



Urban greenspace and anxiety symptoms during the COVID-19 pandemic: A 20-month follow up of 19,848 participants in England

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ARTICLE INFO

Keywords:
Greenspace
Anxiety
COVID-19
Nature
Panel data

ABSTRACT

This study examined the association between greenspace and the growth trajectories of anxiety symptoms during the COVID-19 pandemic. Using data from 19,848 urban residents in England who were followed for 20 months between March 2020 and October 2021, we found that living in an area with higher greenspace coverage (exposure) was associated with fewer anxiety symptoms independent of population density, area deprivation levels, socio-demographics, and health profiles. There was limited evidence that greenspace was related to the change of anxiety symptoms over time. No association with anxiety trajectories was found when considering distance to nearest greenspace (proximity), highlighting potentially differential mental health effects of simply having access to local parks and recreation areas versus living in areas of greater natural environment land cover. These findings have important implications for mental health intervention and policymaking.

1. Introduction

There is a growing body of literature on the effect of exposure to natural environments or greenspace on mental health (Collins et al., 2020; Wendelboe-Nelson et al., 2019; Kotera et al., 2020; Gascon et al., 2015). For example, a Dutch study that used primary care records linked to greenspace in people's postcode areas found that a higher percentage of greenspace was associated with lower odds of depressive and anxiety disorders (Maas et al., 2009). Another large-scale observational study in Australia found that a higher exposure to greenspace was associated with lower incidence of psychological distress (Astell-Burt and Feng, 2019). Further, a German survey that followed the same participants over 12 years found that living a shorter distance (proximity) to urban greenspace was associated with higher life satisfaction (Krekel et al., 2016). Similar findings have also been found in experimental studies. A study in Japan reported that exposure to a forest environment significantly decreased feelings of hostility and depression compared to a control day (not visiting a forested area) (Morita et al., 2007). And a randomised trial in the United States (US) found that feelings of depression and worthlessness were significantly lower in the greening intervention group (cleaning and greening vacant lots) compared to the control group without any intervention (South et al., 2018).

Several theories have been proposed to understand the mechanisms

of the psychological benefits of greenspace. The widely recognised theories include (but are not limited to) the attention restoration theory (ART), stress reduction theory (SRT), and neighbourhood effect theory. ART suggests that natural environment exposure enables recovery from directed attention fatigue due to prolonged engagement in mental-demanding tasks (Kaplan, 1995). Similarly, SRT suggests that exposure to nature can activate a quick positive affective response and initiate the restorative process because it provides a breather from stress or blocks negative thoughts and feelings (Ulrich et al., 1991). Benefits of nature and greenspace may also arise from the lifestyle and behaviours which people engage in when exposed to greenspace. According to the theory of neighbourhood effect, greenspace may help sustain and improve health by providing venues for physical activities (e.g. walking, running, cycling and gardening), and by facilitating social interactions within a community (Duncan and Kawachi, 2018). People living in areas with better access to greenspace may be more motivated to engage in these activities and interactions, which are known to have positive effects on mental health and wellbeing (Fancourt et al., 2021a). More generally, there is a consensus that greenspace can reduce exposure to environmental stressors such as air pollution, heat and noise (Markelych et al., 2017). These theories situate within a generalized framework of three nature-health pathway domains: restoring capacity (e.g. ART and SRT), building capacity (e.g. physical activity and social

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<https://doi.org/10.1016/j.healthplace.2022.102897>

Received 30 April 2022; Received in revised form 9 August 2022; Accepted 10 August 2022

Available online 18 August 2022

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contact), and reducing harm (e.g. reducing exposure to noise). (Markevych et al., 2017).

From December 2019, the world was devastated by the outbreak of coronavirus disease (COVID-19). Many countries, including the United Kingdom (UK), implemented lockdown or stay-at-home orders to control the spread of the virus. These restrictions led to significant reductions in human movement, for example 70–90% decreases in the use of public transport and 40–80% in driving and walking during the first national lockdown (23rd March–10th May 2020) (Hadjidemetriou et al., 2020). Notably, movements remained below usual levels even after the restrictions were lifted in the UK (Hadjidemetriou et al., 2020). Yet despite this general decrease in movements, there was evidence that park/forest visits increased in some countries during the pandemic compared to before (Geng et al., 2021; Venter et al., 2020). This suggests that individuals might have prioritised opportunities to engage in nature and spend time in greenspace, raising the question as to whether such behaviours were undertaken as part of coping strategies to support and sustain mental health and wellbeing.

Studies have consistently shown worsening mental health during the COVID-19 pandemic across all age groups, in particular in countries where greater social restrictions were imposed (Pierce et al., 2020; Shanahan et al., 2020). But as yet, the literature on whether greenspace supported mental health in the pandemic is in its early stages, and results are mixed (Labib et al., 2022). Studies that used self-reported measures of nature experience found that nature views from home and accessible greenspace in the neighbourhood were associated with a lower level of depression and anxiety during the pandemic (Pouso et al., 2021; Soga et al., 2021; Kondo et al., 2022). A study of US college students found that fewer park visits and lower access to residential greenspace was associated with higher levels of emotional distress (Larson et al., 2022). However, in another study, although people who self-reported a decrease in visiting greenspace during the pandemic were found to have a higher risk of major depression, no evidence was found for anxiety (Heo et al., 2021). Similar findings were reported in a study that used tree-rich greenspace measures from residential postcodes (Wortzel et al., 2021). However, most studies on greenspace and mental health during COVID-19 have used cross-sectional data, focusing on particular short periods during the pandemic (e.g. first lockdown). There is a lack of longitudinal studies looking at how greenspace is related to mental health changes over time during the COVID-19 pandemic.

