



# Greenspace use during the COVID-19 pandemic: A longitudinal population mobility study in the United Kingdom

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## ABSTRACT

**Background:** The coronavirus pandemic greatly disrupted the lives of people. Restrictions introduced worldwide to limit the spread of infection included stay-at-home orders, closure of venues, restrictions to travel and limits to social contacts. During this time, parks and outdoor greenspaces gained prominent attention as alternative location for respite. Population mobility data offers a unique opportunity to understand the impact of the pandemic on outdoor behaviour. We examine the role of the restrictions on park use throughout the full span of the pandemic while controlling for weather and region.

**Methods:** This study provides a longitudinal population analysis of park visitation using Google COVID-19 Community Mobility Reports data in the UK. Daily park visitation was plotted and ANOVA analyses tested season and year effects in visitation. Then, regressions examined park visitation beyond weather (temperature and rain), according to COVID-19 restrictions, while controlling for region specificities through unit fixed effect models.

**Results:** Time series and ANOVA analyses documented the significant decrease in park visitation in the spring of 2020, the seasonal pattern in visitation, and an overall sustained and elevated use over nearly three years. Regressions confirmed park visitation increased significantly when temperature was greater and when it rained less. More visitation was also seen when there were fewer COVID-19 cases and when the stringency level of restrictions was lower. Of special interest, a significant interaction effect was found between temperature and stringency, with stringency significantly suppressing the effect of higher temperature on visitation.

**Conclusions:** COVID-19 restrictions negatively impacted park visitation on warm days. Given the general health, social, and wellbeing benefits of greenspace use, one should consider the collateral negative impact of restrictions on park visitation. When social distancing of contacts is required, the few remaining locations where it can safely occur should instead be promoted.

## 1. Introduction

The coronavirus (COVID-19) pandemic greatly disrupted the daily lives of people. To slow the spread of infection, governments around the world introduced policies to limit social contacts. Restrictions varied over time, according in part to disease prevalence, testing, contact tracing, emergent variants, vaccination campaigns and other considerations (Brown and Kirk-Wade, 2021). In the United Kingdom (UK), restrictions included lockdowns with stay-at-home orders, closures of school, universities and workplaces, limits to non-essential travel, closures of leisure venues, limits to social contacts, and a reduction in outdoor exercise allowance (Brown and Kirk-Wade, 2021; Institute for Government, 2021). Some regulations were applied across the UK,

others in constituent nations only, such as England (Tatlow et al., 2020). In addition to the infection and mortality toll, the disruptions had adverse mental health and wellbeing effects, notably in the early stricter days of the pandemic (Pierce et al., 2020; Fancourt et al., 2021). Under pandemic ruling, parks and outdoor greenspaces gained prominent attention as a possible location for respite. Given the growing evidence of the positive association with health and wellbeing (Houlden et al., 2018; Yang et al., 2021; Nguyen et al., 2021; Twohig-Bennett and Jones, 2018; van den Berg et al., 2015), the importance of greenspace use cannot be understated, particularly under isolation conditions. Population mobility data offers a unique opportunity to understand the pattern and drivers of greenspace use in the UK and in England during the full span of the pandemic.

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The positive health and wellbeing benefits of greenspace exposure have been explored across a range of contexts in observational and experimental studies and are well documented in systematic reviews (Houlden et al., 2018; Yang et al., 2021; Nguyen et al., 2021; Twohig-Bennett and Jones, 2018; van den Berg et al., 2015). For instance, greenspace is shown to reduce exposure to environmental stressors such as heat, air pollution, and noise (Yang et al., 2021; Dzhambov et al., 2020). Greenspace is also reported to be a resource for psychological restoration (Ohly et al., 2016). Safe, accessible and aesthetically pleasing greenspaces are shown to foster physical activity and facilitate social connectedness, which in turn have many benefits including reductions in levels of stress, anxiety, and depression, and improved levels of wellbeing (Yang et al., 2021; Markevych et al., 2017; Bowler et al., 2010; Maas et al., 2009).

Pre-pandemic research has shown numerous factors contribute to use of green and outdoor spaces. Availability and proximity to greenspace, type of greenspace (e.g., parks, meadows, woodlands), ease of access, amenities, condition such as cleanliness and safety, and aesthetics all encourage greater use (Nguyen et al., 2021). A large scale nationally representative study of the English population, the 'Monitor of Engagement with the Natural Environment (MENE)' survey (n = 63,890), showed use varied by location, socio-demographics, and according to weather, with poor and unpredictable weather often cited as a reason for not spending outdoor time in greenspaces (Boyd et al., 2018).

Considering the health promoting potential of greenspaces, psycho-social and public health experts called for parks and natural environments to remain open to the public during the pandemic. The hope was that this would facilitate time spent outdoors in nature, physical activity, distanced social interactions, and would encourage greater health and wellbeing in a time of social isolation (McCunn, 2021; Slater et al., 2020). This was highlighted as particularly important for urban dwellers who have limited access to natural features and private spaces like gardens (McCunn, 2021).

