19%)	831 (81%)
Education						
No formal education	1539 (78%)	446 (22%)	900 (45%)	1085 (55%)	446 (41%)	639 (59%)
Secondary	1450 (75%)	481 (25%)	947 (49%)	984 (51%)	481 (49%)	503 (51%)
Tertiary	988 (80%)	246 (20%)	707 (57%)	527 (43%)	246 (47%)	281 (53%)
Higher	2569 (88%)	340 (12%)	1877 (65%)	1032 (35%)	340 (33%)	692 (67%)
Socio-economic group						
Routine & manual	2207 (73%)	829 (27%)	1361 (45%)	1675 (55%)	829 (49%)	846 (51%)
Intermediate	1649 (83%)	344 (17%)	1115 (56%)	878 (44%)	344 (39%)	534 (61%)
Managerial & professional	2402 (89%)	294 (11%)	1682 (62%)	1014 (38%)	294 (29%)	720 (71%)
Other	288 (86%)	46 (14%)	273 (82%)	61 (18%)	46 (75%)	15 (25%)
Equalised household income						

≤ £27, 624	2718 (77%)	834 (23%)	1728 (49%)	1824 (51%)	834 (46%)	990 (54%)
> £27, 624	2554 (88%)	364 (12%)	1826 (63%)	1092 (37%)	364 (33%)	728 (67%)
Undisclosed	1274 (80%)	315 (20%)	877 (55%)	712 (45%)	315 (44%)	397 (56%)
Marital Status						
Single/Separated/Divorced/Widowed	2185 (76%)	689 (24%)	1563 (54%)	1311 (46%)	689 (53%)	622 (47%)
Married/Cohabiting	4361 (84%)	824 (16%)	2868 (55%)	2317 (45%)	824 (36%)	1493 (64%)
Index of multiple deprivation (IMD)						
1st Quintile (most disadvantaged)	945 (69%)	434 (31%)	636 (46%)	743 (54%)	434 (58%)	309 (42%)
2nd Quintile	1178 (76%)	364 (24%)	770 (50%)	772 (50%)	364 (47%)	408 (53%)
3rd Quintile	1357 (83%)	271 (17%)	902 (55%)	726 (45%)	271 (37%)	455 (63%)
4th Quintile	1447 (84%)	275 (16%)	1009 (59%)	713 (41%)	275 (39%)	438 (61%)
5th Quintile (least disadvantaged)	1619 (91%)	169 (9%)	1114 (62%)	674 (38%)	169 (25%)	505 (75%)
Urbanicity						
Rural	1538 (85%)	271 (15%)	1030 (57%)	779 (43%)	271 (35%)	508 (65%)
Urban	5008 (80%)	1242 (20%)	3401 (54%)	2849 (46%)	1242 (44%)	1607 (56%)

Notes: [a] percentages relate to total sample. All other percentages relate to % within each exposure category for each outcome.

respondents (19%) were current smokers. Less than half of the sample (45%) reported ever having regularly smoked and of those respondents who had ever smoked, over half (58%) had given up smoking. The prevalence of current smoking decreased incrementally with each quartile of neighbourhood greenspace. Conversely, smoking cessation rates increased as neighbourhood greenspace increased. For ever-smoking the trend was more nuanced: whilst the 4th (highest) quartile of neighbourhood greenspace had the lowest prevalence of ever smokers overall, the highest rates were observed for respondents residing in the 3rd greenspace quartile.

3.2 Main findings

Fully adjusted Poisson regression models estimating the adjusted prevalence ratios of smoking outcomes, by quartile of neighbourhood greenspace and covariates, are reported in Table 2. Variance inflation factors (VIF) for the models were < 2.46, indicating that multicollinearity was not an issue. The prevalence of current smoking was significantly lower in the highest (*vs*. lowest) quartile of neighbourhood greenspace (Model 1, Table 2). Specifically, living in the highest greenspace quartile (4th) was associated with a 20% lower prevalence of current smoking, compared to living in the lowest greenspace quartile (1st). There were no significant associations between neighbourhood greenspace and the prevalence of ever-smokers (Model 2, Table 2). However, amongst respondents who had ever smoked, residing in the 3rd and 4th greenspace quartiles (*vs*. 1st quartile) was associated with a 10% and 12% higher prevalence of smoking cessation, respectively (Model 3, Table 2).

Table 2: Modified Poisson regression models estimating adjusted prevalence ratio of smoking outcomes for neighbourhood greenspace, controlling for individual and area level covariates.