In light of this, this study aimed to examine the relationship of greenspace with the growth trajectories anxiety across different stages of the COVID-19 pandemic. We used data from 25,390 adults living in urban areas in England who were followed for 20 months between March 2020 and October 2021. Data were analysed using latent growth modelling, which allowed us to examine how access to urban greenspace was related to the level of and rate of change in anxiety across different stages of the COVID-19 pandemic. Our study provides an advance on previous research on greenspace and mental health in several ways. First and methodologically, a challenge in pre-pandemic observational studies is that residential greenspace data are often assumed to be a proxy for greenspace exposure, although it is clear that many people often visit nature some distance from their home (Schindler et al., 2022). However, the COVID-19 restrictions, especially strict lockdowns, confined people to their homes and local neighbourhoods (Ugolini et al., 2021; Natural England, 2021), providing a unique opportunity to explore the psychological benefits of residential greenspace. Second, as mentioned above, the present study followed individuals over a longer period through the course of the pandemic compared to most other studies.²⁰ Such empirical evidence is important given the changing nature of COVID-19 intensity, the associated policy responses, and reported adverse effects across the pandemic on public mental health.

2. Method

2.1. Research design and participants

This study analysed data from the University College London (UCL) COVID-19 Social Study, a large online panel study of the psychological and social experiences of over 75,000 adults (aged 18+) in the UK during the COVID-19 pandemic. The study commenced on 21 March 2020 and involved weekly and then monthly (four-weekly) data collection during the pandemic via self-completed online surveys using REDCap electronic data capture tools hosted at UCL (Harris et al., 2019). The study did not use a random sample design and therefore the original sample is not representative of the UK population. However, it does contain a heterogeneous sample that was recruited using three primary approaches. First, convenience sampling was used, including promoting the study through existing networks and mailing lists (including large databases of adults who had previously consented to be involved in health research across the UK such as UCL BioResource and HealthWise Wales), print and digital media coverage, and social media. Second, more targeted recruitment was undertaken focusing on (i) individuals from a low-income background, (ii) individuals with no or few educational qualifications, and (iii) individuals who were unemployed. Third, the study was promoted via partnerships with third sector organisations to vulnerable groups, including adults with pre-existing mental health conditions, older adults, carers, and people experiencing domestic violence or abuse. The study was approved by the UCL Research Ethics Committee [12467/005] and all participants gave informed consent before proceeding with online surveys. A full protocol for the study is available online at <https://osf.io/jm8ra/>.

In the present study, we restricted the sample to participants living in England ($N = 58,726$) in order to reduce heterogeneity in the dates of implementation of social restrictions. Postcodes that were used to link with greenspace measures were collected at later stages of the COVID-19 Social Study (February and November 2021). These were available for 30,529 participants who had not moved addresses since March 2020. Further, we excluded participants with fewer than three repeated measures (9.1%) or with missing data on any of the outcome variables or predictors (9.2%). This left us an analytical sample of 24,934 participants with a maximum of 20 unique data points (months) from March 2020 to October 2021. Considering the substantive differences in greenspace accessibility and type in rural areas (Alcock et al., 2015), this study focused on participants living in urban areas based on the 2011 rural-urban classification for small area geographies ($N = 12,658$). Please see the [Supplementary Fig. S1](#) for the distribution of the included areas.

2.2. Measurements

2.2.1. Anxiety symptoms

Anxiety symptoms were measured using the Generalized Anxiety Disorder assessment (GAD-7) (Spitzer et al., 2006); a well-validated tool used to screen for generalized anxiety disorder in clinical practice and research. Unlike the original scale, the GAD-7 questions in this study were worded as ‘over the last week’ instead of ‘over the last two weeks’ as data were initially collected weekly. The GAD-7 comprises 7 items with 4-point responses ranging from ‘not at all’ to ‘nearly every day’, with higher overall scores indicating more symptoms of anxiety, ranging from 0 to 21.

2.2.2. Greenspace

This study used ‘greenspace’ as a generic term for natural environments broadly. In the main analyses, greenspace exposure was measured as coverage (in percentages) of natural environment land cover (e.g. woodland, grassland, mountain, heath & bog, arable/horticultural site etc.) within each Lower-layer Super Output Area (LSOA). Land cover data were derived from the 2019 UKCEH Land Cover Map (Morton et al.,

2020). The 20m raster land cover dataset was intersected with LSOA boundaries using a geographic information system (ArcGIS 10.6, ESRI, Redlands CA), and the percentage area of all land cover types excluding urban/suburban was calculated for each area. LSOAs are small areas designed to be of a similar population size, with an average of approximately 1,500 residents. Participants' postcodes were linked to their LSOA of residence using the Office for National Statistics (ONS) Postcode Directory. 12,685 urban LSOAs (out of 26,989 in England) included at least one participant from the analytical sample. The greenspace coverage in the residential area was coded as a categorical variable with four categories: $\leq 10\%$, $<10\text{--}20\%$, $<20\text{--}50\%$, $>50\%$ (Wheeler et al., 2015).

In addition to coverage percentages, we used proximity (distance in hundred meters) to the closest public parks and playing fields as an alternative greenspace measure in sensitivity analyses. The proximity measure was based on Ordnance Survey data obtained from the ONS (Office for National Statistics). In the sensitivity analyses, we also considered a subjective evaluation of greenspace. This was measured by a single question asking how satisfied people were with the availability of useable greenspace/parks in their neighbourhood (satisfied vs neutral/dissatisfied). This information was collected only once in July 2020 and was available for a reduced number of participants (N = 12,570).

2.2.3. Covariates

We controlled for two area level factors, population density and area deprivation. Population density was of particular importance in the context of COVID-19 which might be directly or indirectly related to anxiety symptoms. Population density was defined as number of people per square kilometre, which was obtained from the ONS based on LSOA. This was categorised into three categories: $\leq 2,500$, $<2,500\text{--}5,000$, $>5,000$.