Numerous studies were conducted during the pandemic to explore patterns, experiences and motivations of greenspace use. Studies reported a sharp decline in use at the start of the pandemic when restrictions were first introduced in the UK (Geng et al., 2021; Burdett et al., 2021; Burnett et al., 2021) and internationally (Geng et al., 2021; Curtis et al., 2022; Drake et al., 2020). Then, across the summer of 2020, when restrictions were relaxed, use was reported to have increased relative to pre-pandemic (Geng et al., 2021; Berdejo-Espinola et al., 2021; Burnett et al., 2022) and early pandemic times (England and Kantar Public, 2021). Fresh air, exercise, dog walking and wellbeing benefits were frequently cited as reasons for visiting greenspaces (England and Kantar Public, 2021). As in pre-pandemic times, use varied across groups, with lower usage among older populations (Berdejo-Espinola et al., 2021; England and Kantar Public, 2021) and those of lower socioeconomic level (Burnett et al., 2022; England and Kantar Public, 2021). Numerous benefits of greenspace use continued to be seen. For instance, Poortinga et al. (2021) found that both perceived and reported access to greenspace was associated with greater self-reported subjective wellbeing (Poortinga et al., 2021). Similarly, Bu et al. (2022) observed that anxiety levels were consistently lower among individuals living in areas with higher greenspace coverage, independent of individual and geographical factors. Methodologically, such studies were often cross-sectional (Berdejo-Espinola et al., 2021; Edwards et al., 2023) or short span assessments (Burnett et al., 2022; Poortinga et al., 2021). Also, most studies relied on self-reported greenspace use behaviours from survey questionnaires (Burnett et al., 2021, 2022; Berdejo-Espinola et al., 2021; England and Kantar Public, 2021; Poortinga et al., 2021; Bu et al., 2022; Edwards et al., 2023; Stock et al., 2022) or from social media (England and Kantar Public, 2021; Venter et al., 2020; Phillips et al., 2022), relied on individual's recall of change (Burnett et al., 2021; Berdejo-Espinola et al., 2021; Edwards et al., 2023), and were conducted within the first year of the pandemic (Burnett et al., 2021; Poortinga et al., 2021; Edwards et al., 2023; Stock et al., 2022).

Phone location data is less often used, yet constitutes an interesting indicator of population movement behaviours and changes over time (Geng et al., 2021; Burdett et al., 2021; Curtis et al., 2022; Drake et al., 2020; Rice and Pan, 2021; Johnson et al., 2021). It may be used to address higher level questions on patterns and drivers of use. The open source mobile phone location data from the Google COVID-19 Community Mobility Reports (CMR) on park visitation may be leveraged to examine such questions. This aggregated and anonymized data covers a period of 2 years and 8 months during the pandemic, from February 15, 2020 to October 15, 2022 (Google. Community Mobility Report, 2023). Despite its apparent popularity, it has seldom been used within the UK context to address park use questions (Geng et al., 2021; Burdett et al., 2021; Johnson et al., 2021) and never over the full extended period of the pandemic while also adjusting for weather patterns.

Our study consists of a longitudinal population analysis of high frequency greenspace use mobility data in the United Kingdom. Specifically, we address two gaps identified in the literature: (a) what are the patterns of greenspace use during the full span of the COVID-19 pandemic, and (b) what are the impacts of COVID-19 restrictions on greenspace use when controlling for weather and local conditions.

## 2. Methods

### 2.1. Study design

This is a longitudinal observational study using open source aggregated population data. Since this leverages secondary data no ethical research approval was required on our part.

### 2.2. COVID-19 context in the UK

The first national lockdown was implemented in the UK in March 2020 (Institute for Government, 2021). At first, individuals were only allowed to leave their homes for very limited purposes, including medical needs, shopping for necessities, and for one form of exercise a day, alone or with people from the same household (Cabinet Office, 2020). Starting in May 2020, restrictions were gradually relaxed; people were allowed to meet outside in groups of up to six and eventually up to thirty (Brown and Kirk-Wade, 2021). By the fall, however, following a resurgence of COVID-19 cases, nation specific restrictions were introduced in Wales, Scotland, Northern Ireland and England, with the later enacting a 'tier system' of stringency (Tatlow et al., 2020). Two more national lockdowns were implemented in England, one in November 2020 and another in January–March 2021. During these times, people were told to stay at home and limit their social contacts, but were permitted to form 'support bubbles' and leave home with a 'reasonable excuse'. Individuals could exercise in public places with one other person not in their household. Restrictions were gradually lifted as the country exited lockdown over the spring of 2021 (Brown and Kirk-Wade, 2021; Institute for Government, 2021). The COVID-19 Omicron variant surfaced in December 2021 causing a massive surge in cases. About 80% of the population had received at least two doses of a COVID-19 vaccine at this time and restrictions were limitedly reintroduced (UK Government, 2023b).

While outdoor greenspaces were some of the few locations which remained open to the public during the pandemic, access was nonetheless somewhat restricted, notably early in the pandemic when individuals could only exercise once per day outdoors, as well as in later times when facilities within greenspaces were closed, such as benches and sporting equipment, to discourage social gatherings (Brown and Kirk-Wade, 2021).

### 2.3. Data sources

#### 2.3.1. Dependent variable

**Greenspace use.** As an indicator of outdoor greenspace use, daily

park visitation mobility data was retrieved from the [Google COVID-19 Community Mobility Reports](#) ([Google. Community Mobility Report, 2023](#)). The dependent variable consists of the percent change in daily park visitation relative to a pre-COVID-19 pandemic baseline. The baseline established by Google comes from the median day value during a prior 5-week period (from January 3 to February 6, 2020). The variable includes visitation to places such as, but not limited to, local parks, national parks, public beaches, marinas, dog parks, plazas, and public gardens. Daily park visitation is calculated from mobility information of smart phones equipped with Google applications with the location history service turned on. The data is anonymized and aggregated by area. Of note, this mobility data only includes officially designated outdoor park areas and does not include the general vast outdoor spaces such as found in rural areas.

The data is reported by Google for the United Kingdom as a whole, as well as for 150 lower level regions in England (unitary authorities, local authority districts, counties and London boroughs) – but not in aggregate form per nation for England, Wales, Scotland and Northern Ireland independently. A map and table of regions is found in [Appendix A](#).

The data covers a period of 2 years and 8 months (974 days), from February 15, 2020 to October 15, 2022. Values are set to missing if Google LLC judged there was not enough data to confidently and anonymously estimate the percent change from baseline for a specific day ([Aktay et al., 2020](#)). For more information, see the Google documentation ([Google. Community Mobility Report Help, 2023](#)).