	Current Smoking			Ever Smoker			Smoking Cessation		
	PR	***95% CIs***	***p***	***PR***	***95% CIs***	***p***	***PR***	***95% CIs***	***p***
Neighbourhood greenspace (%)									
1st quartile (M= 5.23, lowest)									
2nd quartile (M= 24.46)	0.92	(0.82, 1.03)	.158	0.93	(0.83, 1.04)	.180	1.03	(0.95, 1.11)	.495
3rd quartile (M= 54.18)	0.91	(0.82, 1.02)	.121	1.00	(0.94, 1.06)	.922	1.10	(1.02, 1.18)	.012
4th quartile (M= 86.35, highest)	0.80	(0.67, 0.96)	.017	0.96	(0.88, 1.06)	.447	1.12	(1.02, 1.22)	.016
Individual-level controls									
Gender (female)	0.82	(0.75, 0.89)	<.001	0.78	(0.74, 0.82)	<.001	1.03	(0.98, 1.09)	.252
Age									
16-34 (ref)									
35-64	0.85	(0.77, 0.94)	.002	1.11	(1.04, 1.19)	.001	1.41	(1.27, 1.56)	<.001
65+	0.29	(0.24, 0.34)	<.001	1.04	(0.97, 1.13)	.266	2.23	(2.01, 2.47)	<.001
Education									
No formal education (ref)									
Secondary	0.88	(0.79, 0.99)	.029	0.96	(0.91, 1.03)	.248	1.00	(0.93, 1.07)	.921
Tertiary	0.68	(0.59, 0.79)	<.001	0.86	(0.79, 0.93)	<.001	1.09	(0.99, 1.20)	.075
Higher	0.54	(0.46, 0.63)	<.001	0.73	(0.68, 0.79)	<.001	1.13	(1.05, 1.22)	.002
Socio-economic group									
Routine & manual (ref)									
Intermediate	0.81	(0.72, 0.90)	<.001	0.90	(0.84, 0.95)	<.001	1.10	(1.03, 1.18)	.007
Managerial & professional	0.66	(0.57, 0.76)	<.001	0.87	(0.81, 0.93)	<.001	1.17	(1.09, 1.26)	<.001
Other	0.35	(0.27, 0.46)	<.001	0.35	(0.28, 0.45)	<.001	0.66	(0.45, 0.98)	<.001
Equalised household income									
≤ £27, 624 (ref)									
> £27, 624	0.75	(0.66, 0.84)	<.001	0.85	(0.80, 0.90)	<.001	1.12	(1.06, 1.20)	<.001

Undisclosed	0.93	(0.83, 1.04)	.180	0.90	(0.85, 0.96)	.001	0.99	(0.92, 1.06)	.790
Marital Status (Married/Cohabiting)	0.73	(0.67, 0.80)	<.001	0.98	(0.93, 1.03)	.378	1.26	(1.18, 1.34)	<.001
Area-level controls									
Index of multiple deprivation (IMD)									
1st Quintile (most disadvantaged, ref)									
2nd Quintile	0.88	(0.79, 0.99)	.034	0.95	(0.89, 1.02)	.182	1.14	(1.03, 1.26)	.015
3rd Quintile	0.71	(0.62, 0.81)	<.001	0.88	(0.82, 0.95)	.001	1.26	(1.14, 1.39)	<.001
4th Quintile	0.77	(0.67, 0.88)	<.001	0.84	(0.78, 0.91)	<.001	1.15	(1.04, 1.28)	.006
5th Quintile (least disadvantaged)	0.50	(0.42, 0.60)	<.001	0.80	(0.73, 0.87)	<.001	1.33	(1.21, 1.47)	<.001
Urbanicity (urban)	0.91	(0.78, 1.05)	.198	0.99	(0.92, 1.07)	.797	1.06	(0.98, 1.14)	.129
Constant	0.17	(0.12, 0.24)	<.001	0.22	(0.17, 0.28)	<.001	0.21	(0.18, 0.25)	<.001
N	8,059			8,059			3628		
Wald's χ^2	859.61***			596.07***			736.32***		
Pearson goodness of fit χ^2	6557.02			4415.95			1480.78		
Pseudo R^2	.09			.03			.05		