Area deprivation was measured by the Index of Multiple Deprivation (IMD, 2019) at LSOA level. This was coded in deciles with 1 being the most deprived and 10 the least deprived. IMD considered seven domains of deprivation, including income, employment, education, health, crime, barriers to housing and services and living environment. The environment domain only included housing condition, outdoor air quality and road traffic accidents, which therefore did not overlap with the greenspace measures.

In addition, we considered a number of individual characteristics as potential confounders. These included gender (women vs men), ethnicity (white vs ethnic minorities), age groups (age 18–29, 30–45, 46–59, 60+), education (up to GCSE levels, A-levels or equivalent, university degree or above), annual household income ($<£16,000$, $\leq£16,000\text{--}29,999$, $\leq£30,000\text{--}59,999$, $\leq£60,000\text{--}89,999$, $\geq£90,000$), employment status (employed vs other), self-reported diagnosis of any physical health condition (e.g., asthma, diabetes) or any disability (yes vs no), and self-reported diagnosis of any mental health condition (e.g., depression, anxiety) (yes vs no). In the sensitivity analyses, we additionally controlled for going outdoors measured by asking participants how many days they had been outside for 15 minutes or more. It was used as a time-varying covariate.

2.3. Statistical analysis

Data were analysed using the latent growth modelling (LGM) approach to estimate growth trajectories of anxiety symptoms in the structural equation modelling framework. More specifically, we used piecewise LGM which deals with nonlinear growth trajectories (Kohli and Harring, 1080). It assumes that there are multiple stages in the developmental process of the outcome variable, with different growth rates. It breaks the overall trajectory into separate linear pieces connected by knots. The choice of knots (break points) was informed by previous research (Fancourt et al., 2021b, 2021c) and the data. We started with an unconditional latent growth model of anxiety symptoms without any predictors, followed by the model with only greenspace to

predict the growth factors (intercept and slope) (Model I). Then, we added the area factors, namely population density and IMD, to the model (Model II). Finally, the full model additionally controlled for individual characteristics (Model III).

In addition to the main analyses, a sensitivity analysis on a subsample (N = 12,570) was conducted to consider both quantity (coverage) and quality (satisfaction) of greenspace exposure. We also tested an alternative approach (free time scores) which makes no assumption about the shape of growth trajectory and allows it to be determined by data. Further, we carried out another sensitivity analysis using an alternative greenspace measure (proximity), as well as controlling the time-varying covariate of going outdoors. Weights were applied throughout the analyses. The analytical sample was weighted to the proportions of gender, age, ethnicity and education in the English population obtained from the ONS (Office for National Statistics, 2019). Main analyses were implemented in Mplus Version 8.

3. Results

3.1. Descriptive statistics

As shown in Table 1, in the unweighted sample of 19,848 participants, women (75.6%) and people with a university degree or above (69.8%) were overrepresented, whereas younger adults (aged 18–29; 4.5%) and people from ethnic minority groups (4.8%) were underrepresented. After weighting, the sample reflected population proportions, with 52.9% women, 36.8% participants with a degree or above, 17% aged under 30, and 13.8% participants belonging to an ethnic minority group. Approximately 48% participants lived in areas of 10 percent greenspace or less, 14.6% between 10 and 20 percent, another 20.7% between 20 and 50 percent, and 16.6% lived in areas with more than 50 percent of greenspace.

Table 1
Characteristics of the final analytical sample of adults living in urban areas in England (N = 19,848).

		Unweighted	Weighted
Greenspace	$\leq 10\%$	46.8%	48.0%
	$<10\text{--}20\%$	14.1%	14.6%
	$<20\text{--}50\%$	20.9%	20.7%
	$>50\%$	18.2%	16.6%
Greenspace Satisfaction (N = 12,570)	Satisfied	84.6%	81.8%
	Neutral/dissatisfied	15.4%	18.2%
Population density	$\leq 2,500$	26.3%	24.2%
	$<2,500\text{--}5,000$	31.6%	31.2%
	$>5,000$	42.2%	44.6%
IMD decile		6.0 (2.8)	5.5 (2.8)
Gender	Men	24.4%	47.1%
	Women	75.6%	52.9%
Ethnicity	White	95.2%	86.2%
	Ethnic minority	4.8%	13.8%
Age group	18–29	4.5%	17.0%
	30–45	25.3%	28.5%
	46–59	34.4%	24.6%
	60+	35.8%	29.9%
Education	GCSE or below	13.6%	32.3%
	A levels or equivalent	16.6%	30.9%
	Degree or above	69.8%	36.8%
Annual income	$<£16,000$	14.2%	18.6%
	$\leq£16,000\text{--}29,999$	24.0%	26.8%
	$\leq£30,000\text{--}59,999$	35.2%	33.5%
	$\leq£60,000\text{--}89,999$	15.7%	13.4%
	$\geq£90,000$	10.9%	7.8%
Employment status	Not employed	36.7%	38.6%
	Employed	63.3%	61.4%
Physical health condition	No	58.5%	58.7%
	Yes	41.5%	41.3%
Mental health condition	No	82.9%	80.2%
	Yes	17.1%	19.8%

3.2. Latent growth models

Fig. 1 shows the estimated growth trajectory of anxiety symptoms from the unconditional LGM, together with the stringency index of the strictness of COVID-19 responses in England (Hale et al., 2021) for reference (not included in LGM) and the number of new confirmed COVID-19 cases (in thousands). Generally, anxiety symptoms decreased over the first national lockdown period and following the easing of restrictions. However, it started to increase around August 2020 and peaked in November when England entered the second national lockdown, before a gradual and slow decrease until the end of the follow-up period.