### 2.3.2. Independent variables

**Weather.** Daily maximum air temperature (°C) and daily rainfall precipitation (mm) data was retrieved from the [HadUK-GRID dataset](#) produced by the meteorological (MET) office Hadley Centre for Climate Science and Services ([Met Office et al., 2018](#)). The gridded raster datasets were developed by interpolating point observations from meteorological stations onto a uniform grid to provide complete and consistent coverage across the UK. The data covers a period of 2 years (731 days) with no missing values, from January 1, 2020 to December 31, 2021. The 1 km × 1 km grid was extracted, the highest resolution available, allowing for greater flexibility when subsequently deriving area averages. At the daily level, the only variables available were temperature and rainfall. For more information, see [Hollis et al. \(2019\)](#).

Further, maximum air temperature (°C) and number of days with a minimum of 1 mm of rainfall precipitation were also gathered from the MET office for 3 years (2020, 2021 and 2022) for winter (December to February), spring (March to May), summer (June to August), and fall (September to November) ([Met Office, 2023](#)).

**COVID-19 incident cases.** Daily COVID-19 cases for England were included as an indicator of disease severity from the [government Coronavirus dashboard](#) ([UK Government, 2023a](#)). Data covering the same period as the mobility data was selected.

**COVID-19 Stringency Index.** Daily Stringency Index data came from the [Oxford COVID-19 Government Response Tracker \(OxCGRT\)](#) ([Mathieu et al., 2020](#)). The index, developed [Hale et al. \(2021\)](#), is a composite measure of nine metrics recording the strictness level of government measures affecting people's behaviour, such as socialization and mobility. The scale ranges from 0 to 100, with higher scores indicating a stricter response. The index covers school closures, workplace closures, cancellation of public events, restrictions on public gatherings, closures of public transport, stay-at-home requirements, public information campaigns, restrictions on internal movements, and international travel controls. Data for the United Kingdom and England was retrieved, and covers a period of 2 years and 11 months (1,066 days) with no missing values, from January 30, 2020 to December 31, 2022. Of note, in instances where policies varied at the subnational level, for example within England, the index is shown as the response level of the strictest sub-region. For information on stringency index differences across England, Wales, Scotland, and Northern Ireland, see [Tatlow et al. \(2020\)](#).

**Geographical boundaries.** A shapefile of the 2019 English unitary authorities, local authority districts, counties and London boroughs boundaries was obtained from the [Office for National Statistics \(ONS\) Open Geography Portal](#) ([Office for National Statistics, 2023](#)). The year 2019 was selected to match the regions of the mobility data. This was used in combination with the weather data in a Geographic Information System (GIS).

## 2.4. Data analysis strategy

### 2.4.1. Park visitation across the pandemic in the UK

First, we investigated the pattern of daily park visitation across the pandemic at the United Kingdom level for a period of 2 years and 8 months, from February 15, 2020 to October 15, 2022 (974 days).

To do so, we created a dataset of UK daily: (i) park visitation percent change relative to the pre-pandemic daily average baseline and (ii) COVID-19 stringency index (range 0–100). We subsequently plotted the data. To capture the time series of park visitation while smoothing out daily variations, a seven-day moving average was fitted to the data. Means and standard deviations for park visitation were calculated. Normality of park visitation was assessed using a Q-Q plot and the Shapiro-Wilk test and confirmed an approximate normal distribution with slight right-skewed tail. An omnibus two-way ANOVA (Type III) was conducted to test the effect of season and year on the outcome park visitation, with Type III adjusting for the unequal number of day values in season by year cells (due to the first winter not including December 2019 and the last fall not including November 2022). Post hoc Tukey multiple comparisons of means were also computed. Tests were run with a two-sided probability and an alpha of 0.05.

### 2.4.2. Role of weather and policy restrictions on park visitation during the pandemic in England

Second, we investigated the role of weather and COVID-19 restrictions on park visitation in England. The analysis was restricted to England given the large amount of missing values for park visitation at the lower level regions in Wales, Scotland and Northern Ireland due to Google's privacy policy.

As a preliminary step, we combined five data sources to create a long format panel dataset for England for daily: (i) park visitation percent change relative to the pre-pandemic daily average baseline, (ii) maximal air temperature (°C), (iii) rainfall precipitation (mm), (iv) COVID-19 cases and (v) COVID-19 stringency index (range 0–100), across all 150 lower level regions of England, from February 15, 2020 to December 31, 2021 (1 year 10.5 months; 685 days). The exact study period was determined by the data availability of the combined data sources. In developing this, we first had to derive daily weather information for all 150 lower level regions (unitary authorities, local authority districts, counties, and London boroughs). Following the MET office methodology ([Hollis et al., 2019](#)), we used the HadUK-GRID 1 km × 1 km raster data and the geographic boundaries shapefile in QGIS (version 3.30) to derive area averages for daily maximum air temperature (°C) and daily rainfall (mm) across all regions using the GIS zonal statistics tool. The coordinate projection was set to the British National Grid (ESPG: 27700). The panel dataset was then built in R (version 4.2.2) by joining all data sources using date and location attributes, such that each 150 lower level region had 685 days of data, for a total of 102,750 rows. Then, we investigated the percent of missing data for park visitation. Of the 150 lower level regions, twenty-three regions with more than 25% of missing park visitation observations were removed (See [Appendix A](#)). The final dataset included 127 lower level regions with on average only 3.6% of missing values. Park visitation approximated a normal distribution.

We conducted six regression analyses. First, in univariate unit fixed effect regressions we modelled the four independent variables (temperature, rainfall, COVID-19 cases and COVID-19 stringency) with the park visitation dependent variable (models 1–4). Then, in a

multivariable unit fixed effect regression, we modelled all four independent variables at once against park visitation (model 5). Lastly, we modelled all four variables at once again, this time adding two interaction terms between temperature and stringency, and rainfall and stringency (model 6). In unit fixed effect models, units (here regions), are compared to themselves over time, thereby serving as their own control, allowing to assess *within* region changes. This process controls for the longitudinal correlated nature of the data which violates the assumption of independence of errors required in traditional regression models (Allison, 2009). Further, by using each region as its own control, the effects of measured and unmeasured time-invariant variables are removed, reducing unobserved heterogeneity and omitted variables bias (Allison, 2009; Kropko and Kubinec, 2020). There is therefore no need to include regional variables which do not vary significantly over the study period (time-invariant), such as park availability, population density, and socio-economic factors. Instead, the unique role of some time-varying variables can be isolated (Huntington-Klein, 2021). Results produce an estimate of the predictors average effect within unit over time (Allison, 2009; Mummolo and Peterson, 2018).

