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# The dynamic impact of COVID-19 pandemic on park visits: A longitudinal study in the United States

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ABSTRACT

During the COVID-19 pandemic, people's park visit pattern has received great attention from both scholars and policy-makers, attributed to parks' established health benefits and thus serving as an effective strategy to mitigate people's stress and improve people's physical and mental health. While burgeoning empirical evidence has been generated, both negative and positive impacts of the pandemic on park visit behaviors have been reported. However, the dynamics of park visits along with the pandemic progress remains underinvestigated. Using locational-based mobile data, this study investigates the longitudinal dynamics of park visits in terms of visiting frequency, travel distance, and time spent within parks across the contiguous United States from January to December 2020. The year-over-year (2019–2020) variations of park visitation patterns are associated with pandemic-relevant variables (i.e., the number of infection cases, and policy stringency index), and the locational characteristics of parks (i.e., "local parks" and "non-local parks" as classified according to ESRI's US parks dataset). The analytical results reveal that (1) on average, park visit frequency, travel distance, and length of stay reduced since the outbreak of the pandemic; (2) the number of infection cases exerted a negative impact on visit frequency, a positive impact on visitors' dwelling time, but the inconsistent impact on travel distance in different pandemic periods; (3) the stringency of containment policies negatively affected visit frequency and travel distance, but its impact on park visitors' dwelling time was inconsistent; and (4) local parks received much fewer visits, even though visitors traveled a longer distance to access some local parks located in peri-urban areas. This study depicts a comprehensive picture of the dynamics of park visitation along with the pandemic progress and sheds light on the ways that parks can aid in recovering from a public health crisis.

## 1. Introduction

### 1.1. *Benefits of park visitations and associated exposure to nature on public health*

Parks, where diverse floral and faunal species inhabit, serve as salutary venues enabling visitors' exposure to nature and thereby improving their physical and mental health (Grilli et al., 2020; Labib et al., 2022; Liu et al., 2020; Romagosa et al., 2015). Recent years have witnessed a blossoming of scientific interest and research focusing on exposure to nature and health outcomes (Barnes et al., 2019; Bowler et al., 2010; Frumkin et al., 2017; Jimenez et al., 2021; Seymour, 2016; Wei et al., 2023). Resultantly, a wealth of empirical evidence has been documented depicting the potential impact of exposure to nature enabled by park visitation on human health along a multiplicity of pathways (Bedimo-Rung et al., 2005; Hartig et al., 2014; Larson and

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Hipp, 2022; Yin et al., 2023).

Amongst plausible mediating mechanisms between parks and public health and wellbeing is the sense of connection with and affinity for nature that people develop during millions of years of co-evolution with nature (Kellert and Wilson, 1995; Swierad and Huang, 2018; Ulrich et al., 1991), which engenders three domains of pathways through which park visitation could (i) benefit individuals' cognitive functioning and psychological wellbeing via enhancing attention restoration (Kaplan and Kaplan, 1989) and relieving physiological stress (Frumkin et al., 2017; Ulrich et al., 1991; Yin et al., 2023); (ii) ensure and improve physical vitality via active (such as walking, performing various sport games, etc.) and/or passive (such as relaxing, viewing scenery, listening to natural sounds, etc.) engagement (Bedimo-Rung et al., 2005; Larson and Hipp, 2022; Schipperijn et al., 2017; Seymour, 2016); and (iii) strengthen social health via encouraging social engagement, maintaining social ties, and promoting social cohesion (Jennings et al., 2016; van den Bosch and Ode Sang, 2017; Maas et al., 2009; Wan et al., 2021).

While it is widely recognized that parks are indispensable for public health, getting to and visiting parks (regardless of the level of activities park visitors engage in while visiting a park, be it active or passive) is essential for establishing meaningful exposure to nature and realizing certain health-related benefits (Bedimo-Rung et al., 2005; Bratman et al., 2019; Grilli et al., 2020; He et al., 2022; Veitch et al., 2022; White et al., 2019; Wolch et al., 2014). Previous research has shown that park visitation behavior (such as frequency, travel distance, and length of stay) are associated with a person's socioeconomic characteristics (such as gender, age, education attainment, etc.) and attitude towards parks (such as the desire to gain nature exposure and health benefits), as well as park characteristics (Bos et al., 2016; Liu et al., 2020; Lu et al., 2021; Yin et al., 2023), such as accessibility (Li et al., 2019; McCormack et al., 2014; Rossi et al., 2015), park type and size (Giles-Corti et al., 2005; Tu et al., 2020), natural aesthetics (Austin et al., 2020; Subiza-Pérez et al., 2020), biodiversity (Carrus et al., 2015; Nghiem et al., 2021; Wood et al., 2018), and park maintenance (Austin et al., 2020).

### 1.2. Park visiting behaviors during the COVID-19 pandemic

The World Health Organization declared on 11 March 2020 the coronavirus outbreak as a global pandemic public health menace, which is still ongoing and insofar has imposed significant impacts on the physical, mental, social, and economic wellbeing of human societies (Moeti et al., 2022; Yin et al., 2023). With the implementation of various containment policies such as lockdowns, stay-at-home orders, or social distancing policies that aim at slowing down the spread of infection (Bo et al., 2021; Wellenius et al., 2021), severe detriments on public mental and psychological health have been introduced simultaneously, including depression, insomnia, loneliness, anxiety, confusion, and anger (Brooks et al., 2020; Ding et al., 2022; Geng et al., 2021; Marroquín et al., 2020; Pfefferbaum and North, 2020).