Results from the conditional LGMs are presented in Table 2. Compared with people living in an area of 10% greenspace or under, those with higher greenspace coverage had lower levels of anxiety at the start of the study period, in particular after controlling for all potential confounders (Model III). There was no evidence that greenspace coverage was related to the growth rate of anxiety during the period of first lockdown. However, there was some indication of an association with the rate of change at later stages of the pandemic. More specifically, people living in an area of 20–50% greenspace had a lower rate of increasing levels of anxiety between the first and second lockdown. This is depicted in Fig. 2, which shows the estimated growth trajectories of anxiety symptoms by greenspace access categories based on the full model.

3.3. Sensitivity analyses

To test robustness of the results after taking into account greenspace quality, we fitted LGMs based on a subsample with information on greenspace satisfaction. The results are presented in Table S1 in the Supplementary Material. Being satisfied with greenspace was associated with fewer anxiety symptoms at baseline, but there was no evidence that it was associated with the rate of change over time. Even after controlling for greenspace satisfaction, the objective measure of greenspace coverage was still found to be associated with the intercept and to a lesser extent with the rate of change of anxiety symptoms. In another sensitivity analysis, the negative relationship between greenspace coverage and anxiety symptoms persisted after controlling for going outdoors (see Table S2).

The more flexible free time scores approach had poorer model fit compared to the piecewise LGM (see Fig. S2 in the Supplementary Material). There was no evidence that greenspace proximity was related to the growth trajectory of anxiety symptoms (Table S3).

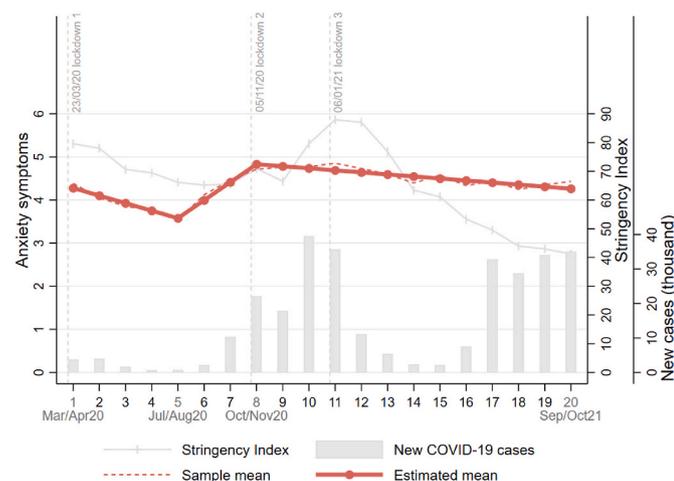


Fig. 1. Overall growth trajectories of anxiety symptoms based on unconditional latent growth model, among adults living in urban areas of England. COVID-19 stringency index and number of new COVID-19 cases provided for reference.

4. Discussion

This study examined how urban residential greenspace was related to the growth trajectory of anxiety symptoms during the COVID-19 pandemic. Our results showed that living in an area with higher greenspace coverage was independently associated with fewer anxiety symptoms consistently across the 20-month observational period between March 2020 and October 2021. There was also some evidence for the association of greenspace coverage with the change of anxiety symptoms across different stages of the pandemic, but the differences in rate of change were relatively small.

Our findings are consistent with pre-pandemic studies (Collins et al., 2020; Wendelboe-Nelson et al., 2019; Gascon et al., 2015) and some of the recent studies during the COVID-19 pandemic (Pouso et al., 2021; Soga et al., 2021) showing potential benefits of greenspace for anxiety. It is promising that greenspace was still shown to be associated with lower anxiety symptoms during the COVID-19 pandemic when there was a heightened risk of anxiety and other mental health conditions. Benefits may arise through a number of mechanisms, as described in the introduction. According to the SRT, exposure to greenspace could improve mental health through expediting recovery from stress (Ulrich et al., 1991). This is further supported by a recent meta-analysis showing that greenspace exposure is associated with decreased salivary cortisol levels which is a biomarker of psychological stress (Twhig-Bennett and Jones, 2018). Our findings could be particularly relevant and salient during the pandemic due to increased stresses overall (e.g. bereavement, relationship breakdown, job loss) and reduced access to other mental health resource and support (WHO. Action required to address, 2021). In addition to stress, greenspace exposure might alleviate anxiety symptoms via other health promoting activities or behaviours. For example, greenspace (e.g. parks) could serve as social gathering locations when indoor activities were prohibited or discouraged during the pandemic (Mouratidis, 2021). This was supported by previous literature showing that people used greenspace as a way to maintain social interactions during the COVID-19 pandemic (McCormack et al., 1080; Borkenhagen et al., 1080), which have been proven to be beneficial for mental health (Kawachi and Berkman, 2001). In this regard, people living in an area with higher greenspace coverage are in an advantaged position. Moreover, previous studies found that the availability of greenspace encourage outdoor activity more generally, in particular physical activity (Kondo et al., 2018). Not only does outdoor activity provide mental health benefits by changing scenery and/or being away from stressors, but also activities like exercise have anxiolytic effects via physiological mechanisms, such as sympathetic nervous system and hypothalamic-pituitary-adrenal axis reactivity (Anderson and Shivakumar, 2013). The association between greenspace and outdoor activity is supported by a recent US study showing that human mobility reduction was lower in communities with better greenspace access during the early stage of the COVID-19 pandemic (Heo et al., 2020).

Our sensitivity analyses showed that the relationship between greenspace and anxiety symptoms remained even after accounting for going outdoors. In other words, the mental health benefits of greenspace cannot be fully attributed to the possibility that people living in areas with higher greenspace coverage might go out more. This is important to note as the benefits of nature come not only from intentional interactions (e.g. visiting a park for recreation), but also from incidental (e.g. walking to work by a park) or indirect interactions (e.g. nature views at home) (Keniger et al., 2013). Thus people might to some extent benefit from greenspace in their residential area without intentional visits or going outdoors. Due to changes in COVID-19 policy responses (e.g. closure/reopening of workplace, restrictions on public gatherings), the patterns of greenspace exposure likely varied across different stages of the COVID-19 pandemic. The predicted anxiety trajectories suggested that the difference in anxiety symptoms between people living in the lowest and highest greenspace coverage areas tended to be larger during lockdown periods, and smaller when COVID-19 restrictions were

Table 2
Results from the latent growth models on anxiety symptoms among adults living in urban areas in England (N = 19,848).