Model selection was built with Google data documentation in mind, where it is recommended to avoid comparing visitation across regions as they have local differences which may mislead (Google. Community Mobility Report Help, 2023). Therefore, only within region comparisons were made. The Hausman test confirmed model specification ( $p < .001$ ) (Allison, 2009). Analyses were carried out in R (version 4.2.2). The package *plm* was used (Rdocumentation. *plm* package).

$$Park\ visitation_{it} = a_i + \beta_1 Temperature_{it} + u_{it} \quad (1)$$

$$Park\ visitation_{it} = a_i + \beta_1 Rainfall_{it} + u_{it} \quad (2)$$

$$Park\ visitation_{it} = a_i + \beta_1 COVID19\ Cases_{it} + u_{it} \quad (3)$$

$$Park\ visitation_{it} = a_i + \beta_1 COVID19\ Stringency_{it} + u_{it} \quad (4)$$

$$Park\ visitation_{it} = a_i + \beta_1 Temperature_{it} + \beta_2 Rainfall_{it} + \beta_3 COVID19\ Cases_{it} + \beta_4 COVID19\ Stringency_{it} + u_{it} \quad (5)$$

$$Park\ visitation_{it} = a_i + \beta_1 Temperature_{it} + \beta_2 Rainfall_{it} + \beta_3 COVID19\ Cases_{it} + \beta_4 COVID19\ Stringency_{it} + \beta_5 Temperature_{it} \times COVID19\ Stringency_{it} + \beta_6 Rainfall_{it} \times COVID19\ Stringency_{it} + u_{it} \quad (6)$$

where  $Park\ visitation_{it}$  is the dependent variable observed for unit  $i$  at time  $t$ ,  $a_i$  designates the unit-specific intercepts which captures heterogeneities across units and  $u_{it}$  is the error term.

### 3. Results

#### 3.1. Park visitation across the pandemic in the UK

Fig. 1 shows parks visitation in the United Kingdom during a period of 2 years and 8 months, from February 15, 2020 to October 15, 2022. The seven-day moving average of park visitation is presented as a solid green line, representing the percent change in park visitation relative to the pre-pandemic baseline, illustrated by the horizontal line at zero. The UK stringency index for COVID-19 restrictions is plotted as a dashed black line. Vertical orange bands designate lockdown periods.

Three key observations are noted. First, a drop in park use relative to

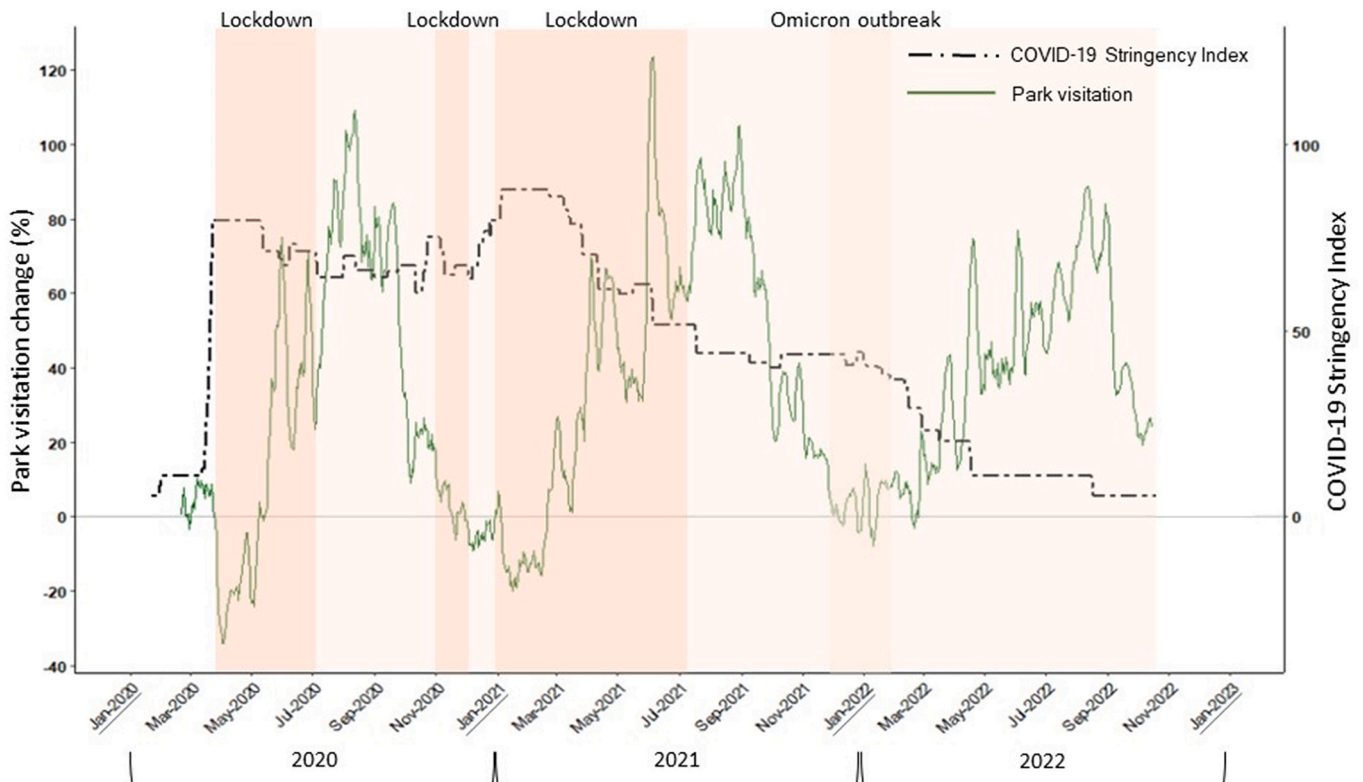


**Fig. 1.** Seven-day moving average of park visitation percent change from pre-pandemic baseline, United Kingdom. *Notes:* Solid green line is for park visitation percent change from pre-pandemic baseline. Horizontal bar at zero is for pre-pandemic baseline. Dash black line is for stringency index. Orange vertical bands for lockdown periods (exact lockdown dates varied by nation).