Parks, the only out-of-home natural sites remaining available for various social and recreational activities and left untouched by the pandemic, have received renewed attention from the general citizens, scholars, and policymakers (Berdejo-Espinola et al., 2021; Haase, 2021; Yin et al., 2023; Tansil et al., 2022; Taczanowska et al., 2022). And the health benefits generated by parks have become more conspicuous (Lee et al., 2022; Ugolini et al., 2020). It has been well-documented that contact with nature during the pandemic could help ameliorate depression/stress and improvinge mental health (Dzhambov et al., 2021; Pouso et al., 2021; Soga et al., 2021). However, park visitation (as an essential way for nature exposure) behaviors have changed significantly during the pandemic, attributed to various factors like the severity of the pandemic, the stringency of restrictive policies, and the accessibility of parks (Chen et al., 2022; Christiana et al., 2022; Derks et al., 2020; Geng et al., 2021; Hamidi and Zandiatashbar, 2021; Lu et al., 2021). And relevant empirical findings about park visitation behaviors have been inconsistent. For example, Geng et al. (2021) found park visitation frequency across 48 countries worldwide has increased since the pandemic began, which was mainly attributed to the closures of many public places such as shopping malls and restaurants thus making parks one of the places people can visit for outdoor activities and more importantly, nature exposure (Grima et al., 2020; Venter et al., 2020). In contrast, a decline in park visitation frequency has also been reported between March 15 and May 9, 2020 in 620 counties in the United States (Curtis et al., 2022), during March and November 2020 in Poland (Noszczyk et al., 2022), and in April 2020 in Chengdu, China (Xie et al., 2020).

Besides visit frequency, changes in dwelling time in parks and preferences for different types of parks have also been observed. Robinson et al. (2021) found that during April and July 2020 in England people tended to spend longer time (about 106 min) in natural environments (than before the pandemic at an average of 66 min) and easily accessible urban parks were preferred (besides private gardens). In comparison, significantly shortened stay (comparing before and during the pandemic) has been reported in China (Chen et al., 2022) and Saudi Arabia (Addas and Maghrabi, 2022). To better maintain social distancing policies that have been imposed by many national/local governments and reduce using public transport to visit parks far away from home, people preferred large and uncrowded parks in proximity to home during the pandemic, as observed in Sweden (Samuelsson et al., 2021), Finland (Korpilo et al., 2021), and the United States (Ding et al., 2022). However, a study in Hungary has indicated that mid-sized parks attracted more people in comparison with the smallest and largest parks during the pandemic, because these parks could better balance the accessibility and maintenance of social distance (Csomós et al., 2023).

### 1.3. Research gaps

The mixed empirical evidence concerning park visitation behaviors during the pandemic might be attributed to the variation of the time period for data collection. The majority of empirical studies cover relatively short periods of time, from one week (as in Chen et al. (2022), Xie et al. (2020)) to a couple of months (as in Ding et al. (2022)), during which time there might be fluctuations of infection risks, which might lead to changes in park visitation behaviors (Labib et al., 2022). Additionally, either social surveys (as in Xie et al. (2020); Veitch et al. (2022)) or mobile-based location data (as in Venter et al. (2020); Ding et al. (2022)) are applied. While mobile-based location data provide accurate spatial locations with weekly park visitation, the total aggregated park visitation number on the basis of multiple POIs (points of interest) might be overestimated (Ding et al., 2022). Similarly, social surveys, which usually invite respondents to recall their behavior before and after the pandemic during survey periods, tend to be time-consuming, costly, and unable to cover a large amount of parks in the context of the ever-changing pandemic, and limitations associated with sample representativeness in social surveys might arise (Xie et al., 2020). Furthermore, the majority of empirical studies focus on park visit frequency, and limited evidence exists about other characteristics like the length of stay inside of parks and travel distance across large study areas and considering the complex and ever-changing pandemic situation over a relatively long period of time.

This study aims to fill in the abovementioned research gaps. Using geotagged big datasets that represent nearly 10% of all mobile devices and all parks (including national, state, county, regional, and local parks as specified in the ESRI dataset) across the contiguous United States for 2019 (non-pandemic period) and 2020 (pandemic period), this study unveiled the one-year longitudinal dynamics of three park visitation characteristics (i.e., frequency, travel distance, and length of stay) under a long period impact of the pandemic via using mixed effects analytical models. To be more specific, three research questions as follows are investigated to depict a clear picture of the dynamics of park visitation behaviors:

i) How did park visitation behaviors, in terms of visit frequency, travel distance, and length of stay, change comparing different stages of the pandemic (2020) with the non-pandemic period (2019)?
ii) What were the differences in park visitation behaviors between local vs. non-local parks?
iii) What were the impacts of the progress of the pandemic on the changing dynamics of park visitation behaviors?

## 2. Methodology

### 2.1. The study area

This study covers all parks across the contiguous United States. Relying on the ESRI "US Parks" dataset (https://www.arcgis.com/home/item.html?id=578968f975774d3fab79fe56c8c90941), five types of parks are considered, including national (816), state (4542), county (1315), regional (1875), and local parks (48,795). Overall, a total of 57,343 parks are included in this study (Fig. 1a). The summary statistics of these types of parks refer to Table S1 in the supplementary material.

### 2.2. Park visitation characteristic before and during the pandemic

#### 2.2.1. Weekly visit data

Similar to Ding et al. (2022), visitation data is derived from the SafeGraph' Weekly Patterns dataset for the period from January 1, 2019 to December 31, 2020. SafeGraph is a data-service company providing about 4.4 million Points of Interest (POIs, which represent geographical locations that people may find interesting) data from nearly 10% of anonymous mobile devices in the United States (Safegraph, 2022). This dataset is considered to be highly representative of the general population and has been used for understanding people's park visitation behaviors, albeit still limited (Ding et al., 2022; Jay et al., 2022). This Weekly Patterns dataset contains aggregated visitation information to each POIs on the weekly basis (as shown in Appendix Table S2), mainly including but not limited to raw counts of visitation, median visitation distance from visitors' home, and median length of stay at POIs.

In the Weekly Patterns dataset, "raw_visit_counts" represents the aggregated raw visit counts of POIs from the panel of mobile devices, and only those stays longer than 4 min would be counted as a meaningful visit to a given POI (Safegraph Weekly Patterns Data. 2022). "Distance_from_home" is the median distance from visitors' home to the POI in meters, calculated by taking the haversine distance between the visitor's home and the location of the POI for each visit, and the median of all of the home-POI distance pairs is derived. The POIs that have fewer than 5 visitors will be assigned to the null value. And "Median_dwell" contains the median of the dwell times of each visit to the POIs. According to the official definition, the dwell time is determined by looking at the first and last ping from a mobile device during a visit to a POI.