	Model I			Model II			Model III		
	Coef.	SE	p	Coef.	SE	p	Coef.	SE	p
Greenspace:									
Intercept									
<10–20% (vs. ≤10%)	−0.50	0.19	0.007	−0.49	0.20	0.017	−0.54	0.18	0.003
<20–50% (vs. ≤10%)	−0.11	0.19	0.539	−0.14	0.23	0.539	−0.42	0.19	0.026
>50% (vs. ≤10%)	−0.55	0.18	0.002	−0.52	0.29	0.078	−0.72	0.24	0.003
Slope 1									
<10–20% (vs. ≤10%)	0.03	0.03	0.331	0.04	0.04	0.243	0.04	0.04	0.239
<20–50% (vs. ≤10%)	0.02	0.04	0.590	0.04	0.04	0.410	0.04	0.04	0.304
>50% (vs. ≤10%)	0.01	0.03	0.848	0.03	0.05	0.566	0.04	0.05	0.491
Slope 2									
<10–20% (vs. ≤10%)	−0.03	0.04	0.391	−0.05	0.04	0.190	−0.05	0.04	0.167
<20–50% (vs. ≤10%)	−0.04	0.03	0.175	−0.08	0.04	0.051	−0.09	0.04	0.024
>50% (vs. ≤10%)	−0.03	0.04	0.446	−0.06	0.05	0.247	−0.07	0.05	0.199
Slope 3									
<10–20% (vs. ≤10%)	0.01	0.01	0.683	0.01	0.01	0.328	0.01	0.01	0.287
<20–50% (vs. ≤10%)	0.00	0.01	0.698	0.01	0.01	0.442	0.01	0.01	0.558
>50% (vs. ≤10%)	0.01	0.01	0.142	0.02	0.02	0.191	0.02	0.02	0.138
Growth factor:									
Intercept	4.46	0.10	0.000	5.85	0.33	0.000	5.97	0.41	0.000
Slope 1	−0.18	0.02	0.000	−0.18	0.06	0.001	−0.21	0.09	0.025
Slope 2	0.44	0.02	0.000	0.57	0.06	0.000	0.59	0.10	0.000
Slope 3	−0.05	0.01	0.000	−0.07	0.02	0.000	−0.07	0.03	0.018
Model fit:									
RMSEA [†]	0.01			0.01			0.01		
CFI [†]	0.99			0.99			0.99		
TLI [†]	0.98			0.98			0.98		
SRMR [†]	0.01			0.01			0.01		

Notes: Model I, no covariate; Model II, controlling for population density and index of multiple deprivation; Model III, additionally controlling for individual characteristics; [†]RMSEA, Root Mean Square Error of Approximation; CFI, Comparative Fit Index; TLI, Tucker-Lewis Index; SRMR, Standardised Root Mean Square Residual.

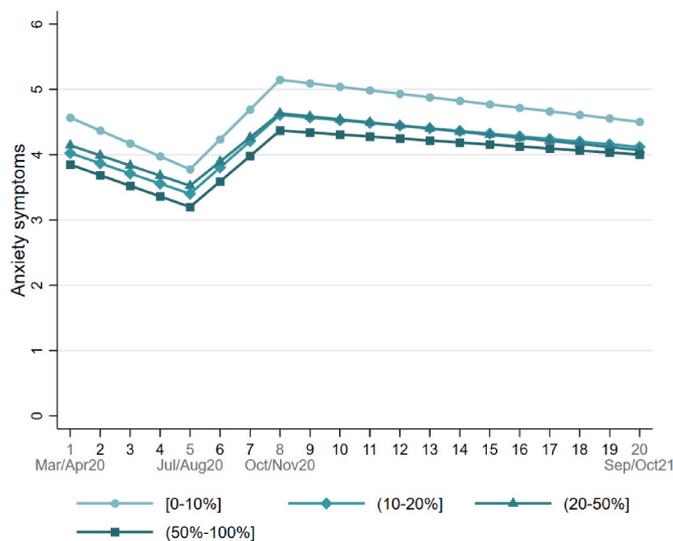


Fig. 2. Estimated growth trajectories of anxiety symptoms by greenspace coverage based on conditional latent growth model (Model III), among adults living in urban areas of England.

relaxed. This suggests that people living in areas with higher greenspace coverage might have a greater advantage during lockdowns when their movements were restricted. However, once lockdown measures were eased, the impact of residential greenspace on people’s anxiety might have been reduced due to increased human movements and opportunities for other activities with mental health benefits.

It is worth noting that although consistent and robust results were found for greenspace coverage, there was little evidence that greenspace proximity was related to the growth trajectories of anxiety symptoms. Although both coverage and proximity are indicators of residential greenspace, there are some fundamental differences between them

(Rigolon et al., 2018). Proximity simply describes the distance to the closest greenspace, whereas greenspace coverage takes into account both the size of greenspace and the existence of other greenspace in the same geographic area. Given our study examined only anxiety symptoms, there is the possibility that greenspace proximity may be associated with other mental health and wellbeing measures. Future research is encouraged to explore the potentially differential effects of greenspace coverage and proximity on mental health and wellbeing. Another potential explanation is related to measurement quality. Our proximity measure taken from ONS only considered public parks and playing fields. In contrast, our greenspace coverage measure included all natural environment land cover and hence provided a more valid and comprehensive measure, which was therefore used in our main analysis. By also presenting the results using the alternative proximity measure, we hope to demonstrate how the choice of different greenspace measures might lead to different findings. This could have implications when informing current and future practices and policy activities relating to urban planning.