baseline is seen during the first months of the pandemic, in March through May 2020, when COVID-19 protection measures were first introduced. These included strict stay-at-home orders where people were only allowed to leave their homes for essential reasons or for outdoor exercise once per day. Second, a seasonal pattern is observed, with greater park visitation in summer months and lower visitation in winter. Third, across the pandemic (except March–May 2020) park visitation was substantially greater than the established pre-COVID-19 baseline, suggesting high park visitation over time. Of course, we note that the baseline covered the winter period where park visitation was likely at its lowest, possibly over estimating the comparison.

To further understand park visitation across the pandemic, a two-way ANOVA was conducted to analyse the effect of seasons and years on park visitation. A significant main effect was observed for Season ( $F(3, 962) = 105.7, p < .001$ ), confirming expected seasonal differences in park use, as observed in Fig. 1. No significant Year effect was found, suggesting overall stable total visitation across the years 2020–2022 ( $F(2, 962) = 2.2, p = .11$ ). Of special interest, a significant interaction effect was identified between seasons and years, indicating the variation in park use by seasons varied based on year ( $F(6, 962) = 13.5, p < .001$ ). To describe this interaction, post-hoc Tukey pairwise comparisons were conducted within seasons and are presented in Table 1, with significance between years indicated by different subscript letters, along with mean and standard deviation. Based on these comparisons, three statistically significant observations at the  $p < .001$  level are noted and depicted in Fig. 2. First, there was significantly lower park use in the spring of 2020 (March–May) when the first lockdown was enacted, in comparison to the spring of 2021 and 2022, despite similar weather trends (see Appendix A). This confirms the pattern observed in Fig. 1. Second, there was significantly lower park visitation in the winter of 2021 compared to the winter of 2022, corresponding to the implementation of the third lockdown and the increase in stringency index, despite similar weather trends. Third, visitation was significantly greater in the summer of 2021 compared to the summer of 2020 and 2022, despite similar weather trends.

### 3.2. Role of weather and policy restrictions on park visitation during the pandemic in England

Next, we investigated how policy restrictions related to changes in park visitations during the COVID-19 pandemic within each region unit, while controlling for weather. A correlation matrix is also available in Appendix A.

Unit fixed effects regressions produce an estimate of the average effect of a variable within units over time (Allison, 2009; Mummolo and Peterson, 2018). Table 2 presents univariate and multivariate models, one for main effects only and one with two interaction terms.

In the univariate models 1 through 4, all predictors were statistically significant at the  $p < .001$  level. These relationships were sustained in the multivariate model 5. With all other variables held constant, there was greater park visitation during warmer days and on days with less

rain. There was less park use for every single COVID-19 case increase, resulting in an approximate 5% decrease in park use for every 100,000 cases. Further, there was also less park use when the COVID-19 stringency index was greater.

In model 6, two interactions terms were added to understand the role of stringency on parks use in combination with weather. The model accounted for 38% of the total variance in park use. The significant effects of rainfall and cases remained the same. Further, the interaction between temperature and stringency was significant, by which stringency significantly suppressed the effect of higher temperature. Here, it is worth remembering that when an interaction term is added, the coefficients of the terms by themselves must be interpreted in function of the coefficient of the interaction term and not as standalone; this is important as the sign for the stringency term changes which may otherwise be misleading.

Fig. 3 depicts a more detailed view of this complex interaction, of which two things can be said. First, the graphic clearly shows that for the same stringency level, regardless of if it was low or high, there was greater park visitation when temperatures were greater. Second, albeit less visually clear due to scaling, the function lines show a disordinal interaction, by which in colder weather ( $<10^\circ\text{C}$ ), as stringency increased, park visitation increased; however, in warmer weather ( $\geq 10^\circ\text{C}$ ), as stringency increased, park visitation decreased. In other words, while on average individuals used parks more on nicer days they still adjusted their behaviours and reduced their visitation when restrictions were more severe.

## 4. Discussion

Our study investigated the pattern of actual park visitation using phone mobility data in the UK during the full stretch of the pandemic, as well as investigated the role of weather and COVID-19 restriction on park visitation in England.

### 4.1. Park visitation across the pandemic in the UK

Three key observations on park visitation were brought to light in the first phase of our analysis: (a) a significant drop in park visitation following the start of the pandemic, (b) a seasonal pattern in visitation, and (c) a sustained elevated use over nearly three years.

First, we presented evidence of significantly lower park visitation in the spring of 2020 at the start of the pandemic in comparison to the two following years, perhaps explained by early fear, uncertainty and the first implementation of the COVID-19 restrictions. Indeed, during this time, individuals were only permitted to leave their homes for very limited purposes, including medical needs, shopping for necessities, and for one form of exercise per day (Cabinet Office, 2020). As our study does not allow for analyses of subjective experiences, we turn to other works to elucidate our findings. Burnett et al. (2022) reported some of the reasons cited for not visiting greenspaces at the start of the pandemic (April 2020) included having an alternative outdoor space for personal use (e.g., garden), fear for one's health going outdoors, being a member of a household with individuals at high risk for serious complications from COVID-19 and being worried about social distancing within greenspaces. The proportion of individuals citing fear-based reasons for limiting their use diminished as the pandemic progressed (Burnett et al., 2022). Other studies using Google mobility data present a similar drop in park visitation at the start of the pandemic in the UK (Geng et al., 2021; Burdett et al., 2021; Drake et al., 2020) and internationally (Geng et al., 2021; Curtis et al., 2022). Evidence from self-reported surveys also replicates this reduction in the early stages of the pandemic in the UK (Burnett et al., 2021; England and Kantar Public, 2021; Phillips et al., 2022). In some countries however, a contrasting pattern in greenspace use was seen. In Norway for instance, recreational greenspace use, assessed via STRAVA GPS data, increased by three-fold during the first lockdown. The authors suspect this may in part be driven by the less