#### 2.2.2. Park visitation characteristics

The US Parks dataset provided by ESRI is applied to delineate the geographic boundary of all parks, including local and non-local ones. However, direct use of a single POI as a park destination may be misleading, as for many large parks multiple POIs may exist. To accurately measure park visitation characteristics, all POIs within the boundary of a park are labeled with an identical park ID (as shown in Fig. 1b). Then raw visit counts (visit frequency), median travel distance, and dwell time (length of stay) are aggregated based on park IDs. These three measurements are calculated for each park and each week during the study period from January 1 to December 31, 2019 (as the non-pandemic period) and January 1 to December 31, 2020 (as the pandemic period).

#### 2.2.3. YOY changes in park visitation characteristics

Park visitation changes might also be associated with seasonal changes in the weather such as temperature and precipitation (Hewer et al., 2016; Rice and Pan, 2021). To control potential seasonal effects, the year-over-year (YOY) comparison for each week in 2020 and the same week in 2019 is adopted to capture the changes in park visitation characteristics. Such a YOY variation is able to eliminate the seasonal effects. It is given by

$$YOY_{ij} = CPV_{ij} - PPV_{ij} \tag{1}$$

in which $YOY_{ij}$ represents the year-over-year change of park visitation characteristics (including frequency, travel distance, and length of stay) in park $i$ and week $j$; $CPV_{ij}$ is the current value (2020) for park $i$ and week $j$; $PPV_{ij}$ is the previous value (2019) for park $i$ at week $j$. This YOY measurement can provide a clear picture of how park visitation behaviors changed, comparing those taking place during the pandemic period (11 March to 31 December 2020) and the non-pandemic period (01 January to 31 December 2019), with negative values indicating a decline and positive values indicating an increase in the year of 2020.

### 2.3. The progress of the COVID-19 pandemic in 2020

#### 2.3.1. Different stages of the COVID-19 pandemic

From the first infection case confirmed in January to the full outbreak after March in the United States, the number of infection cases went through several stages in the absence of vaccination in 2020 (Fig. 2). To understand the dynamic impact of the pandemic on park visitation behaviors, the whole year of 2020 is divided into six periods (Period 0 to Period 5) based on the development stage of the pandemic, as the severity of the pandemic may affect people's mobility patterns including park visitation (Geng et al., 2021; Landry et al., 2021; Ma et al., 2021).

The brbreakpoints are selected at the beginning and the end of a new pandemic wave (the number of infection cases significantly increased). As shown in Fig. 2, Period 0 is the pre-outbreak stage, including the onset of the COVID-19 pandemic (01 January to 11 March), Period 1 is the first wave of the pandemic (12 March to 20 April) when containment policies such as lockdown, "stay-at-home" orders, or social distancing policies were strictly implemented in most states and then were gradually lifted throughout the rest of 2020, Period 2 signifies a stable period (21 April to 15 June), Period 3 is the second wave of the pandemic (16 June to 10 August) with a new round of increase of infection cases, Period 4 is the second stable period (11 August to 15 October), and Period 5 is the third wave of the pandemic, with enormous new infection cases until the end of 2020 (16 October to 31 December).

#### 2.3.2. Amount of infection cases

Perceived infection risk is a critical factor affecting people's park visit intention and cognate activities during the COVID-19 pandemic (Chan et al., 2020; Landry et al., 2021; Ma et al., 2021). People might intentionally reduce park visitation when infection cases surged significantly, as observed during the three waves of the pandemic. The weekly average amount of new infection cases in the state where the park is located is adopted as a measure of the pandemic severity at the park location, which is included in the analytical model as an independent variable to explain how the pandemic severity might affect park visitation behaviors. The number of infection cases is obtained from the Centers for Disease Control and Prevention (2020). The curve in orange in Fig. 2 shows the weekly average number of infection cases across the contiguous United States.

#### 2.3.3. Policy stringency index

The containment policies enforced by national and local governments could also significantly restrict people's mobility and curtail park visitation activities (Ding et al., 2022; Geng et al., 2021). To take this variable into account, the stringency index derived from the COVID-19 Government Response Tracker/OxCGRT dataset compiled by a group of