We recognize that it is challenging to draw any causal inference in observational studies. One challenge is to effectively control for confounders. When it comes to the relationship between greenspace and mental health, one of the most important factors is socioeconomic position (SEP). People from disadvantaged backgrounds are typically more restricted in their access to greenspace (private or public), due to either quantity or quality (Geary et al., 2021). Meanwhile, they tend to be at a higher risk of mental health problems (Marmot et al., 2020). However, our analyses controlled for relevant covariates at both individual and area levels, including income, education, population density and area deprivation. Thus, the observed association between greenspace and anxiety in this study could not be simply attributed to confounding by SEP.

This study has a number of strengths. It utilized a large sample with sufficient heterogeneity to include good stratification across all major socio-demographic groups and good coverage of geographic areas in England. The analyses were weighted on the basis of population

estimates of core demographics, with the weighted data showing good alignment with a nationally representative study (Bu et al., 2020). The availability of postcode information allowed us to obtain greenspace coverage at small geographic areas (LSOA), controlling for other relevant geographic factors, including population density and area deprivation. Due to the longitudinal design of the COVID-19 Social Study, we were able to examine the growth trajectories of anxiety symptoms since the first lockdown in England across different stages of the COVID-19 pandemic over 20 months. Despite these strengths, the limitations of our study raise important points for further research. First, our data were from a non-probability sample. Despite the effort to make our sample representative to the population in England by weighting, there is still the possibility of potential biases due to omitting representation of other demographic factors that could be associated with survey participation in the weighting process. Second, there is a lack of pre-pandemic data. It therefore remains unclear how the mental health benefits of greenspace in the context of COVID-19 pandemic compare to a normal scenario. Future research is encouraged to examine the mental health benefits of greenspace using data collected both prior to and during the pandemic. This study focused on anxiety symptoms. Future studies could examine the relationship of greenspace with other mental health (e.g. depression, stress) and wellbeing (e.g. life satisfaction, happiness) measures (Beall et al., 2022; Brent Jackson et al., 2021). Finally, more research using alternative greenspace measures (e.g. actual usage, greenspace quality) is also needed to establish a better understanding of the mental health benefits of greenspace.

5. Conclusions

The COVID-19 pandemic has had a profound effect on public mental health and led to a sharp increase in the demand for mental health assistance and interventions, presenting an unprecedented challenge to the National Health Service (NHS) in England. Greenspace is increasingly being recognised as an important asset for supporting mental health by policy makers and practitioners. In 2020, England launched a £5.77 million project on green social prescribing to prevent and tackle mental ill health. The recent Levelling Up White Paper included making greenspace accessible to all populations as one of its missions, by enhancing and maintaining green belts, parks, woodlands, particularly in communities with the lowest greenspace access (HM Government, 2022). Our study showed that anxiety levels were consistently lower throughout the pandemic in areas with higher levels of greenspace, independent of other individual and geographical factors. This highlights the value of long-term investments in urban green infrastructure planning, as well as in improvement and maintenance of existing greenspace as a way of improving public mental health. Equally important is to raise public awareness of the mental health benefits of greenspace, and to facilitate and support engagement with greenspace especially among disadvantaged groups as a means to tackle mental health inequality.

Ethics approval and consent to participate

The study was approved by the UCL Research Ethics Committee [12467/005] and all participants gave informed consent.

Funding

This Covid-19 Social Study was funded by the Nuffield Foundation [WEL/FR-000022583], but the views expressed are those of the authors and not necessarily the Foundation. The study was also supported by the MARCH Mental Health Network funded by the Cross-Disciplinary Mental Health Network Plus initiative supported by UK Research and Innovation [ES/S002588/1], and by the Wellcome Trust [221400/Z/20/Z]. DF was funded by the Wellcome Trust [205407/Z/16/Z].

Author contributions

FB, AS and DF developed the study idea and the analysis plan. BW derived the land cover metric. FB analysed the data. FB and HWM wrote the first draft. FB, HWM and DF had accessed and verified the underlying data. All authors provided critical revisions, read and approved the submitted manuscript.

Declaration of competing interest

All authors declare no conflicts of interest.

Data availability

Data will be made available on request.

Acknowledgements

The researchers are grateful for the support of a number of organisations with their recruitment efforts including: the UKRI Mental Health Networks, Find Out Now, UCL BioResource, SEO Works, FieldworkHub, and Optimal Workshop. The study was also supported by HealthWise Wales, the Health and Care Research Wales initiative, which is led by Cardiff University in collaboration with SAIL, Swansea University. We thank the three anonymous reviewers whose comments and suggestions helped improve and clarify this manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.healthplace.2022.102897>.

