The role of the physical environment in adolescent mental health

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Abstract

The existing literature suggests an association between the physical environment and mental health but also complex relationships between the social and the physical environment as well as between objective and subjective measures of the environment. In this study, we attempted to explore the role of the residential neighbourhood's physical environment in adolescent mental health, taking this complexity into account. Using data on 3683 ten- to 15-year-olds from England and Wales who participated in Understanding Society, we investigated the role of neighbourhood greenspace and air pollution in adolescent mental health (measured with the Strengths and Difficulties Questionnaire) while controlling for measures of neighbourhood and family socio-economic disadvantage as well as subjective perceptions of social cohesion, crime, safety, and noise in the neighbourhood. In linear regression models, greenspace and air pollution could not predict mental health. However, fear of being a victim of crime was a consistent predictor of mental health and behaviour, indicating the essential role of young people's subjective experience of their neighbourhoods for their mental health and well-being.

Keywords: greenspace; air pollution; fear of crime; mental health; neighbourhood; Understanding Society

Introduction

The physical environment is associated with the physical and mental health, cognitive performance, and behaviour of its users, as shown in numerous studies. In the existing epidemiological literature, two aspects of the physical environment have been predominantly examined in relation to people's health, cognition, and behaviour: air pollution and greenspace. These two physical aspects of the environment typically produce similar outcomes, such that physical health, cognition, and mental health are negatively associated with exposure to air pollution (Attademo, Bernardini, Garinella, & Compton, 2017; Brockmeyer & D'Angiulli, 2016; Cipriani, Danti, Carlesi, & Borin, 2018; Suades-González, Gascon, Guxens, & Sunyer, 2015; Xu, Ha, & Basnet, 2016) and positively associated with exposure to greenspace (Fong, Hart, & James, 2018; Kondo, Fluehr, McKeon, & Branas, 2018; Krefis, Augustin, Heinke Schlünzen, Oßenbrügge, & Augustin, 2018; McCormick, 2017; Tillman, Tobin, Avison, & Gilliland 2018). However, we still do not know how these two aspects of the physical environment, taken together, are associated with mental health. This, however, is important because air pollution and greenspace are spatially correlated, such that higher levels of greenspace are related to lower levels of air pollution (see Nieuwenhuijsen et al., 2018). At the same time, air pollution and greenspace can affect mental health via different mechanisms (Bloemsma et al., 2018). Greenspace can improve physical and mental health by facilitating physical activity (Almanza, Jerrett, Dunton, Seto, & Pentz, 2012; Bowler, Buyung-Ali, Knight, & Pullin, 2012; Dewulf, Neutens, van Dyck, de Bourdeaudhuij, Broekx, Beckx, & van de Weghe, 2016) and is linked to a reduced risk of stress and anxiety (Triguero-Mas et al., 2015; White, Alcock, Wheeler, & Depledge, 2013). Air pollution, in contrast, is associated with poor mental health outcomes, such as depression (Roberts et al., 2019) and psychosis (Newbury et al., 2019), arguably via a direct effect on the brain due to neuroinflammation, oxidative stress, microglial activation, cerebrovascular

dysfunction, and changes in the blood-brain barrier (Block & Calderón-Garcidueñas, 2009; Genc, Zadeoglulari, Fuss, & Genc, 2012). Neuroinflammation, for example, is strongly related to poor mental health, including depression, in some individuals (Howren, Lamkin, & Suls, 2009; Kiecolt-Glaser, Derry, & Fagundes, 2015). For the aforementioned reasons of 1) spatial correlation and 2) distinct aetiological mechanisms, it is essential to consider both greenspace and air pollution simultaneously in order not to misattribute their effects. The present study aimed to bridge this gap in the literature and to examine associations between both greenspace and air pollution with mental health in adolescence, a period of life relatively neglected by epidemiological research on the physical environment effects on mental health. The following sections provide a brief review of the literature on the links between greenspace, air pollution, and mental health.

Greenspace and Adolescent Mental Health

The role of greenspace in both child and adolescent mental health has received much attention in the last decade. For example, Feng and Astell-Burt (2017) investigated the link between the mental well-being of 4968 children from Australia at the age of four to five years and quantity and quality of neighbourhood greenspace. They found correlations between children's scores on the Strengths and Difficulties Questionnaire (SDQ) – a measure of mental health, also used in the present study – and objectively measured greenspace quantity as well as parent-reported greenspace quality. Flouri, Midouhas, and Joshi (2014), also using the SDQ, examined the association between urban neighbourhood greenspace and children's emotional and behavioural resilience. Their study on 6384 children at the age of three to five years in England showed that garden access and use of parks was associated with fewer conduct, peer, and hyperactivity problems. Although they did not find a relationship between neighbourhood greenspace quantity and behavioural and emotional outcomes in children in general, they showed positive effects for the emotional well-being of poor children.

Balseviciene et al. (2014) examined associations between residential greenness but also proximity to city parks and children's mental health measured with the SDQ. They analysed data of 1468 mothers of four- to six-year-old children from Lithuania and also found some evidence for positive effects in more disadvantaged groups. In their study, closer proximity to city parks was positively associated with mental health in children of mothers of low education, while residential greenness was negatively associated with mental health in children of mothers with higher education.

Studies have also established links in adolescents. For instance, Li, Deal, Zhou, Slavenas, and Sullivan (2018) found an association between daily exposure to nature and mood in adolescents at the age of 13 to 19 years. They tracked movements of 155 adolescents from Illinois with GPS over a period of four days and correlated exposure to nature (i.e., vegetation) with self-reported mood measured with the Profile of Mood States (POMS). They found that exposure to a greater concentration of nature was associated with lower scores on depression, anger, and fatigue, and with better overall mood. Similarly, Feda, Seelbinder, Baek, Raja, Yin, and Roemmich (2015) investigated the association between neighbourhood park area quantity and perceived stress in 12- to 15-year-old adolescents. They correlated scores on the Perceived Stress Scale of 68 adolescents from New York with neighbourhood park area quantity (i.e., nature trails, bike paths, playgrounds, athletic fields, and parks) and found that less exposure to such greenness was associated with more perceived stress. Finally, Younan et al. (2016) examined environmental determinants of aggression in 1287 adolescents from California at the age of nine to 18 years. Their findings indicated a negative association of neighbourhood greenspace quantity and parent-reported aggressive behaviour measured with the Child Behavior Checklist (CBCL/6-18).