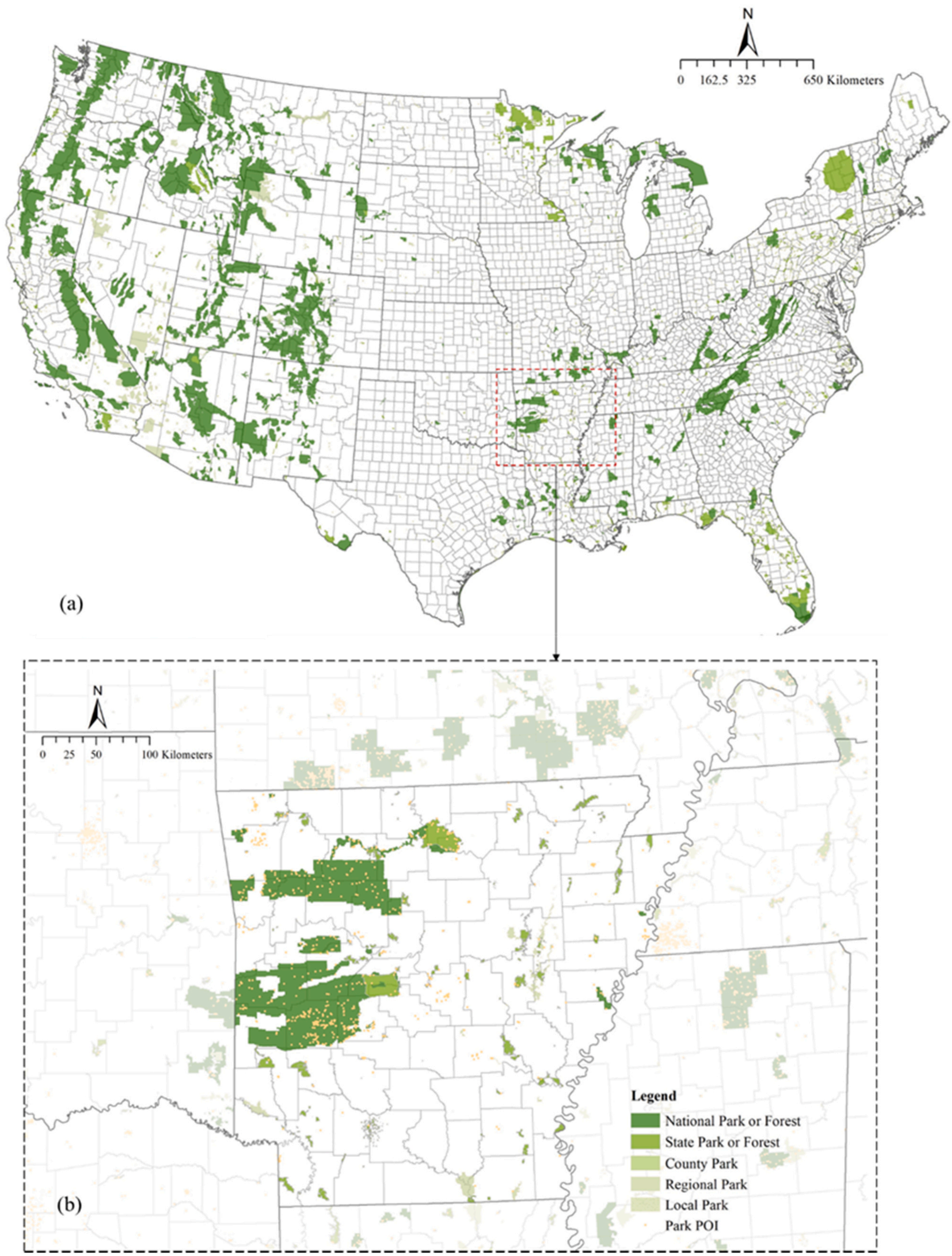


**Fig. 1.** The US parks: (a) spatial distribution of all parks; (b) examples of park boundaries and Points of Interest; (c) national parks, state parks, county parks, and regional parks are grouped as non-local parks.

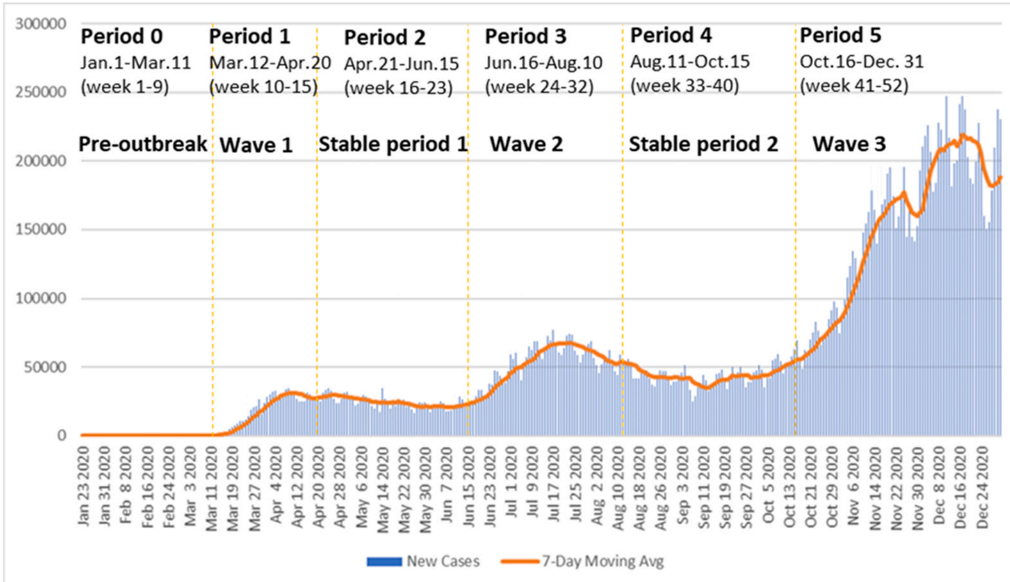


**Fig. 2.** Number of infection cases and the pandemic periods in the United States (Centers for Disease Control and Prevention, 2020).

researchers worldwide (Hale et al., 2021) is adopted as an additional explanatory variable. The original daily data is at the state level, considering seven types of containment policies, i.e., closing schools, closing workplaces, public event cancelations, gathering restrictions, closing public transport, stay-at-home requirements, and restrictions to internal movement and international travel. In this study, the weekly average stringency index for the state where the park is located is computed and included in the analytical model as an independent variable.

### 2.4. *Locational characteristics of parks*

To verify whether different types of parks would attract different visit patterns and shape the changes in park visitation behavior in different ways, all parks are re-grouped as local ones and non-local ones (including national, state, county, and regional parks) according to the classification given in ESRI's US parks dataset, due to the sharp contrast between local parks (in close proximity to the majority of population) and all other four types of parks (with large size, and fragmentally distributed in relatively pristine areas). And the group of non-local parks is regarded as the reference group in the analytical model.

### 2.5. *Data analysis*

Mixed effects model, also known as the multi-level model, is applied in this case to examine the dynamic impact of the COVID-19 pandemic on park visitation behaviors longitudinally in six periods across local and non-local parks. This model permits the change of a given outcome (park visit behaviors in this study) over time while controlling for other time-varying variates and accounting for the dependency of repeated measures over time. Park visitation changes are analyzed for six pandemic periods, including the pre-outbreak period, the first wave, the first stable period, the section wave, the second stable period, and the third wave, respectively.

A two-level data structure with time-varying park visitation behaviors nested within different types of parks with time-unvarying locational and other features is constructed in this study. To detect whether a one-level parsimonious model or a two-level model is appropriate, the intraclass correlation coefficient (ICC) is estimated, which quantifies the proportion of the total variation in park visitation behaviors accounted for by park types. As the ICC value is greater than 0, it indicates that the impacts associated with park types cannot be overlooked and the multilevel modeling should be adopted (Asparouhov, 2006).

The analytical model is then given by

$$YOY_{ij} = \beta_{0i} + \beta_{1i}week_{ij} + \beta_2 case_{ij} + \beta_3 stringency_{ij} + \varepsilon_{ij} \tag{2}$$

$$\begin{cases} \beta_{0i} = \beta_0 + \beta_4(park \quad type)_i + b_{0i} \\ \beta_{1i} = \beta_1 + b_{1i} \end{cases} \tag{3}$$

in which $YOY_{ij}$ denotes the YOY changes of park visiting characteristics (in terms of frequency, travel distance, and length of stay) for park $i$ for week $j$ since the beginning of 2020 as derived using Eq. (1); $week_{ij}$ is a variable explaining the longitudinal progress of the study time; $case_{ij}$ is the amount of COVID-19 infection cases in the state where the park $i$ is located for week $j$; $stringency_{ij}$ is the policy stringency score in the state where the park $i$ is located for week $j$; $(park\ type)_i$ is a categorical variable representing whether a park is local or non-local.