References

- Alcock, I., et al., 2015. What accounts for 'England's green and pleasant land'? A panel data analysis of mental health and land cover types in rural England. *Landscape Urban Planning*. 142, 38–46.
- Anderson, E., Shivakumar, G., 2013. Effects of exercise and physical activity on anxiety. *Front. Psychiatry*. 4, 27.
- Astell-Burt, T., Feng, X., 2019. Association of urban green space with mental health and general health among adults in Australia. e198209–e198209 *JAMA Netw. Open*. 2.
- Beall, J.M., et al., 2022. Self-reported participation in outdoor and nature-based recreation before and during the COVID-19 pandemic supports psychological health and well-being. *Wellbeing Space Soc.* 3, 100094.
- Borkenhagen, D. et al. The Effect of COVID-19 on Parks and Greenspace Use during the First Three Months of the Pandemic – a Survey Study. <https://doi.org/10.1080/23748834.2021.1963646> (2021) doi:10.1080/23748834.2021.1963646.
- Brent Jackson, S., Stevenson, K.T., Larson, L.R., Nils Peterson, M., Seekamp, E., 2021. Outdoor activity participation improves adolescents' mental health and well-being during the COVID-19 pandemic, 2506 18, 2506 *Int. J. Environ. Res. Pub. Health* 2021 18.
- Bu, F., Steptoe, A., Fancourt, D., 2020. Who is lonely in lockdown? Cross-cohort analyses of predictors of loneliness before and during the COVID-19 pandemic. *Publ. Health* 186, 31–34.
- Collins, R.M., et al., 2020. A systematic map of research exploring the effect of greenspace on mental health. *Landscape Urban Planning*. 201, 103823.
- Duncan, D.T., Kawachi, I., 2018. *Neighborhoods and Health*. Oxford University Press.
- Fancourt, D., Aughterson, H., Finn, S., Walker, E., Steptoe, A., 2021a. How leisure activities affect health: a narrative review and multi-level theoretical framework of mechanisms of action. *Lancet Psychiatr.* [https://doi.org/10.1016/S2215-0366\(20\)30384-9](https://doi.org/10.1016/S2215-0366(20)30384-9).
- Fancourt, D., Bu, F., Mak, H.W., Paul, E., Steptoe, A., 2021b. Covid-19 social study: results release 40. https://www.covidsocialstudy.org/files/ugd/064c8b_86930ba_d37754dc9ac0553ef4caa902.pdf.
- Fancourt, D., Steptoe, A., Bu, F., 2021c. Trajectories of anxiety and depressive symptoms during enforced isolation due to COVID-19 in England: a longitudinal observational study. *Lancet Psychiatr.* 8, 141–149.
- Gascon, M., et al., 2015. Mental health benefits of long-term exposure to residential green and blue spaces: a systematic review. *Int. J. Environ. Res. Publ. Health* 12, 4354–4379, 12, 4354–4379 (2015).
- Geary, R.S., et al., 2021. A call to action: improving urban green spaces to reduce health inequalities exacerbated by COVID-19. *Prev. Med.* 145, 106425.
- Geng, D., Christina), Innes, J., Wu, W., Wang, G., 2021. Impacts of COVID-19 pandemic on urban park visitation: a global analysis. *J. For. Res.* 32, 553–567.