Air Pollution and Adolescent Mental Health

The relationship between air pollution and mental health in adolescence is less clear, as most epidemiological studies on air pollution to date investigated associations with brain development and cognitive performance. Nevertheless, a few studies, most of which on adult samples, suggest a negative relationship between air pollution and mental health and well-being. For example, Du, Shin, and Managi (2018) investigated the link between air pollution and life satisfaction in China. They correlated local air pollution with self-reported life satisfaction in 958 and 881 people who were 20 years or older and lived in Beijing and Shanghai respectively. Higher levels of sulphur dioxide (SO_2) and nitrogen dioxide (NO_2) were associated with lower life satisfaction. In another recent study, also in China, Yuan, Shin, and Managi (2018) found the same negative relationship between air pollution and life satisfaction but also a positive correlation of green coverage with life satisfaction. Finally, Zhang, Zhang, and Chen (2017) examined the link between air pollution and life satisfaction, depressive status, and hedonic happiness, using subjective well-being data of 16,000 to 23,400 individuals from the China Family Panel Studies and correlating it with a day-to-day air pollution index including SO_2, NO_2, and particulate matter (PM_{10}) concentrations. They found that long-term life satisfaction was not associated with day-to-day air pollution. Hedonic happiness and depressive symptoms, however, were both related (negatively and positively, respectively) to it.

Only five studies have, to our knowledge, looked at adolescents, but all suggest links between air pollution and mental health. Forns et al. (2015) analysed data of 2897 children and adolescents from Spain at the age of seven to eleven years and found an association between indoor and outdoor air pollution (i.e., elemental carbon, black carbon, and NO_2) with parent-reported behavioural problems measured with the SDQ. Similarly, Younan et al. (2018) investigated the associations between air pollution and behaviour in 683 children and adolescents from California aged nine to 18 years and found a relationship between $PM_{2.5}$

concentration and parent-reported delinquent behaviour (e.g., lying, cheating, and stealing) measured with the CBCL/6-18. Laffan (2018), using data on 4277 participants, aged 16 years or older, of the Monitor of Engagement with the Natural Environment survey, found that particulate matter concentration was negatively associated with life satisfaction, visits to the outdoors, and engagement in physical activity. Moreover, visits to the outdoors explained 22 per cent of the relationship between air pollution and life satisfaction. More recently, Roberts et al. (2019) used a sample of 284 adolescents from London, followed from age 12 to age 18 years, and found associations between exposure to annualised $PM_{2.5}$ and NO_2 concentrations (estimated at address-level when children were aged 12) and mental health outcomes. Exposure was unrelated to concurrent mental health problems but was significantly associated with increased odds of major depressive disorder at age 18, even after controlling for confounding. Finally, in another recent study, Newbury et al. (2019) analysed data on 2063 adolescents from England and Wales, investigating the relationships between air pollution and psychotic experiences. The study included measures of four air pollutants: NO_2, nitrogen oxides (NO_X), PM_{10}, and $PM_{2.5}$. Higher levels of NO_2, NO_X, and $PM_{2.5}$ were associated with higher numbers of psychotic experiences from 12 to 18 years of age, and, strikingly, NO_2 and NO_X explained 60 per cent of the relationship between urbanicity and psychotic experiences in adolescents.

The Present Study

The existing epidemiological evidence suggests that greenspace and air pollution are positively and negatively, respectively, correlated with mental health and well-being. However, the research on which it is based has a number of limitations. First, very few studies focussed on mental health in adolescence specifically. Second, most studies included measures of either greenspace or air pollution but not both simultaneously. Third, the role of the social environment was not always considered, which is problematic because the social

environment is associated with both mental health and the physical environment; i.e., it may be a confounding variable that should be taken into account. Finally, even the studies that did consider the physical alongside the social environment measured both with objective measures. Although this approach is fundamentally correct, it ignores people's subjective perceptions of their environments, frequently related to health outcomes even more strongly than objective measures (Weden, Carpiano, & Robert, 2008). People's perceptions of their social environments especially are clearly associated with mental health outcomes such as anxiety and depression (Ellaway, Macintyre, & Kearns, 2001; Ellaway, Morris, Curtice, Robertson, Allardice, & Robertson, 2009). For example, McElroy et al. (2019) found direct and indirect associations of both neighbourhood social cohesion and neighbourhood social disorder with anxiety: people who perceived their neighbourhoods as less socially cohesive and more socially disordered showed worse symptoms of anxiety. Such relationships make it essential to consider people's subjective perceptions of their neighbourhoods in the investigation of relationships between objective neighbourhood characteristics and mental health.

In the present study, we addressed the aforementioned limitations. Using data from Understanding Society (https://www.understandingsociety.ac.uk/), a large UK general population household study, we investigated the relationships between both neighbourhood greenspace and air pollution and mental health in adolescents from England and Wales at the age of ten to 15 years. In addition, we considered both subjective and objective measures of the social and the physical environment. That is, alongside objective measures of air pollution, greenspace, and socio-economic deprivation in the neighbourhood, we included subjective perceptions of neighbourhood noise, safety, crime, and social cohesion. We also adjusted for gender, age, ethnicity, and social class, and controlled for urbanicity/rurality.

Methods

Study Sample

Understanding Society is a longitudinal study that includes data of the members of approximately 40,000 households across the United Kingdom at Wave 1 (2009 to 2011) and consists of eight waves so far (2009 to 2018). In the present study, we used the youth dataset from Wave 3 (2011 to 2013), including data on young people at the age of ten to 15 years. Demographic information about the respondents was added, if missing at Wave 3, from Waves 1 and 2 to reduce the amount of missing data in the covariates. In our analytic sample (N = 3683), we included respondents who were between 10 and 15 years old, lived in England or Wales, and had valid data on the SDQ at Wave 3. We excluded respondents from Scotland and Northern Ireland, as we did not have air pollution data for those UK countries.