**Table 1**  
Park visitation percent change across seasons and year in the UK<sup>a</sup>.

| Year | Mean (SD) park visitation percent change <sup>b</sup> |                          |                          |                          |
|------|-------------------------------------------------------|--------------------------|--------------------------|--------------------------|
|      | Winter                                                | Spring                   | Summer                   | Fall                     |
| 2020 | −1.9 (16.3) <sup>a,b</sup>                            | 2.3 (31.4) <sup>a</sup>  | 64.9 (36.0) <sup>a</sup> | 27.4 (30.8) <sup>a</sup> |
| 2021 | −5.6 (16.4) <sup>a</sup>                              | 41.1 (32.0) <sup>b</sup> | 80.2 (24.0) <sup>b</sup> | 35.3 (24.4) <sup>a</sup> |
| 2022 | 5.4 (14.2) <sup>b</sup>                               | 35.1 (21.3) <sup>b</sup> | 65.0 (20.4) <sup>a</sup> | 31.3 (11.9) <sup>a</sup> |

<sup>a,b</sup> Means with different letters within each season are significantly different from each other ( $p < .001$ ).

<sup>a</sup> Seasons are defined as winter (December of previous year, January, February), spring (March, April, May), summer (June, July, August), and fall (September, October, November)

<sup>b</sup> Park visitation data covers February 15, 2020 to October 15, 2022.

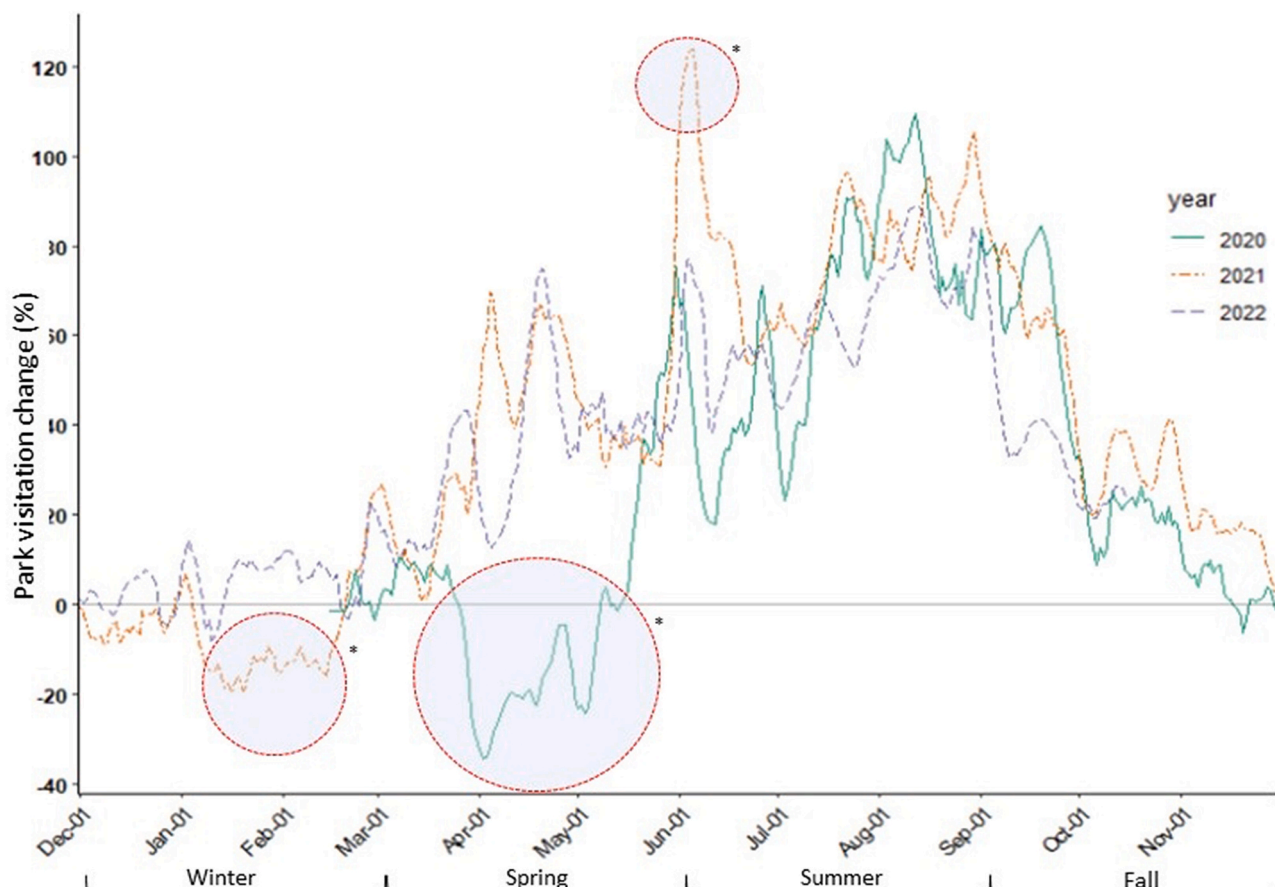


Fig. 2. Seven-day moving average of park visitation percent change from baseline during the COVID-19 pandemic in the United Kingdom. Notes: Sections of interest with significant interactions in pairwise comparisons are highlighted in bubbles.