Eq. (2) pertains to the impacts introduced by time-varying independent variables and Eq. (3) pertains to the impacts brought by time-unvarying independent variables. $\beta_{0i}$ is a random intercept across parks; $\beta_{1i}$ is a random slope for time dynamics; $\beta_0$ is a fixed (overall) intercept, $\beta_1$, $\beta_2$, and $\beta_3$ are the coefficients of time, infection cases, and policy stringency, respectively; $b_{0i}$ and $b_{1i}$ represent the deviation of park $i$'s intercept and slope from the overall intercept and slope. To facilitate the interpretability of analytical results, all variables, excluding park type, are mean-centered. Moreover, to address potential outliers for regression model validity, the interquartile range technique (Vinutha et al., 2018) is used to remove all outliers identified in $YOY_{ij}$.

## 3. Results

### 3.1. *Changes in park visitation in 2020*

#### 3.1.1. *Overall trends*

Fig. 3 plots the YOY changes of three park visitation characteristics. To provide a more precise and intuitive description of these variations, we further included a descriptive statistical table (Table S3 in supplementary material) to complement Fig. 3 with specific values. Overall, park visitation declined throughout the whole year of 2020, with a decrease in visit frequency from 80.96 times per week in 2019–69.80 times per week in 2020 (i.e., a 13.8% decline), travel distance from 8.38 km to 7.87 km (6.1%), and dwelling time from 49.3 min

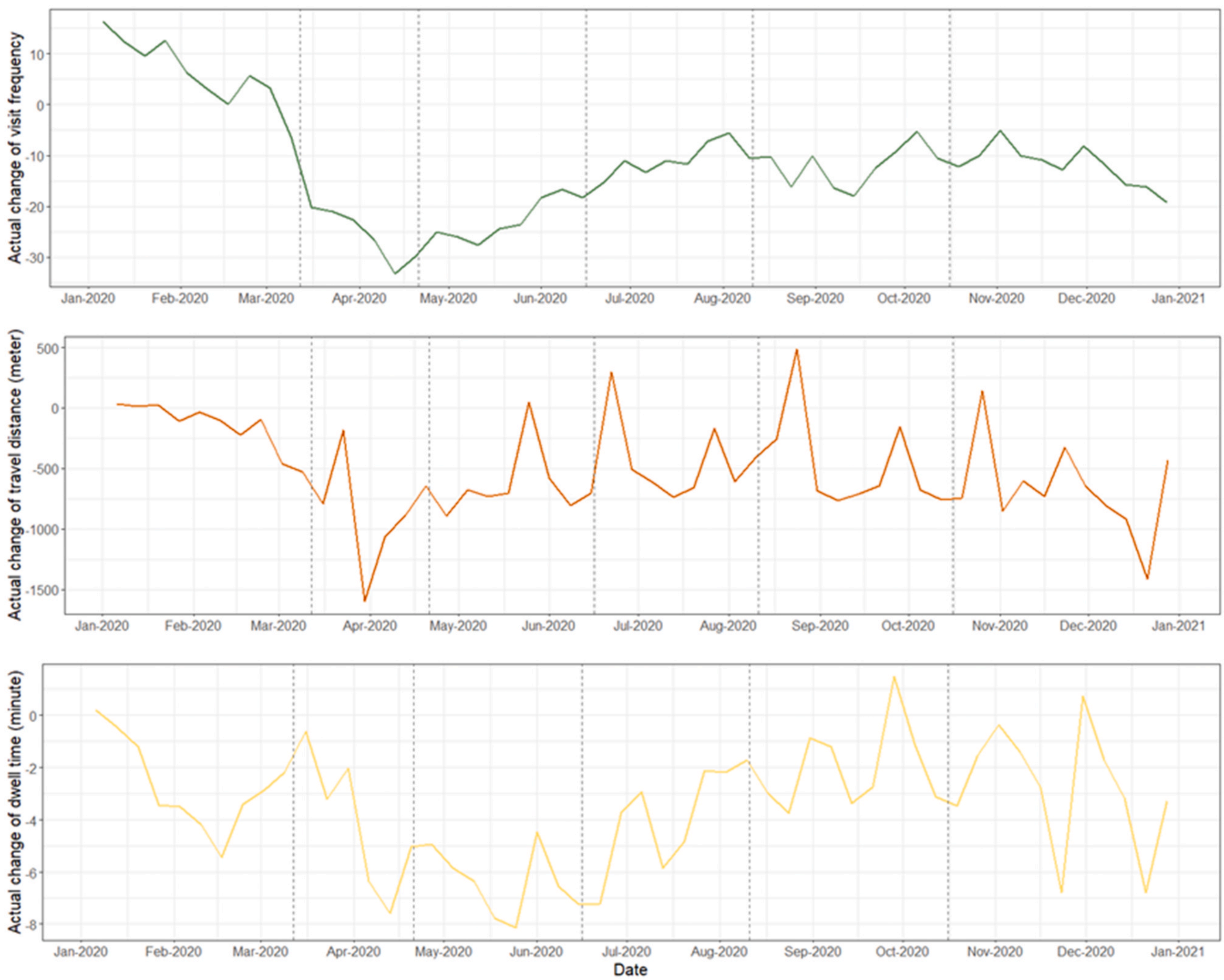


**Fig. 3.** Year-over-year changes in weekly park visitation characteristics.

to 45.8 min (7.1%).

Moreover, variations along the progress of the pandemic (from Period 1 to Period 5) can be readily observed. During the first wave period (12 March to 20 April), visitation frequency, travel distance, and dwelling time declined sharply, with the visit counts dropping by 28.6%, travel distance dropping by more than 11.1%, and the length of stay by 7.7% on average. From the first stable period (Period 2) onwards, there was a clear trend of recovery of park visitation, even though the amount of infection cases was highest in Period 5 than in all preceding periods, as illustrated by Fig. 2. Sometimes travel distance and dwelling time even became higher than the same period in 2019, despite the implementation of travel restrictions during the pandemic period.