Measures

Mental health and behaviour. Mental health and behaviour were measured with the self-completed Strengths and Difficulties Questionnaire (SDQ), a psychometrically valid and widely used index of emotional symptoms, conduct problems, hyperactivity/inattention, and peer relationship problems. Each of the four SDQ subscales includes five items that are rated on three-point Likert-type scales ranging from 'not true' to 'certainly true'. Scores for each subscale may range between 0 and 10. The 20 items of the four subscales can be combined to a total difficulties score ranging from 0 to 40. The subscale 'emotional symptoms' includes items such as 'I worry a lot', 'I am often unhappy', and 'I have many fears.' Example items of the subscale 'conduct problems' are 'I get very angry', 'I fight a lot', and 'I take things that are not mine.' The subscale 'hyperactivity/inattention' contains items such as 'I am restless', 'I am easily distracted', and 'I am constantly fidgeting.' Finally, items of the subscale 'peer relationship problems' include 'I am usually on my own', 'Other children or young people pick on me', and 'I get on better with adults than with people my age.' The Cronbach's alphas in our sample were: .68 for emotional symptoms, .62 for conduct

problems, .69 for hyperactivity/inattention, .53 for peer relationship problems, and .67 for total difficulties.

Objective measures of the physical and social environment. The objective measures of the environment in our model were neighbourhood greenspace, neighbourhood air pollution, neighbourhood deprivation, and urbanicity/rurality. *Neighbourhood greenspace* was measured with data from the Multiple Environmental Deprivation Index (MEDIx) at ward-level. The amount of greenspace was measured by combining land use data from the Coordination of Information on the Environment (CORINE; EEA, 2000) and the 2001 Generalised Land Use Database (GLUD; Minister, 2005). It offers an indicator of the percentage of greenspace per ward and includes all vegetated areas larger than $5m^2$ (except for domestic gardens), regardless of their accessibility (i.e., public or private). Richardson and Mitchell (2010) used both CORINE and GLUD to make estimations of the percentage of greenspace within each UK ward that were used in the present study (and measured in deciles). CORINE is a land cover dataset from 2000 for the UK that was derived from remotely sensed satellite imagery. It is only sensitive to larger green spaces such as parks and does not capture green spaces smaller than about 1ha. GLUD classifies land use across England at high geographical resolution into nine categories, i.e., greenspace, domestic gardens, fresh water, domestic buildings, non-domestic buildings, roads, paths, railways, and other. *Neighbourhood air pollution* was measured with model-based estimates of annual concentrations of NO_2 in micrograms per cubic meter of air ($\mu g/m^3$). Concentrations were estimated for Lower Layer Super Output Areas (LSOAs) in England and Wales from 2009 to 2011 (Mukhopadhyay & Sahu, 2017). LSOAs are built from Output Areas, the smallest standard areas of UK geography, and typically include about 600 homes and 1500 residents. Mukhopadhyay and Sahu (2017) modelled air pollution data collected from 144 active Automatic Urban and Rural Network (AURN) stations in England and Wales. They

predicted NO_2 concentrations at the corners of 1-km-grid-squares and used those data to obtain estimates of NO_2 concentrations at LSOA-level. *Neighbourhood deprivation* was measured, also at LSOA-level, with the 2011 Carstairs Index (in quintiles ranging from 1 'least deprived' to 5 'most deprived'). The Carstairs Index is based on four unweighted Census variables, i.e., proportions of low social class households, households with not a car or a van, overcrowded households, and male unemployment (Carstairs & Morris, 1989; Wheeler, 2014). The overall index reflects the level of material deprivation in the LSOA, and may be negative (i.e., more deprived) or positive (i.e., less deprived). Finally, we included *urbanicity/rurality*, i.e., whether respondents lived in urban or rural areas, as a fourth objective measure of the environment. In the UK, an area is defined as urban if it has a population of 10,000 or more.

Subjective measures of the physical and social environment. We included five measures of subjective perceptions of the environment, as follows. *Neighbourhood cohesion* was measured with a scale of 13 items, answered by the mothers of the adolescents, on quality of relationships with neighbours, sense of community and attraction to the neighbourhood, and network and neighbourhood homogeneity. The items were: 1. 'Overall do you like living in this neighbourhood?' 2. 'I am going to read out a set of statements that could be true about your neighbourhood. Please tell me how much you agree or disagree that each statement describes your neighbourhood: (a) First, this is a close-knit neighbourhood; (b) People around here are willing to help their neighbours; (c) People in this neighbourhood can be trusted; (d) People in this neighbourhood generally don't get along with each other.' 3. 'Here are some statements about neighbourhoods. Please enter the number that indicates how strongly you agree or disagree with each statement: (a) I feel like I belong to this neighbourhood; (b) Local friends mean a lot; (c) Advice is obtainable locally; (d) I can borrow things from neighbours; (e) I am willing to improve neighbourhood; (f) I plan to stay

in neighbourhood; (g) I am similar to others in neighbourhood; (h) I talk regularly to neighbours.' All items were recoded into binary variables in accordance with the scoring procedure followed by Emerson, Hatton, Robertson, and Baines (2014), with 0 reflecting less and 1 reflecting more neighbourhood cohesion. The 13 items were combined to a total score ranging from 0 to 13, with higher scores indicating greater neighbourhood cohesion (Cronbach's alpha in our sample was .83). We also considered the mothers' assessment of *noise* that was available in the dataset: 'Does your accommodation experience noise from neighbours?' (YES/NO). Finally, we used three variables assessing *adolescents' perceptions of the neighbourhood*, i.e.: 'Do you like living in this neighbourhood?' (YES/NO); 'How much do you worry that you might be a victim of crime?' (1 'a big worry' to 4 'not a worry at all'); and 'How safe would you feel walking alone in this area after dark?' (1 'very safe' to 4 'very unsafe').