- Hadjidemetriou, G.M., Sasidharan, M., Kouyialis, G., Parlikad, A.K., 2020. The impact of government measures and human mobility trend on COVID-19 related deaths in the UK. *Transp. Res. Interdiscip. Perspect.* 6, 100167.
- Hale, T., et al., 2021. A global panel database of pandemic policies (Oxford COVID-19 Government Response Tracker), 4 5 *Nat. Human Behav.* 5, 529–538, 2021.
- Harris, P.A., et al., 2019. The REDCap consortium: building an international community of software platform partners. *J. Biomed. Inf.* 95, 103208.
- Heo, S., Lim, C.C., Bell, M.L., 2020. Relationships between local green space and human mobility patterns during COVID-19 for Maryland and California, USA. *Sustainability* 12, 9401, 12, 9401 (2020).
- Heo, S., Desai, M.U., Lowe, S.R., Bell, M.L., 2021. Impact of changed use of greenspace during covid-19 pandemic on depression and anxiety. *Int. J. Environ. Res. Publ. Health* 18, 5842.
- HM Government, 2022. Levelling up the United Kingdom. www.gov.uk/official-documents.
- Kaplan, S., 1995. The restorative benefits of nature: toward an integrative framework. *J. Environ. Psychol.* 15, 169–182.
- Kawachi, I., Berkman, L.F., 2001. Social ties and mental health, 3 78 *J. Urban Health* 78, 458–467, 2001.
- Keniger, L.E., Gaston, K.J., Irvine, K.N., Fuller, R.A., 2013. What are the benefits of interacting with nature? *Int. J. Environ. Res. Publ. Health* 10 (10), 913–935, 913–935 (2013).
- Kohli, N. & Harring, J. R. Modeling Growth in Latent Variables Using a Piecewise Function. <https://doi.org/10.1080/00273171.2013.778191> 48, 370–397 (2013).
- Kondo, M.C., Fluehr, J.M., McKeon, T., Branas, C.C., 2018. Urban green space and its impact on human health. *Int. J. Environ. Res. Publ. Health* 15, 445, 15, 445 (2018).
- Kondo, M.C., et al., 2022. Stress and distress during the COVID-19 pandemic: the role of neighborhood context. *Int. J. Environ. Res. Publ. Health* 19, 2779, 19, 2779 (2022).
- Kotera, Y., Richardson, M., Sheffield, D., 2020. Effects of shinrin-yoku (forest bathing) and nature therapy on mental health: a systematic review and meta-analysis. *Int. J. Ment. Health Addiction* 1–25. <https://doi.org/10.1007/S11469-020-00363-4/TABLES/6>.
- Krekel, C., Kolbe, J., Wüstemann, H., 2016. The greener, the happier? The effect of urban land use on residential well-being. *Ecol. Econ.* 121, 117–127.
- Labib, S.M., Browning, M.H.E.M., Rigolon, A., Helbich, M., James, P., 2022. Nature's contributions in coping with a pandemic in the 21st century: a narrative review of evidence during COVID-19. *Sci. Total Environ.* 833, 155095.
- Larson, L.R., et al., 2022. Greenspace and park use associated with less emotional distress among college students in the United States during the COVID-19 pandemic. *Environ. Res.* 204, 112367.
- Maas, J., et al., 2009. Morbidity is related to a green living environment. *J. Epidemiol. Community* 63, 967–973.
- Markevych, I., et al., 2017. Exploring pathways linking greenspace to health: theoretical and methodological guidance. *Environ. Res.* 158, 301–317.
- Marmot, M., Allen, J., Boyce, T., Goldblatt, P., Morrison, J., 2020. Health Equity in England: the Marmot Review 10 Years on - the Health Foundation. <https://www.health.org.uk/publications/reports/the-marmot-review-10-years-on>.
- McCormack, G. R., Petersen, J., Naish, C., Ghoneim, D. & Doyle-Baker, P. K. Neighbourhood Environment Facilitators and Barriers to Outdoor Activity during the First Wave of the COVID-19 Pandemic in Canada: a Qualitative Study. <https://doi.org/10.1080/23748834.2021.2016218> (2022) doi:10.1080/23748834.2021.2016218.
- Morita, E., et al., 2007. Psychological effects of forest environments on healthy adults: shinrin-yoku (forest-air bathing, walking) as a possible method of stress reduction. *Publ. Health* 121, 54–63.
- Morton, R.D., Marston, C.G., O'Neil, A.W., Rowland, C.S., 2020. Land Cover Map 2019 (20m Classified Pixels, GB). <https://doi.org/10.5285/643eb5a9-9707-4fbb-ac76-e8e53271d1a0>.
- Mouratidis, K., 2021. How COVID-19 reshaped quality of life in cities: a synthesis and implications for urban planning. *Land Use Pol.* 111, 105772.
- Natural England, 2021. The people and nature survey for England: data and publications from adults survey year 1. April 2020 - March 2021). <https://www.gov.uk/government/statistics/the-people-and-nature-survey-for-england-data-and-publications-from-adults-survey-year-1-april-2020-march-2021-official-statistics/the-people-and-nature-survey-for-england-data-and-publications-from-adults-survey-year-1-april-2020-march-2021-official-statistics-main-finding>.
- Office for National Statistics, 2019. Population Estimates for Great Britain. <https://www.ons.gov.uk/economy/environmentalaccounts/datasets/accesstogardensandpublicgreenspaceingreatbritain>.
- Office for National Statistics, 2019. Population Estimates for the UK, England and Wales, Scotland and Northern Ireland. <https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/bulletins/annualmidyearpopulationestimates/mid2018>.
- Pierce, M., et al., 2020. Mental health before and during the COVID-19 pandemic: a longitudinal probability sample survey of the UK population. *Lancet Psychiatr.* 7, 883–892.
- Pouso, S., et al., 2021. Contact with blue-green spaces during the COVID-19 pandemic lockdown beneficial for mental health. *Sci. Total Environ.* 756, 143984.
- Rigolon, A., Browning, M.H.E.M., Lee, K., Shin, S., 2018. Access to urban green space in cities of the global south: a systematic literature review. *Urban Sci.* 2, 67, 2, 67 (2018).
- Schindler, M., le Texier, M., Caruso, G., 2022. How far do people travel to use urban green space? A comparison of three European cities. *Appl. Geogr.* 141, 102673.
- Shanahan, L., et al., 2020. Emotional distress in young adults during the COVID-19 pandemic: evidence of risk and resilience from a longitudinal cohort study. *Psychol. Med.* 1–10. <https://doi.org/10.1017/S003329172000241X>.
- Soga, M., et al., 2021. A room with a green view: the importance of nearby nature for mental health during the COVID-19 pandemic. *Ecol. Appl.* 31, e2248.
- South, E.C., Hohl, B.C., Kondo, M.C., MacDonald, J.M., Branas, C.C., 2018. Effect of greening vacant land on mental health of community-dwelling adults: a cluster randomized trial. e180298–e180298 *JAMA Netw. Open* 1.
- Spitzer, R.L., Kroenke, K., Williams, J.B.W., Löwe, B., 2006. A brief measure for assessing generalized anxiety disorder. *Arch. Intern. Med.* 166, 1092.
- Twohig-Bennett, C., Jones, A., 2018. The health benefits of the great outdoors: a systematic review and meta-analysis of greenspace exposure and health outcomes. *Environ. Res.* 166, 628–637.
- Ugolini, F., Massetti, L., Pearlmutter, D., Sanesi, G., 2021. Usage of urban green space and related feelings of deprivation during the COVID-19 lockdown: lessons learned from an Italian case study. *Land Use Pol.* 105, 105437.
- Ulrich, R.S., et al., 1991. Stress recovery during exposure to natural and urban environments. *J. Environ. Psychol.* 11, 201–230.
- Venter, Z.S., Barton, D.N., Gundersen, V., Figari, H., Nowell, M., 2020. Urban nature in a time of crisis: recreational use of green space increases during the COVID-19 outbreak in Oslo, Norway. *Environ. Res. Lett.* 15, 104075.
- Wendelboe-Nelson, C., Kelly, S., Kennedy, M., Cherrie, J.W., 2019. A scoping review mapping research on green space and associated mental health benefits. *Int. J. Environ. Res. Publ. Health* 16, 2081, 16, 2081 (2019).
- Wheeler, B.W., et al., 2015. Beyond greenspace: an ecological study of population general health and indicators of natural environment type and quality. *Int. J. Health Geogr.* 14, 1–17.
- WHO. Action required to address the impacts of the COVID-19 pandemic on mental health and service delivery systems in the WHO European Region: recommendations from the European Technical Advisory Group on the mental health impacts of COVID-19, 30 June 2021. <https://www.euro.who.int/en/health-topics/noncommunicable-diseases/mental-health/publications/2021/action-required-to-address-the-impacts-of-the-covid-19-pandemic-on-mental-health-and-service-delivery-systems-in-the-who-european-region-recommendations-from-the-european-technical-advisory-group-on-the-mental-health-impacts-of-covid-19-30-june-2021>, 2021.
- Wortzel, J.D., et al., 2021. Association between urban greenspace and mental wellbeing during the COVID-19 pandemic in a U.S. Cohort. *Front. Sustain. Cities* 3, 56.