### *3.1.2. A comparison between visits to local and non-local parks*

A comparison of park visitation characteristics between local and non-local parks is plotted in Fig. 4. Interestingly, local parks received more visits (84.18 times per week, 7.83 times more in 2020) than non-local parks (69.37 times per week, 6.07 times more in 2020) during the pre-outbreak period (P0). This trend switched completely since the outbreak of the pandemic and fewer visits were made to local parks (64.98 times per week during P1 and P5, 17.46 times less than in 2019), while visit frequency to non-local parks was 77.50 times per week for the same period, which is 5.25 times less as compared with the same period in 2019.

With regard to travel distance, both local and non-local parks have witnessed a rather stable decline throughout the year 2020, as illustrated by the middle part of Fig. 4. Considering the absolute value, the travel distance to local parks was 7869.94 m in 2020, with a 510.83 m decrease compared with the travel distance to local parks in 2019. The average travel distance for visiting non-local parks decreased a little more, from 20303.48 m in 2019–19545.19 in 2020 (a decrease of 758.29 m).

On average, visitors stayed a little longer in local parks (45.91 min per week in 2020, 49.42 min in 2019) than in non-local parks (44.32 min per week in 2020, 47.71 min in 2019). After an initial decline during P0 and P1, the largest reduction occurred during the first stable period (P2, 6.14 min decrease), and then visitors' dwelling time increased gradually towards the end of 2020. Clearly, visitors tended to spend less time in both local and non-local parks in 2020, and the decrease is more for local parks (−3.51 min) than non-local parks (−3.39 min). Combined together with travel distance, these results suggested that people would like to maintain their stay to the non-pandemic level when visiting farther non-local parks.

Overall, the comparison between local and non-local parks indicated that visitors to local parks reduced their visit frequency significantly, traveled slightly shorter distances to parks close to their homes, and spent shorter time in parks. Comparatively, non-local parks have attracted similar visiting frequency (except for P1), shorter travel distances, and also slightly reduced length of stay. Taken together, these results suggest that visits to non-local parks have been largely sustained after the first wave of the pandemic. When park visitation was possible, local and non-local parks with shorter travel distances were selected.

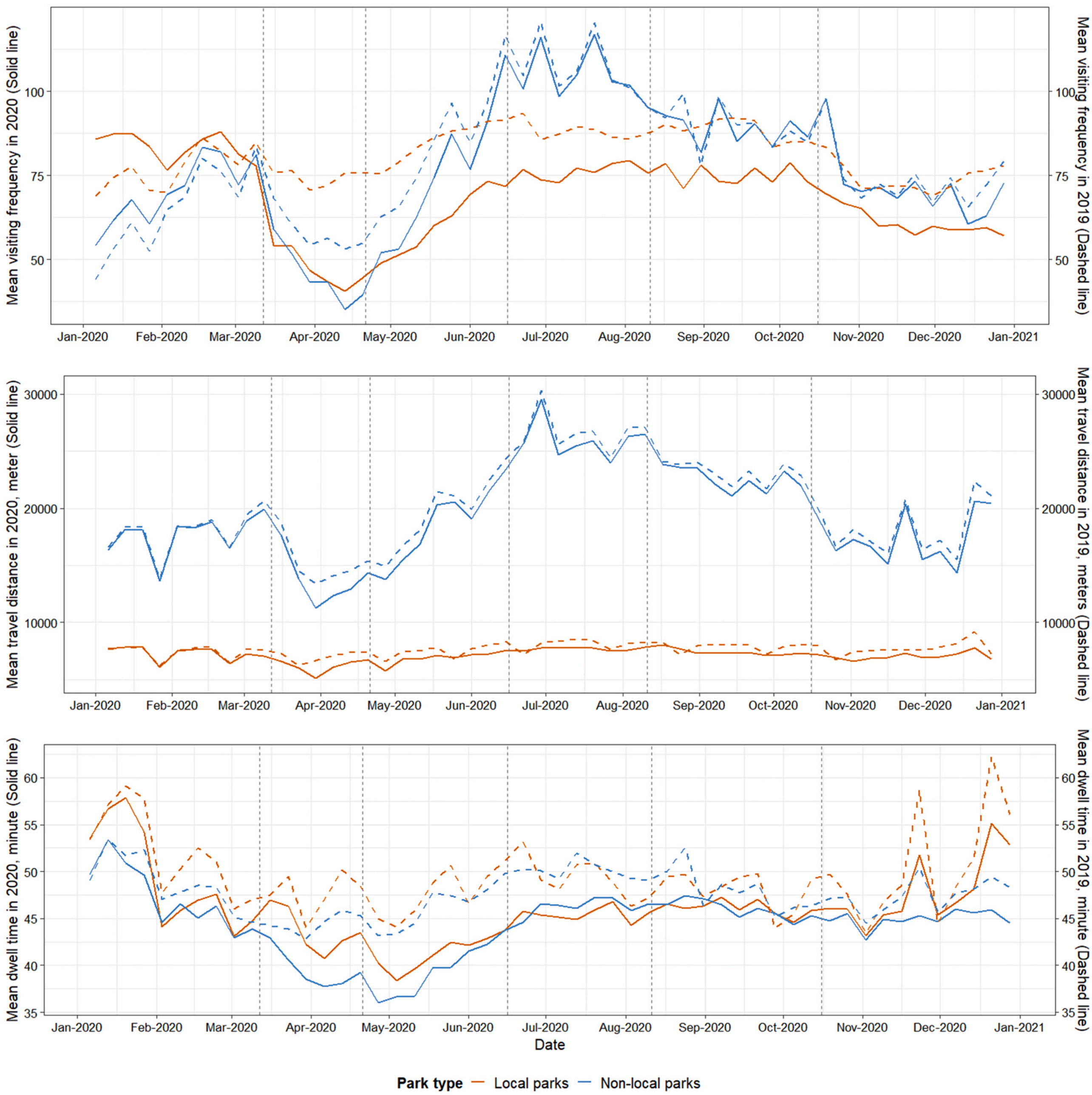


**Fig. 4.** Changes in park visitation characteristics: local vs. non-local parks. Note: the solid lines represent values in 2020, and the dashed lines represent values in 2019.