Other covariates. Our covariates included gender, age in years, education of the mother (university degree or not), and ethnicity. The original ethnicity variable divided respondents into 22 ethnic groups. However, for practical reasons, we categorised respondents into two groups, i.e., 'White' and 'other'. The category White included 'White British', 'White English', 'White Scottish', 'White Welsh', 'White Northern Irish', 'White Irish', 'Gypsy or Irish traveller', and 'Any other White background'.

Statistical Analysis

First, we examined descriptive statistics of the analytic sample and correlations between all study variables. Then, we ran three linear regression models (A, B, and C) for all four SDQ subscales as well as the SDQ total difficulties scale as dependent variables in Stata/IC 15.1. All models accounted for the complex sampling design of Understanding Society. Analyses took into account stratification (by Government Office Region, population density, and minority ethnic density), non-independence of observations due to cluster

sampling (individuals in households and households within postal sectors), and weighting that adjusts for unequal selection probabilities, differential nonresponse, and potential sampling error.

Model A included the four objective measures of the environment, i.e., neighbourhood greenspace, neighbourhood air pollution, neighbourhood deprivation, and urbanicity/rurality as independent variables. Model B added to Model A the five subjective measures of the environment, i.e., neighbourhood cohesion, liking of living in the neighbourhood, fear of being a victim of crime, perception of safety, and noise from neighbours. Finally, Model C added to Model B four additional covariates, i.e., gender, age, mother's education, and ethnicity. We ran all three models for five dependent variables, i.e., the four SDQ subscales as well as the SDQ total difficulties scale. Thus, we ran 15 models in total. For parsimony, we only report models B and C in Tables 3 to 7.

Results

Descriptive Statistics

The great majority of participants lived in urban areas (80 per cent). On average, participants described their neighbourhoods as fairly safe and only had an occasional worry they might be a victim of crime. The sample consisted equally of 50 per cent male and female participants. 85 per cent were White, and mothers of 32 per cent of the participants had a university degree. Table 1 presents the descriptive statistics of all study variables. All objective measures of the environment were highly correlated, as expected. Greenspace was correlated negatively with air pollution and deprivation and positively with rurality. Air pollution was positively correlated with deprivation and negatively correlated with rurality. Finally, deprivation was negatively correlated with rurality. Furthermore, all SDQ variables were positively correlated. Table 2 shows the correlations among all study variables.

Table 1
Descriptive statistics of all study variables (N = 3683)

Continuous variables		n	*M(SD)*
SDQ emotional symptoms		3683	2.76(2.18)
SDQ conduct problems		3683	2.13(1.79)
SDQ hyperactivity/inattention		3683	3.83(2.27)
SDQ peer relationship problems		3683	1.74(1.65)
SDQ total difficulties		3683	10.45(5.68)
Neighbourhood greenspace		2148	4.46(2.51)
Neighbourhood air pollution		2148	37.55(7.87)
Neighbourhood deprivation		2148	3.14(1.41)
Neighbourhood cohesion (mother)		3117	11.47(2.41)
Perception of safety		3655	2.47(0.89)
Fear of being a victim of crime		3669	3.32(0.86)
Age		3683	12.24(1.73)
Categorical variables		n	*%*
Urbanicity/rurality	urban	3002	80.3
	rural	681	19.7
Likes living in neighbourhood	yes	3236	89
	no	418	11
Noise from neighbours (mother)	yes	740	18.3
	no	2937	81.8
Gender	male	1843	50.6
	female	1840	49.4
University degree (mother)	yes	708	32.2
	no	1592	67.8
Ethnicity	other	793	14.6
	White	2409	85.4

Note. Ns are unweighted. Means, standard deviations, and percentages are weighted. Greenspace: 1 = least, 10 = most; deprivation: 1 = least, 5 = most; cohesion: 0 = least, 13 = most; perception of safety: 1 = very safe, 4 = very unsafe; fear of being a victim of crime: 1 = a big worry, 4 = not a worry at all; urbanicity/rurality: 1 = urban, 2 = rural; likes living in neighbourhood: 1 = yes, 2 = no; noise from neighbours: 1 = yes, 2 = no; gender: 1 = male, 2 = female; university degree: 0 = no, 1 = yes; ethnicity: 0 = other, 1 = White.

Table 2
Correlations (Pearson's *r* coefficients) among all variables

	ES	CP	HA	PP	TD	NH GS	NH AP	NH depriv.	Rurality	NH cohes.	Liking	Safety	Crime	Noise	Gender	Age	Degree	Ethnicity
ES	1																	
CP	.30***	1																
HA	.32***	.53***	1															
PP	.37***	.26***	.22***	1														
TD	.72***	.73***	.77***	.61***	1													
NH GS	.01	-.03	.04	-.01	.01	1												
NH AP	.00	.01	-.06**	.01	-.02	-.67***	1											
NH depriv.	.01	.08***	.00	.05*	.04*	-.54***	.44***	1										
Rurality	.01	-.03	.03	.01	.01	.67***	-.50***	-.38***	1									
NH cohes.	-.07***	-.11***	-.07***	-.11***	-.12***	.10***	-.12***	-.22***	.13***	1								
Liking	.12***	.13***	.10***	.12***	.16***	-.06**	.08***	.14***	-.02	-.24***	1							
Safety	.21***	.04*	.01	.13***	.14***	-.17***	.13***	.17***	-.13***	-.13***	.16***	1						
Crime	-.27***	-.14***	-.10***	-.16***	-.24***	.11***	-.10***	-.10***	.07***	.07***	-.13***	-.27***	1					
Noise	-.03	-.04**	-.02	-.07***	-.05**	.11***	-.10***	-.13***	.07***	.14***	-.09***	-.06***	.05**	1				
Gender	.20***	-.12***	-.1***	-.07***	-.02	-.02	-.01	.01	-.02	.00	-.03	.18***	-.03	.03	1			
Age	.04*	.00	.03*	-.04*	.02	.01	-.01	.01	-.00	-.01	.06***	-.25***	.00	.01	.01	1		
Degree	.00	-.04	-.03	-.02	-.03	.06*	-.02	-.16***	.05*	.03	-.04*	-.05*	-.00	.02	.03	-.05*	1	
Ethnicity	.05**	.02	.11***	.04*	.09***	.41***	-.49***	-.40***	.25***	.07***	-.05**	-.04*	.05**	.06***	-.00	-.03	-.03	1