Note: *** = p <.001

3.*3 Comparison of associations with socio-demographic effects*

We compared the prevalence ratio associated with residing in either the 3rd or 4th quartiles of neighbourhood greenspace (vs. 1st quartile) to: a) living in the least *vs.* most disadvantaged neighbourhoods, b) having a higher *vs*. no formal education, c) holding a managerial/professional (highest) *vs*. routine (lowest) socioeconomic position, and d) reporting an equivalised income of > £27, 624 (highest) *vs*. ≤ £27, 624 (lowest). For current smoking, the prevalence ratio associated with living in the 4th (*vs*. 1st) quartile of neighbourhood greenspace (*PR* = .80, *CI* = 0.67, 0.96, *p* < .017), was less than half the size of that associated with living in the least (*vs*. most) disadvantaged neighbourhoods (*PR* = .50, *CI* = 0.42, 0.60, *p* < .001). The prevalence ratio of being a current smoker for those residing in the 4th (vs. 1st) quartile of neighbourhood greenspace was smaller than that associated having a higher education (*PR* = .54, *CI* = 0.79, 0.99, *p* < .001) or holding a managerial socioeconomic position (*PR* = .35, *CI* = 0.27, 0.46, *p* < .001), but similar in magnitude to earning more than £27, 624 a year (*PR* = 0.75, *CI* = 0.66, 0.84, *p* <.001).

For smoking cessation, the prevalence ratios for individuals residing in the 3rd and 4*th* greenspace quartiles (*PR* = 1.10, *CI* = 1.02, 1.18, *p* = .012; PR = 1.12, *CI* = 1.02, 1.22, *p* = .016, respectively) were roughly one third of the size of that associated with living in the least (*vs.* most) disadvantaged neighbourhoods (*PR* = 1.33, *CI* = 1.21, 1.47, *p* < .001). Prevalence ratios for smoking cessation associated with living in the 3rd or 4th greenspace quartile (*vs*. 1st) quartile of neighbourhood greenspace were at least two thirds the size of those associated with holding a managerial socioeconomic position (*PR* = 1.17, *CI* = 1.09, 1.26, *p* < .001), yet similar to having a higher education (*PR* = 1.13, *CI* = 1.05, 1.22, *p* = .002) and earning more

than £27, 624 a year (*PR* = 1.12 *CI* = 1.06, 1.20, $p < .001$). Overall, these comparisons suggest that for being a current smoker, the effects of neighbourhood greenspace are similar in magnitude to the existing socio-demographic benchmark of household income. However, for smoking cessation the effects of greenspace are comparable to both having a higher education and earning more than £27, 624 a year.

3.4 Robustness checks

To ensure the observed associations between neighbourhood greenspace, current smoking and smoking cessation were not simply an artefact of groups that are less likely to smoke residing in greener areas (see section 2.4), we conducted a series of additional models testing potential moderation effects (Supplementary Materials 4-8). Overall, there was no evidence of moderation effects by area or individual level characteristics, in the 3rd and 4th quartiles of neighbourhood greenspace, where the differences in smoking behaviours as a function of neighbourhood greenspace were observed. Thus, associations between neighbourhood greenspace and smoking outcomes within these quartiles were not simply due to the composition of the population who resided in them.

4. Discussion

Extending prior research into area-level characteristics and smoking prevalence, this study constitutes the first investigation of the associations between neighbourhood greenspace and smoking behaviours in England. The aims of the study were two-fold: 1) to establish whether neighbourhood greenspace was inversely associated

with the prevalence of current smoking, after controlling for a range of individual and area level covariates; 2) to assess whether this relationship was attributable to lower rates of ever-smoking and/or higher rates of smoking cessation.

We found that neighbourhood greenspace was inversely associated with the prevalence of current smoking (see Table 2). Specifically, there was a lower prevalence of current smoking amongst individuals living in the highest greenspace quartile, relative to those who lived in the lowest quartile. The relationship between greenspace and smoking prevalence within the current study was upheld after adjusting for a range of covariates, extending previous bivariate observations (Astell-Burt, Feng & Kolt ,2014; Van Herzele & de Vries, 2012). This suggests that the relationship between greenspace and current smoking is not due to the socio-economic composition of the population at either the individual or area level. Further, the associations between greenspace and smoking prevalence were largely unmoderated by three measures of socio-economic status, indicating that our results are not simply due to socio-economic groups who are less likely to smoke residing in greener areas. Taken together, these findings strongly suggest that high greenspace neighbourhoods are independently associated with a lower prevalence of current smoking, irrespective of the socio-demographic characteristics of the individuals who reside in them. Although it is difficult to establish the mechanisms by which neighbourhood greenspace influences smoking behaviour using cross sectional data, the results obtained for ever-smoking and smoking cessation are nonetheless informative.

Specifically, no association was found between neighbourhood greenspace and ever-smoking (see Table 2). The null effects observed here may reflect aspects of the study design, specifically that the measurement of ever-smoking was related

to respondents' current area of residence. Given that smoking uptake typically occurs during adolescence (Wellman et al., 2016) individuals may have migrated to another neighbourhood since initiation, effectively weakening the relationship between ever-smoking and neighbourhood greenspace. Yet, the significance of other area-level characteristics (e.g. deprivation) within our ever-smoking models suggests that this was not the case here. Whilst we had speculated that reduced stress might underlie an inverse association between neighbourhood greenspace and ever-smoking, in relative terms, normative influences (e.g., peer and familial attitudes and behaviours) may exert greater influence over uptake than psychological distress (Carvajal & Granillo, 2006; O'Loughlin, Karp, Koulis, Paradis, & DiFranza, 2009).