Table 2

Unit fixed effect regressions on park visitation in England (127 regions).

|                                | Univariate  |            |                | Multivariate <sup>a</sup> |            |              |            |
|--------------------------------|-------------|------------|----------------|---------------------------|------------|--------------|------------|
|                                | Model 1 - 4 |            |                | Model 5                   |            | Model 6      |            |
|                                | Coefficient | Std. Error | R <sup>2</sup> | Coefficient               | Std. Error | Coefficient  | Std. Error |
| Temperature                    | 4.54 ***    | 0.02       | 0.33           | 4.31 ***                  | 0.02       | 5.81 ***     | 0.06       |
| Rainfall                       | -2.64 ***   | 0.04       | 0.06           | -2.12 ***                 | 0.03       | -2.05 ***    | 0.07       |
| COVID-19 cases                 | -0.0003 *** | 0.00       | 0.02           | -0.00005 ***              | 0.00       | -0.00007 *** | 0.00       |
| COVID-19 stringency index      | -0.24 ***   | 0.01       | 0.01           | -0.07 ***                 | 0.01       | 0.28 ***     | 0.01       |
| Temperature X Stringency index |             |            |                |                           |            | -0.03 ***    | 0.00       |
| Rainfall X stringency index    |             |            |                |                           |            | -0.001       | 0.00       |
| Day-region observations        |             |            |                | 83,610                    |            | 83,610       |            |
| F statistic                    |             |            |                | 12,270                    |            | 8,380        |            |
| Adjusted R <sup>2</sup>        |             |            |                | 0.369                     |            | 0.375        |            |

\*\*\* ( $p \leq .001$ ); \*\* ( $0.001 < p \leq .01$ ); \* ( $0.01 < p \leq .05$ ).

<sup>a</sup> Adjusted for all other predictors in the model.

strict COVID-19 policies, the widely embraced culture of outdoor physical activity and the principle of common access to outdoor space (Venter et al., 2020).

Second, we statistically established the overall seasonal trend in park visitation in the UK. It replicates previously identified seasonal trends in self-reported greenspace use (Roberts et al., 2017), and while perhaps an unsurprising finding, it is for the first time demonstrated from high frequency longitudinal data of actual visitation spanning nearly three years.

Third, we presented longitudinal evidence for sustained and elevated park visitation over the course of the pandemic after the initial observed drop in the spring of 2020. This suggest a possible re-discovery of

natural environments, a finding echoed in UK social survey studies (Burnett et al., 2022; England and Kantar Public, 2021; Office for National Statistics, 2021). Reasons cited for increased outdoor use during this time includes psychological benefits, physical activity, connection to nature and fresh air (Berdejo-Espinola et al., 2021; England and Kantar Public, 2021). As greenspace use is beneficial to health and wellbeing, the observed increase in time spent outdoors may have buffered against some of the negative wellbeing impacts of the pandemic, and indeed many users reported perceived benefits (Poor-tinga et al., 2021; Stock et al., 2022).

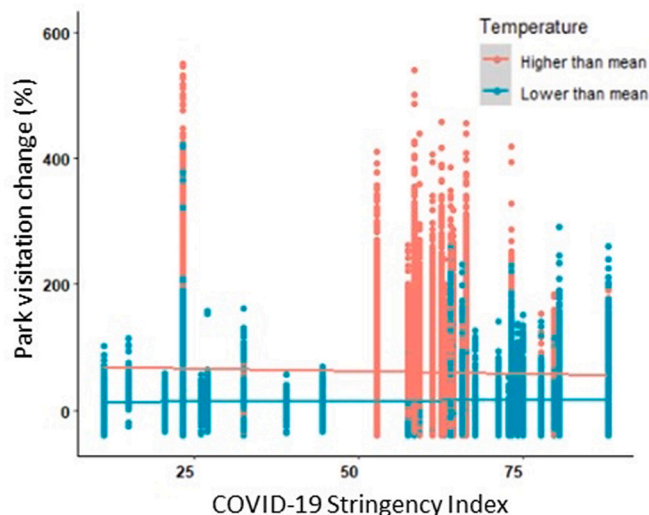


**Fig. 3.** Park visitation percent change by stringency index on days with high or low temperature in England. *Notes:* Orange is for days with high temperature. Blue is for days with low temperature. The mean temperature was selected as cut off for visualization purposes. Vertical bars indicate level of park visitation by stringency index. Horizontal lines indicate trends at two temperature zones.

#### 4.2. Role of weather and policy restrictions on park visitation during the pandemic in England

In regression analyses controlling for region characteristics, we presented evidence for the role of weather and COVID-19 policies on park visitation. Notably, we confirmed that park use significantly increased when temperatures were greater and when it rained less. Further, park use increased significantly when there were fewer COVID-19 cases. In addition, our findings uncovered an interaction effect not previously discussed in the literature between temperature and stringency of restrictions, by which stringency significantly suppressed the effect of higher temperature on visitation. In other words, in warmer weather ( $\geq 10^\circ\text{C}$ ), while visitation was overall elevated, it was tempered by restrictions, such that when stringency increased park visitation decreased.

Our findings align with early Google mobility studies. For instance, a study in the western United States (US) reported the main sources of park visitation change to be elevation and latitude-driven climatic differences. In their study, restrictions were not significantly related to changes in park visitation; however, the study only looked at 3 months of data in the spring of 2020 when there was likely little variation in restrictions (Rice and Pan, 2021). Another US study found decreases in park visitation were smaller in regions with greater park availability. Again, this study only looked at the first 3 months of data (Curtis et al., 2022). Corroborating our findings on weather, another UK study covering the first 7 months of the pandemic observed the same direction of effect for temperature and precipitation (Burdett et al., 2021). In a similar fashion, a UK study showed park visitation increased when the reproduction number ( $R$ ) decreased (Li et al., 2021), and indeed we found park visitation decreased as COVID-19 cases increased, with an approximate 5–7% decrease in park use for every 100,000 cases. Evidence from surveys also converge with our findings. For instance, the People and Nature Survey (PANS) for England ( $n = 2,080$  adults every wave) described that the most frequently cited deterrents to spending free time outdoor in greenspaces during the pandemic were poor weather and government restrictions (England and Kantar Public, 2021).