Note. ES: emotional symptoms; CP: conduct problems; HA: hyperactivity/inattention; PP: peer relationship problems; TD: total difficulties; NH GS: neighbourhood greenspace; NH AP: neighbourhood air pollution; NH depriv.: neighbourhood deprivation; rurality: urban or rural area; NH cohes.: neighbourhood cohesion; liking: likes living in neighbourhood; safety: perception of safety; crime: fear of being a victim of crime; noise: noise from neighbours; gender: adolescent's gender; age: adolescent's age; degree: mother is university-educated or not; ethnicity: adolescent is 'other' or 'White'. (For information on the values of each variable see footnote of Table 1.) $*p < .05$, $**p < .01$, $***p < .001$.

Linear Regression Models

Emotional symptoms. Table 3 shows regression models B and C for emotional symptoms. None of the objective measures of the environment were predictors of emotional symptoms. However, the subjective measures 'perception of safety' and 'fear of being a victim of crime' predicted emotional symptoms in models B and C. Participants who felt less safe and were more worried about being a victim of crime showed more emotional symptoms.

Conduct problems. Table 4 shows regression models B and C for conduct problems. Neighbourhood deprivation was a predictor of conduct problems. Higher scores of neighbourhood deprivation were associated with more conduct problems. The other objective neighbourhood measures did not predict conduct problems. Nevertheless, the subjective measures 'likes living in neighbourhood' and 'fear of being a victim of crime' were predictors of conduct problems in model B, and the latter remained a predictor in the fully adjusted model C. Participants who were more worried about being a victim of crime showed more conduct problems.

Hyperactivity and inattention. Table 5 shows regression models B and C for hyperactivity/inattention. Air pollution was a predictor of hyperactivity and inattention in model B but not in the fully adjusted model C. The other objective measures of the environment did not predict hyperactivity/inattention. However, the subjective measures 'likes living in neighbourhood' and 'fear of being a victim of crime' were predictors of hyperactivity and inattention in models B and C. Participants who did not like living in their neighbourhoods and participants who were more worried about being a victim of crime had higher scores in hyperactivity and inattention.

Peer relationship problems. Table 6 shows regression models B and C for peer relationship problems. Neighbourhood deprivation was a predictor of peer relationship

problems in the fully adjusted model C. Participants who lived in more deprived areas had more peer relationship problems. The other objective measures of the environment did not predict peer relationship problems. Nevertheless, the subjective measure 'fear of being a victim of crime' was a predictor in models B and C. Participants who were more worried about being a victim of crime had more peer relationship problems. Furthermore, in the fully adjusted model C, mother-reported neighbourhood cohesion was associated with peer relationship problems. Mothers who perceived their neighbourhood as more cohesive had adolescents with fewer peer relationship problems.

Total difficulties. Table 7 shows regression models B and C for total difficulties. None of the objective measures of the environment could predict total difficulties. Nonetheless, the subjective measures 'likes living in neighbourhood' and 'fear of being a victim of crime' were predictors in model B, and the latter remained a predictor in the fully adjusted model C. Participants who were more worried about being a victim of crime had more emotional and behavioural difficulties.

Supplementary Analysis

We ran additional analyses to test the robustness of our findings, the results of which can be found in Tables S1 to S9 in the supplementary material. First, we ran multilevel models where LSOA and ward codes were used as cluster variables. Tables S1 and S2 show that our sample is not clustered in LSOAs or wards, respectively, supporting our statistical approach in the analysis. Second, in consideration of the large variety of air pollutants, we included an additional air pollution measure, $PM_{2.5,}$ in our models to test whether it changed results. Table S3 shows that this was not the case. Third, we attempted to measure exposures more precisely by including additional variables for family socio-economic status and residential stability and by considering if urbanicity/rurality may moderate effects. Adding the interaction term 'rural*greenspace' in the models did not change results, nor did the

additional variables ‘estimated income’ (more specifically, estimated income of [and by] the adolescents’ mothers) and ‘year moved’ to current address (a good proxy for when adolescents moved to their current neighbourhoods), as shown in Tables S4 to S8. We also restricted our sample to urban cases only and re-fitted Model C for total difficulties. However, as Table S9 shows, the regression results remained the same. Finally, we ran logistic regression models in which the five dependent variables were made into binary variables using the SDQ cut-offs for ‘borderline/abnormal’ (emotional symptoms 6+; conduct problems 4+; hyperactivity/inattention 6+; peer relationship problems 4+; total difficulties 16+). The substantive findings remained unchanged (results available on request).