Conversely, neighbourhood greenspace was positively associated with smoking cessation (see Table 2). Notably, there was a higher prevalence of smoking cessation amongst respondents living in the 3rd and 4th quartiles of neighbourhood greenspace, compared to those who lived in the 1st quartile. That these associations remained after accounting for a range of individual and area-level covariates suggests that they are not due to the socio-demographic composition of the population. Whilst speculative, there are a number of inter-connected mechanisms through which neighbourhood greenspace may influence smoking cessation. Notably, exposure to natural environments has been associated with: reductions in stress (Roe et al., 2013), craving (Martin et al., 2019), impulsivity (Kuo, Tyler and Sullievan, 2002) and temporal discounting (Berry et al., 2014; 2015; 2020). As improvements across these domains are also associated with successful smoking cessation (Barlow, McKee, Reeves, Galea & Stuckler, 2016; Muraven, 2010; Killen &

Fortmann, 1997), future research might usefully explore these potential mediating pathways.

It is surprising that urban/rural residency did not significantly predict smoking behaviours within the multivariate analyses (See Table 2), considering prior research demonstrating higher smoking prevalence in urban, relative to rural neighbourhoods (Martinez et al., 2006; Völzke et al., 2006). The divergent findings may relate to the inclusion of other area-level controls within our models, which were largely unaccounted for within prior studies. Indeed, additional analyses showed that urban/rural status significantly predicted current smoking in the unadjusted models, but this effect was reduced to non-significance once neighbourhood greenspace and deprivation were entered into the partially adjusted models (Supplementary Materials 2 and 9). This suggests that, in the current study at least, the prevalence of current smoking as a function of urban/rural residency was due to variations in neighbourhood greenspace and neighbourhood deprivation.

Taken together, our findings suggest that the association between greenspace and current smoking is due to a higher likelihood of smoking cessation, rather than a lower likelihood of smoking initiation. In relative terms, neighbourhood deprivation, and socio-economic group were stronger predictors of these two smoking behaviours (see Table 2). Nevertheless, we interpret the associations between neighbourhood greenspace, current smoking and smoking cessation to be practically meaningful, given that they were similar in magnitude to existing socio-demographic benchmarks which are less amenable to change (i.e. education and income).

4.1 Limitations

Whilst providing unique insights into the relationships between neighbourhood greenspace and smoking behaviours, the present study is not without limitations. First, the cross-sectional approach limits our ability to make causal inferences. Despite experimental evidence demonstrating behavioural improvements following exposure to natural environments (Berry et al., 2014; 2015; 2020; Wang et al. 2017), it cannot be ruled out that individuals already exhibiting healthier lifestyles selectively migrate towards more natural settings. Second, results are based on self-report data. Whilst self-reported smoking behaviours correlate strongly with objective indices (Vartiainen, Seppälä, Lillsunde & Puska, 2002), due to well-known negative health consequences of smoking, we cannot rule out possible misclassifications in smoking outcomes due to social desirability bias. Third, to ensure respondent anonymity only categorical data for area-level variables (e.g. green space, deprivation and urbanicity) were made available to the authors by the HSCIC/NHS Digital. With no way of identifying which geographical area (LSOA) respondents lived in, we are unable to assess spatial autocorrelation in the current dataset. Further research should explore this possibility given appropriate data. Fourth, as already noted, ever-smoking was measured retrospectively and related to the respondent's current place of residence. As individuals may have migrated to another neighbourhood since uptake, migration effects have the potential to confound their associations to neighbourhood greenspace. Fifth, our findings are based on data from 2012, and given the steady decline in smoking prevalence in the general population over the last decade (WHO, 2018) it is unclear to what extent the associations observed here translate to present day trends in smoking behaviours. Further studies utilising more recent datasets and longitudinal designs are therefore needed to assess the robustness of our findings.

4.3 Concluding comments

As a major determinant of morbidity and mortality, smoking constitutes a significant public health issue. The current study provides novel evidence that neighbourhood greenspace is inversely associated with the prevalence of current smokers, and that this can be attributed to higher rates of smoking cessation in high greenspace neighbourhoods. Recognition of these associations advocates the need to protect and invest in natural resources, in order to maximise the public health benefits they may afford. If our findings are substantiated by further work, then nature-based interventions may assist individuals attempting to give up smoking.

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