**Table 1**
Modeling results for visit frequency.

| Visit frequency | Pre-outbreak (P0) | First wave (P1) | First stable period (P2) | Second wave (P3) | Second stable period (P4) | Third wave (P5) |
|---|---|---|---|---|---|---|
| (Intercept) | -0.031 * | 0.201 * | 0.300 * | 0.237 * | 0.290 * | 0.255 * |
| | (−0.053, −0.009) | (0.176, 0.226) | (0.273, 0.327) | (0.213, 0.262) | (0.265, 0.315) | (0.231, 0.279) |
| Week | -0.165 * | -0.189 * | 0.094 * | 0.099 * | 0.038 * | -0.075 * |
| | (−0.169, −0.161) | (−0.195, −0.183) | (0.089, 0.099) | (0.096, 0.103) | (0.034, 0.041) | (−0.079, −0.071) |
| Infection case | 0.015 * | -0.014 * | -0.018 * | -0.029 * | -0.022 * | 0.012 * |
| | (0.012, 0.019) | (−0.020, −0.008) | (−0.023, −0.013) | (−0.035, −0.023) | (−0.029, −0.016) | (0.007, 0.016) |
| Stringency index | – | -0.101 * | -0.075 * | -0.060 * | -0.068 * | -0.032 * |
| | – | (−0.106, −0.096) | (−0.081, −0.069) | (−0.066, −0.055) | (−0.075, −0.062) | (−0.037, −0.027) |
| Local park | 0.066 * | -0.304 * | -0.426 * | -0.298 * | -0.358 * | -0.322 * |
| | (0.042, 0.089) | (−0.331, −0.277) | (−0.455, −0.398) | (−0.323, −0.272) | (−0.384, −0.332) | (−0.348, −0.296) |

95% confidence intervals are given in brackets; * denotes a statistical significance level of 5% or better.

The lower visit frequency and shorter dwelling time in both local and non-local parks might be attributed to visitors' intention to minimize head-on interactions when more visitors showed up in parks.

### 3.2. Dynamic impacts of the COVID-19 pandemic on park visitation throughout 2020

#### 3.2.1. Visit frequency

Table 1 presents the analytical results pertinent to the association between the change in park visit frequency and explanatory variables for each stage of the pandemic progress, respectively. Along with the continuous increase in the number of infection cases (as an indicator of the severity of the pandemic) since the outbreak of the COVID-19 pandemic (P1 onwards), its impact displayed a U-shape trend, and the largest negative impact occurred during the second wave period ($\beta_2 = -0.029$, $p < 0.001$). Interestingly, such a negative impact of infection cases on park visit frequency diminished gradually and turned into a positive impact ($\beta_2 = 0.012$, $p < 0.001$) during the third wave of P5 even though the pandemic got increasingly worse (Fig. 2).

While policy stringency consistently exerted negative impacts on park visit frequency (all $\beta_3 < 0$, $p < 0.001$), the magnitude of its impact reduced along with the progress of the pandemic. The lessening stringency of containment policies (from 66.97 in P1 to 58.43 in P5) together with its weakened impacts would stimulate more park visits, which explained the gradual rebound of visit frequency (Fig. 3). As for park types, during the pre-outbreak period (P0), local parks received a higher amount of visits than non-local ones ($\beta_4 = 0.066$, $p < 0.001$). However, from the first wave (P1) onwards, local parks consistently received much fewer visits as compared with non-local ones (all $\beta_4 < 0$, $p < 0.001$).

#### 3.2.2. Travel distance

Table 2 presents the analytical results for travel distance. The impact of the number of infection cases on travel distance is not consistent, with the only negative impact being observed during the second wave period (P3: $\beta_2 = -0.012$, $p < 0.001$). The significantly reduced travel distance induced by a sharp increase in infection cases during this period (16 June to 10 August) might be attributed to an increase in people's awareness of the pandemic severity, so park users tend to avoid long-range distance visits. Except for this period, the increase of infection cases had a positive impact, either statistically significant (P4) or not (P1, P2, P5), suggesting that even though people's travel distance to parks reduced on average (Fig. 4), an increase of the state level infection cases might push park visitors to travel a longer distance.

This result is corroborated by the positive impacts of local parks on visitors' travel distance (all $\beta_4 > 0$, $p < 0.001$), revealing that travel distances to local parks is significantly longer. Compared with non-local parks, travel distance to local parks increased during the pandemic period, revealing people tended to travel longer distance to visit local parks. This preference for local parks located a little farther from visitors' home places might be associated with an avoidance of crowdedness in nearby local parks. Similar to its impacts on visit frequency, policy stringency negatively affected travel distance consistently from P1 to P5 (all $\beta_3 < 0$). With the implementation of more stringent policies, visitors' travel distance to all parks was reduced significantly.

#### 3.2.3. Length of stay

Table 3 reports the analytical results concerning people's dwelling time inside of parks that they visited. A clear trend pertains to an increase in the length of stay brought by the increase of infection cases during the early periods and the last period (all $\beta_2 > 0$, $p < 0.001$), except for the mid-time (P3 and P4) when the relevant impact became statistically insignificant. Despite an overall decrease in dwelling time in parks as revealed by Fig. 4, the increase in infection cases pushed visitors to spend a longer time when visiting a park. The impact of policy stringency on park visitors' dwelling time is not consistent, being positive during the first wave of the pandemic ($\beta_3 = 0.073$, $p < 0.001$) and the second stable period ($\beta_3 = 0.010$, $p < 0.001$), and negative during the first stable period ($\beta_3 = -0.021$, $p < 0.001$), and the third wave period ($\beta_3 = -0.009$, $p < 0.001$). This varied impact might be attributed to what type of containment policies were enacted during each time period, particularly whether outdoor activities (such as park visits) were allowed.

As for the change of the dwelling time between local and non-local parks, visitors spent much less time in local parks as compared with non-local parks ($\beta_4 = -0.054$, $p < 0.05$) during the pre-outbreak period (P0). After the outbreak of the pandemic, no significant difference between local and non-local parks can be detected. Combined with the pattern shown in Fig. 4, our results suggest that visitors reduced their length of stay similarly in both local and non-local parks, even though the pandemic got increasingly worse.