Table 3
Regression results for emotional symptoms

Predictors	Model B (n = 1392)				Model C (n = 1082)			
	b	SE	95% CI	beta	b	SE	95% CI	beta
NH greenspace	0.078	0.05	[-0.02, 0.177]	0.091	0.087	0.058	[-0.029, 0.202]	0.101
NH air pollution	-0.007	0.014	[-0.034, 0.021]	-0.024	0.000	0.015	[-0.03, 0.031]	0.001
NH deprivation	-0.033	0.063	[-0.157, 0.092]	-0.022	0.025	0.073	[-0.12, 0.169]	0.016
Rural	-0.24	0.321	[-0.872, 0.392]	-0.043	-0.164	0.388	[-0.931, 0.603]	-0.03
NH cohesion	-0.018	0.042	[-0.099, 0.064]	-0.018	-0.021	0.041	[-0.102, 0.06]	-0.02
Does not like living in NH	0.444	0.318	[-0.182, 1.069]	0.058	0.408	0.385	[-0.353, 1.169]	0.054
Thinks NH is unsafe	0.415**	0.099	[0.22, 0.609]	0.166	0.339**	0.125	[0.092, 0.585]	0.134
No fear of being a victim of crime	-0.582**	0.111	[-0.801, -0.363]	-0.233	-0.622**	0.12	[-0.859, -0.384]	-0.244
No noise from neighbours	0.162	0.226	[-0.283, 0.608]	0.029	0.241	0.229	[-0.212, 0.694]	0.043
Female					0.824**	0.176	[0.476, 1.172]	0.186
Age					0.112*	0.049	[0.016, 0.208]	0.09
Mother is university-educated					0.003	0.165	[-0.322, 0.328]	0.001
White					0.689**	0.262	[0.172, 1.206]	0.13
Constant	3.402**	1.245	[0.95, 5.854]	0.007	-0.143	1.475	[-3.057, 2.771]	-0.008
R^2 adjusted	0.112				0.166			

Note. For information on the values of each variable see footnote of Table 1. *$p < .05$, **$p < .01$.

Table 4
Regression results for conduct problems

Predictors	Model B (n = 1392)				Model C (n = 1082)			
	b	SE	95% CI	beta	b	SE	95% CI	beta
NH greenspace	0.035	0.04	[-0.044, 0.114]	0.051	0.044	0.047	[-0.049, 0.137]	0.065
NH air pollution	-0.02	0.01	[-0.04, 0.001]	-0.091	-0.02	0.012	[-0.043, 0.004]	-0.091
NH deprivation	0.114*	0.052	[0.012, 0.217]	0.095	0.142*	0.062	[0.02, 0.264]	0.117
Rural	-0.332	0.217	[-0.759, 0.096]	-0.075	-0.3	0.276	[-0.845, 0.245]	-0.069
NH cohesion	-0.039	0.029	[-0.095, 0.017]	-0.051	-0.05	0.033	[-0.116, 0.015]	-0.062
Does not like living in NH	0.478*	0.195	[0.094, 0.863]	0.08	0.326	0.27	[-0.207, 0.858]	0.055
Thinks NH is unsafe	-0.017	0.079	[-0.174, 0.139]	-0.009	0.054	0.106	[-0.155, 0.262]	0.027
No fear of being a victim of crime	-0.32**	0.087	[-0.491, -0.149]	-0.163	-0.32**	0.106	[-0.529, -0.112]	-0.16
No noise from neighbours	-0.16	0.185	[-0.524, 0.204]	-0.036	-0.073	0.206	[-0.479, 0.333]	-0.016
Female					-0.409**	0.127	[-0.659, -0.159]	-0.118
Age					0.002	0.04	[-0.078, 0.081]	0.002
Mother is university-educated					-0.077	0.141	[-0.355, 0.202]	-0.021
White					0.134	0.193	[-0.247, 0.515]	0.032
Constant	3.979**	0.82	[2.364, 5.594]	0.012	4.276**	1.004	[2.293, 6.259]	0.002
R^2 adjusted	0.061				0.075			

Note. See Table 3.

Table 5
Regression results for hyperactivity/inattention

Predictors	Model B (n = 1392)				Model C (n = 1082)			
	b	SE	95% CI	beta	b	SE	95% CI	beta
NH greenspace	0.014	0.05	[-0.084, 0.113]	0.016	0.014	0.056	[-0.097, 0.124]	0.015
NH air pollution	-0.027*	0.011	[-0.05, -0.005]	-0.097	-0.013	0.015	[-0.041, 0.016]	-0.044
NH deprivation	0.053	0.065	[-0.075, 0.181]	0.034	0.062	0.078	[-0.091, 0.215]	0.04
Rural	-0.235	0.252	[-0.731, 0.261]	-0.041	-0.135	0.312	[-0.752, 0.482]	-0.024
NH cohesion	-0.004	0.043	[-0.088, 0.079]	-0.004	0.002	0.049	[-0.095, 0.098]	0.001
Does not like living in NH	0.746**	0.255	[0.243, 1.248]	0.095	0.648*	0.321	[0.014, 1.282]	0.084
Thinks NH is unsafe	-0.068	0.102	[-0.269, 0.134]	-0.026	0.048	0.121	[-0.191, 0.287]	0.019
No fear of being a victim of crime	-0.277**	0.102	[-0.478, -0.076]	-0.108	-0.294*	0.118	[-0.526, -0.062]	-0.113
No noise from neighbours	-0.141	0.214	[-0.563, 0.281]	-0.024	0.039	0.239	[-0.434, 0.512]	0.007
Female					-0.429*	0.184	[-0.791, -0.067]	-0.095
Age					0.051	0.053	[-0.053, 0.155]	0.04
Mother is university-educated					-0.103	0.19	[-0.478, 0.272]	-0.022
White					0.484*	0.225	[0.039, 0.928]	0.089
Constant	5.435**	1.09	[3.289, 7.582]	0.034	3.82*	1.638	[0.586, 7.054]	0.01
R^2 adjusted	0.03				0.041			

Note. See Table 3.