Of course, we concur that other factors play a role in park visitation, such as park availability, typically included in studies, but usually confounded with socioeconomic factors. Here, by statistical design,

fixed effect models control for within region time-invariant factors, like park availability and demographic factors. It allowed us to isolate the unique role of weather and COVID-19 context while controlling for stable factors that are not expected to change significantly across the study period. It provides a different strategy and outlook on ecological dynamics.

Our study through its retrospective examination suggest insights on the impact of the restrictions put in place during the pandemic. While we do not present mental health and wellbeing data in this study, surveys doing so reported better outcomes among those with greater use and proximity to greenspace (Poortinga et al., 2021; Bu et al., 2022; Edwards et al., 2023; Stock et al., 2022). Given the potential benefit of greenspace experiences, it is important to reflect on the collateral impact of restrictions which discouraged and diminished use of greenspace. Once epidemiological data established outdoor transmission was limited, perhaps a better approach would have been to actively encourage safe greenspace use, particularly for vulnerable groups and urban dwellers without private gardens. Such strategies could have included signage to remind people to distance themselves, one direction pathways, and open street initiatives to allow pedestrians and cyclists more space to move freely, particularly near and around parks (Slater et al., 2020). In crises where social distancing is required, the few locations where this can occur safely should be promoted. While we saw that overall park visitation was high during the majority of the pandemic, it remains important to reflect on whether measures may have negatively affected individuals who could have benefited greatly from respite.

#### 4.3. Strengths and limitations

This work uniquely allowed for a population level analysis of park visitation using large amounts of objectively assessed high frequency data with large geographical and temporal coverage. It is a comprehensive assessment of the pattern of daily park visitation over the course of the pandemic. It allowed for the average estimated effect of factors playing a significant role in park use over time, including temperature, rainfall and COVID-19 context within a repeated time series design.

However, limitations remain. The study draws on publicly available data from four sources, each with drawbacks. The mobility data is limited to smart phone users with Google applications who have turned on their location history service. Individuals without mobile devices are not included; children and older individuals are therefore likely to be underrepresented in our findings (Aktay et al., 2020). Further, the data only considers officially designated outdoor greenspaces and does not cover the general outdoors found in rural areas. Actual greenspace visitation is likely to be greater. Additionally, the data is presented as the relative change in park visitation in relation to a pre-pandemic baseline. The assumption that the baseline represents a period of average mobility may be too strong; still values remain unbiased as the same reference point is used throughout for comparisons. As the baseline was established by Google we were unable to alter it. Data from Google is not available beyond October 15, 2022, rendering post-pandemic comparisons not possible. For weather, we derived daily area averages using raster data. Individuals in specific locations may have experienced different weather patterns on any given day than the computed area averages. As for the total number of COVID-19 cases, its impact on park use likely varied over time. In early days, when few had immunity and outdoor transmission was poorly understood, public information on case number was likely more relevant to park visitation behaviours. We note, of course, that the manner in which cases were recorded varied with testing capacities, reporting protocols and variants. Here, it is included as a control variable. Lastly, while it is true the COVID-19 stringency index includes some measures that may not have direct impacts on park use (e.g., international travel controls), it speaks to the greater COVID-19 context under which people lived. The index is provided at the UK and national level only; in instances where policies varied at the subnational level, the index is shown as the response level of the strictest

sub-region (Hale et al., 2021). Nonetheless, it is the most comprehensive open access resource on COVID-19 restrictions that exists. Of course, it does not speak to the enforcement of or adherence to the restrictions.

Methodologically, this study relied on an ecological design where aggregate data was analysed. We caution the risk of the ecological fallacy: inferences about park visitation at the individual level cannot be made from inferences about the group to which those individuals belong. It is possible that analyses at different spatial granularities would reveal contrasting dynamics. Interpretations must remain prudent and non-causal. As unit fixed effects were used to produce an estimate of the predictor average effect within regions nothing can be said of the between region patterns. The study relies on a naturalistic field design and variables were not independent or orthogonal of each other. Given the historical chronology, there was a correlation between restrictions and temperature, and between case numbers and temperature, notwithstanding progress in testing and vaccination. Longer longitudinal designs remain essential as well as more sophisticated models with linked databases if they become available. Lastly, no demographic information on park use was available and as such stratified analyses were not possible. Similarly, no other behavioural information was available. The work is best seen as complementary to individual level studies on self-reported motivations, barriers, and experiences of greenspace use during the pandemic.

## 5. Conclusion

This study provides evidence on the pattern of park visitation during the full span of the pandemic, as well as on the role of weather and COVID-19 context on park visitation while controlling for region characteristics. Notably, we found park visitation to be significantly reduced at the beginning of the pandemic following the onset of the restrictions, with a later increase, and sustained elevated use across the entire pandemic. We observed a seasonal trend in park visitation, with greater use in the summer than in the winter. In subsequent analyses, we uncovered the average effect of temperature, rainfall, COVID-19 cases, and COVID-19 stringency index on park visitation. It confirmed that more greenspace use was observed as the temperature rose and as it rained less. Similarly, more use was seen when there were fewer COVID-19 cases and when the stringency level of restrictions was lower. Of special interest, an interaction effect was found between temperature and stringency, by which stringency significantly suppressed the effect of higher temperature on park visitation. This finding underscores that the policies involved in the stringency index had a significant impact in reducing park visitation during warmer days. Taking stock of the potential health and wellbeing benefits of using greenspaces, it is important to consider the negative collateral impact of restrictions which discouraged and diminished park use, as demonstrated by our findings.

## Credit author statement

Anais Lemyre: Conceptualization, Data curation, Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing. Jane P Messina: Conceptualization, Formal analysis, Methodology, Writing – review & editing.

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## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

The links to downloadable datasets are provided in the reference list.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.envres.2023.117360>.

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