Table 6
Regression results for peer relationship problems

Predictors	Model B (n = 1392)				Model C (n = 1082)			
	b	SE	95% CI	beta	b	SE	95% CI	beta
NH greenspace	0.053	0.039	[-0.025, 0.13]	0.083	0.047	0.047	[-0.046, 0.139]	0.075
NH air pollution	-0.001	0.01	[-0.02, 0.018]	-0.006	-0.011	0.011	[-0.033, 0.011]	-0.056
NH deprivation	0.072	0.052	[-0.03, 0.174]	0.064	0.126*	0.061	[0.006, 0.246]	0.113
Rural	-0.095	0.23	[-0.548, 0.358]	-0.023	-0.184	0.274	[-0.724, 0.357]	-0.045
NH cohesion	-0.052	0.033	[-0.118, 0.013]	-0.072	-0.088**	0.033	[-0.154, -0.023]	-0.118
Does not like living in NH	0.167	0.261	[-0.347, 0.681]	0.03	0.122	0.273	[-0.416, 0.66]	0.022
Thinks NH is unsafe	0.098	0.082	[-0.062, 0.259]	0.053	0.009	0.098	[-0.184, 0.203]	0.005
No fear of being a victim of crime	-0.259**	0.084	[-0.425, -0.094]	-0.14	-0.294**	0.08	[-0.453, -0.135]	-0.158
No noise from neighbours	-0.218	0.179	[-0.571, 0.135]	-0.052	-0.044	0.165	[-0.37, 0.283]	-0.011
Female					-0.271*	0.125	[-0.519, -0.024]	-0.084
Age					-0.054	0.035	[-0.123, 0.015]	-0.06
Mother is university-educated					-0.132	0.138	[-0.405, 0.142]	-0.039
White					0.127	0.187	[-0.243, 0.496]	0.033
Constant	2.908**	0.89	[1.155, 4.662]	0.017	4.736**	1.234	[2.299, 7.174]	0.014
R^2 adjusted	0.05				0.074			

Note. See Table 3.

Table 7
Regression results for total difficulties

Predictors	Model B (n = 1392)				Model C (n = 1082)			
	b	SE	95% CI	beta	b	SE	95% CI	beta
NH greenspace	0.18	0.127	[-0.07, 0.43]	0.082	0.191	0.148	[-0.102, 0.484]	0.088
NH air pollution	-0.055	0.031	[-0.116, 0.006]	-0.078	-0.043	0.036	[-0.115, 0.028]	-0.062
NH deprivation	0.207	0.163	[-0.114, 0.527]	0.053	0.354	0.201	[-0.042, 0.751]	0.092
Rural	-0.902	0.775	[-2.427, 0.624]	-0.062	-0.783	0.948	[-2.655, 1.091]	-0.056
NH cohesion	-0.113	0.115	[-0.34, 0.113]	-0.045	-0.158	0.109	[-0.373, 0.056]	-0.061
Does not like living in NH	1.834**	0.694	[0.468, 3.201]	0.094	1.505	0.816	[-0.107, 3.116]	0.079
Thinks NH is unsafe	0.428	0.264	[-0.091, 0.948]	0.067	0.45	0.317	[-0.176, 1.076]	0.07
No fear of being a victim of crime	-1.438**	0.288	[-2.006, -0.871]	-0.224	-1.53**	0.312	[-2.145, -0.914]	-0.238
No noise from neighbours	-0.356	0.617	[-1.572, 0.859]	-0.025	0.164	0.589	[-0.999, 1.327]	0.012
Female					-0.286	0.435	[-1.145, 0.574]	-0.026
Age					0.111	0.11	[-0.106, 0.327]	0.035
Mother is university-educated					-0.308	0.457	[-1.211, 0.594]	-0.026
White					1.433*	0.556	[0.335, 2.532]	0.107
Constant	15.724**	2.955	[9.903, 21.546]	0.025	12.689**	3.336	[6.101, 19.277]	0.006
R^2 adjusted	0.097				0.113			

Note. See Table 3.

Discussion

This study explored associations between aspects of the physical environment and mental health among adolescents in England and Wales, using data from a large, general population sample. Its important strength was the use of objective measures of greenspace and air pollution alongside subjective measures of the environment and key covariates, including area social deprivation, individual social class, and urbanicity/rurality.

The key finding of this study was that subjective measures of the environment were associated with mental health and behaviour in adolescents. Perhaps the most striking finding was that fear of being a victim of crime was significantly associated with all five mental health and behavioural outcomes we examined (i.e., emotional symptoms, conduct problems, hyperactivity and inattention, peer relationship problems, and total difficulties). With this finding, our study supports the existing literature on the relationship between fear of crime and mental health (Lorenc et al., 2012). Of course, due to the correlational nature of our study, we cannot assume a causal link between fear of being a victim of crime and mental health. For example, it would be possible that adolescents with more mental health problems are simply more worried of being a victim of crime than adolescents with fewer problems. In a literature review on the relationships between crime, fear of crime, environment, and mental health, Lorenc et al. (2012) elaborated on their complexity and the difficulty in disentangling it. Thus, more research is needed to uncover the causal mechanisms underlying the link between fear of being a victim of crime and mental health.

Interestingly, perception of safety predicted only emotional symptoms but not the other four outcome variables. This is somewhat surprising, as one may assume that perception of safety and fear of being a victim of crime are substantially related (i.e., the more unsafe one finds an environment, the more worried one may be about becoming a victim of crime in that environment). However, in the present study, the two variables only

showed a small to moderate correlation. A possible explanation why fear of being a victim of crime appears to play a more important role in adolescent mental health may be that perceiving a neighbourhood as unsafe gives one the opportunity to, for instance, avoid being outside in the dark. Therefore, although someone may perceive their neighbourhood as generally unsafe, they may not be personally affected by its (objective or subjective) dangerousness. On the contrary, when someone is worried about being a victim of crime, they experience a significant threat to their personal life that may have a direct impact on their mental health. Neighbourhood social cohesion also appeared to be related to adolescent behaviour, but only in terms of peer problems. More mother-reported social cohesion in the neighbourhood was independently associated with fewer adolescent-reported peer problems, in line with much evidence pointing to the role of neighbourhood collective efficacy for preventing or attenuating social problems among adolescents (Schmidt, Pierce, & Stoddard, 2016). A last finding pointing to the role of subjective area perceptions for mental health and behaviour was the higher scores of hyperactivity, even after full adjustment, of those adolescents reporting that they did not like living in their neighbourhood.

A rather surprising key finding, however, was that objective measures of neighbourhood greenspace and air pollution did not predict mental health or behaviour in adolescents. By contrast, the 'objective' measure of the social environment we considered, the Carstairs Index, was related to adolescent behaviour, albeit only in terms of conduct and peer problems, in line with much previous research on the association between neighbourhood socio-economic disadvantage and child and adolescent antisocial and aggressive behaviour (Galán, Shaw, Dishion, & Wilson, 2017). We offer four possible explanations for our null findings about the role of the physical environment. First, the relationships between the physical environment, mental health, and behaviour have proven to be very complex and likely moderated by other factors. For example, Flouri et al. (2014)

found an association of neighbourhood greenspace and mental health only in poor children in their study. Similarly, Balseviciene et al. (2014) reported associations between residential greenness, proximity to city parks, and children's mental health that differed significantly by the education level of their mothers. These findings illustrate that the physical environment, in itself complex, is only one of many influencing factors, which makes it difficult to reveal its role in (adolescent) mental health. The second possible explanation is that the physical environment may exert both positive and negative 'social' effects. For example, it is conceivable that adolescents who live in greener areas get bored more easily than adolescents in less green areas and consequently show more mental health and behavioural problems. This potentially negative 'side-effect' of greener areas may cancel out the expected positive effect of greenspace on mental health, especially in adolescence, a period of life often characterised by sensation-seeking. The third possible explanation may be the lack of consistency between our measures and others'. For example, previous studies have used measures of different air pollutants, including SO_2 and PM, to estimate neighbourhood air pollution. Importantly, different types of pollutants may have different effects on human health (Kampa & Castanas, 2008), and it is likely that links may exist only between specific air pollutants and specific mental health outcomes. Similarly, scientists have used various operationalisations of greenspace. For example, Flouri et al. (2014) included measures of neighbourhood greenspace, garden access, and use of parks; Balseviciene et al. (2014) investigated residential greenness and proximity to city parks; and Feda et al. (2015) used a measure of neighbourhood park area that included parks, nature trails, bike paths, playgrounds, and athletic fields. Studies also used several measures of mental health and behaviour, including the SDQ (e.g., Feng & Astell-Burt, 2017), the POMS (e.g., Li et al., 2018), and the CBCL/6-18 (e.g., Younan et al., 2016). All these variations in definitions, estimates, and instruments may contribute to inconsistencies across studies. Finally, it is

plausible that, for adolescents, their residential LSOA (a very small geographical unit, especially in urban areas where the vast majority of our sample lived) or even ward may not be the most relevant physical context. Adolescents, probably more than any other segment of the population, likely spend most of their time in school, 'hanging out' with their friends, or loitering in public spaces that are not in their immediate neighbourhood (Browning & Soller, 2014). We were not able to link physical environment data on those locations to the individuals. Thus, we could not fully capture adolescents' actual everyday spatial behaviour and therefore more precise exposure to greenspace and air pollution.

Given our study's design, we cannot make claims about causal effects of physical and social environments on adolescent mental health. However, our consistent finding of the negative relationship between someone's fear of being a victim of crime in the neighbourhood and their mental health highlights the important role of adolescents' experience of their neighbourhoods. This robust finding, which is also supported by the existing literature (Lorenc et al., 2012), suggests that area policies should focus not only on reducing crime but also on understanding what physical and social aspects of neighbourhoods may increase their residents' fear of crime. By uncovering such environmental influences, local areas may be able to develop local solutions and interventions in order to improve the mental health and well-being of their young inhabitants.

As has already been indicated throughout the discussion, our study is not without limitations. First, its correlational nature does not allow us to make inferences about causal links. Future research can shed light on causal mechanisms, for example, by using a range of methods, including longitudinal, location-technology, and virtual reality studies. Second, our estimates of air pollution and greenspace are limited. For example, we used 2001 data to estimate the amount of greenspace in English and Welsh neighbourhoods in 2011-2013. This could be problematic, as one may assume changes in neighbourhood greenspace over time.

However, although there is only little research on area changes in the United Kingdom over time (Lupton & Power, 2004), evidence indicates that area characteristics do not change substantially over a decade (Gambaro, Joshi, Lupton, Fenton, & Lennon, 2016; Kontopantelis et al., 2018), suggesting that the greenspace measure used in our study was appropriate. Furthermore, NO_2 concentrations were estimated on LSOA level, and, although this is a relatively small geographical area, it may be too large to capture an individual's direct exposure to outdoor pollutants. Finally, as mentioned earlier, measures of neighbourhood greenspace and air pollution may not reflect the adolescents' actual everyday exposure to greenspace and air pollution. It is likely that adolescents move around not only in their own immediate neighbourhoods but in other areas too and spend most of their time in school, which for secondary school students, our sample, is typically not in their own LSOA. More studies are needed that track participants' exposures to and use of their actual, as opposed to administratively-defined, physical environments and over a period of time, as in Li et al. (2018). Another limitation of our study is that, although we considered a number of key covariates in our statistical models, we cannot rule out confounding or misclassification entirely. For example, we included a variable that measured the mother's experience of noise from neighbours, but we did not have measures of the adolescent's perception of noise or indeed objective noise levels. However, noise, particularly traffic noise, is likely to be spatially related to both air pollution and greenspace (Nieuwenhuijsen et al., 2018) and to be associated with mental health, e.g., by disrupting sleep (de Kluizenaar, Janssen, van Lenthe, Miedema, & Mackenbach, 2009; Onakpoya, O'Sullivan, Thompson, & Heneghan, 2015). Thus, future studies should include variables of objective and subjectively perceived noise levels to rule out misattribution or misinterpretation of effects of greenspace and air pollution on mental health. Finally, our study sample includes respondents from two UK countries, England and Wales, which limits the generalisability of findings. Future studies should

investigate relationships between objective and subjective measures of the environment and adolescent mental health across countries and cultures.

In summary, we did not find significant associations between objective measures of greenspace and air pollution in the residential neighbourhood and adolescent mental health. However, subjective measures of the neighbourhood's social environment, particularly fear of being a victim of crime, were associated significantly with mental health in adolescence, even after adjusting for many common risk factors. Together, these findings suggest an important association between young people's experience of their neighbourhoods and their mental health.

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