## 4. Discussion

The COVID-19 pandemic has major repercussions on people's overall mobility, and significantly reshaped people's park visit behaviors (Ding et al., 2022; Geng et al., 2021), even though parks are among the limited outdoor places remaining available for citizens to enjoy various physical activities and reduce psychological stress introduced by the continuously worsening pandemic in 2020 (Berdejo-Espinola et al., 2021; Haase, 2021; Yin et al., 2023), especially when limited medical solutions were available to control the pandemic spread across the whole world. Using a big dataset from SafeGraph on visits to various parks made by approximately 10% of the total population, this study presented a one-year (from 01 January to 31 December 2020) longitudinal analysis of park visitation behavior changes (2020 vs. 2019) across the contiguous United States. Three park visit characteristics in terms of visiting frequency, travel distance, and length of stay are associated with the changing pattern of the COVID-19 pandemic, to generate a better understanding of the dynamic impact of the pandemic progress on park visitation and shed additional light on the ways that various parks can aid in promoting public health.

**Table 2**
Modeling results for travel distance.

| Travel distance | Pre-outbreak (P0) | First wave (P1) | First stable period (P2) | Second wave (P3) | Second stable period (P4) | Third wave (P5) |
|---|---|---|---|---|---|---|
| (Intercept) | -0.031 * | -0.136 * | -0.113 * | -0.080 * | -0.050 * | -0.036 * |
| | (−0.053, −0.010) | (−0.162, −0.111) | (−0.137, −0.090) | (−0.101, −0.059) | (−0.073, −0.026) | (−0.057, −0.016) |
| Week | -0.033 * | -0.043 * | 0.010 * | -0.012 * | -0.046 * | -0.024 * |
| | (−0.037, −0.029) | (−0.051, −0.036) | (0.005, 0.016) | (−0.016, −0.008) | (−0.050, −0.042) | (−0.028, −0.020) |
| Infection case | 0.000 | 0.007 | 0.001 | -0.012 * | 0.030 * | 0.001 |
| | (−0.004, 0.004) | (0.001, 0.013) | (−0.004, 0.006) | (−0.017, −0.006) | (0.024, 0.035) | (−0.004, 0.005) |
| Stringency index | – | -0.017 * | -0.015 * | -0.009 * | -0.002 | -0.023 * |
| | – | (−0.024, −0.010) | (−0.022, −0.009) | (−0.014, −0.004) | (−0.004, 0.007) | (−0.028, −0.018) |
| Local park | 0.032 * | 0.141 * | 0.116 * | 0.080 * | 0.048 * | 0.035 * |
| | (0.011, 0.054) | (0.115, 0.168) | (0.092, 0.140) | (0.058, 0.102) | (0.024, 0.073) | (0.014, 0.057) |

95% confidence intervals are given in brackets; * denotes a statistical significance level of 5% or better.

**Table 3**
Modeling results for dwelling time.

| Dwelling time | Pre-outbreak (P0) | First wave (P1) | First stable period (P2) | Second wave (P3) | Second stable period (P4) | Third wave (P5) |
|---|---|---|---|---|---|---|
| (Intercept) | 0.044 * | -0.007 | -0.022 | 0.007 | -0.009 | 0.017 |
| | (0.027, 0.062) | (−0.028, 0.013) | (−0.041, −0.003) | (−0.011, 0.025) | (−0.028, 0.010) | (−0.000, 0.034) |
| Week | -0.054 * | -0.137 * | -0.032 * | 0.066 * | 0.035 * | -0.021 * |
| | (−0.058, −0.050) | (−0.144, −0.130) | (−0.038, −0.027) | (0.062, 0.069) | (0.031, 0.039) | (−0.025, −0.017) |
| Infection case | 0.024 * | 0.008 * | 0.007 * | -0.005 | 0.000 | 0.009 * |
| | (0.021, 0.028) | (0.002, 0.014) | (0.002, 0.012) | (−0.010, 0.000) | (−0.005, 0.006) | (0.004, 0.014) |
| Stringency index | – | 0.073 * | -0.021 * | -0.003 | 0.010 * | -0.009 * |
| | – | (0.066, 0.080) | (−0.027, −0.015) | (−0.008, 0.002) | (0.004, 0.015) | (−0.013, −0.004) |
| Local park | -0.054 * | 0.018 | 0.025 | -0.008 | 0.013 | -0.017 |
| | (−0.072, −0.036) | (−0.003, 0.039) | (0.005, 0.045) | (−0.026, 0.011) | (−0.007, 0.033) | (−0.034, 0.001) |

95% confidence intervals are given in brackets; * denotes a statistical significance level of 5% or better.

### *4.1. The changing pattern of park visitation behaviors during the pandemic*

On average, visiting frequency, travel distance, and length of stay all reduced since the pandemic outbreak from 11 March to the end of 2020. Even though it was reported that the pandemic had stimulated a renewed mass recognition of parks as a critical lifeline for urbanized society (Jay et al., 2022; Sisson, 2020) and public visits to urban parks have boomed in early 2020 in several countries (Derks et al., 2020; Geng et al., 2021; Robinson et al., 2021; Sisson, 2020; Venter et al., 2020), this study unfortunately revealed that overall park visitation across the United States dropped in comparison with the non-pandemic period of 2019, when weekly average park visit patterns are considered. Additionally, a clear and gradual rebound (albeit not yet at the same level as compared to the preceding year) can also be detected, which is consistent with empirical evidence (Ciesielski et al., 2022).

Despite an overall decreasing trend, park visiting frequency dropped significantly in the early stage and rebounded slightly towards the end of 2020, even though the pandemic got increasingly worse (as suggested by the number of infection cases). While such a decline in the early pandemic period is consistent with previous studies that reported reduced park visits (Curtis et al., 2022; Larson et al., 2021; Noszczyk et al., 2022), a clear recovery trend of park visit frequency along with the unfolding pandemic revealed by our longitudinal study can be explained by a theoretical model commonly applied in the domain of behavioral science, namely the Capability, Opportunity, and Motivation Model of Behavior model (Michie et al., 2011). This model recognizes that behavior is influenced by many factors, and behavior changes might be induced by modifying at least one of these components. In our case, when the first wave ended and the containment policies were gradually lifted, people started regaining the opportunity to move freely. Thus, those who cannot go to the parks in the early stages may start to visit parks again since the second wave of the pandemic onwards. Moreover, people's desire to return back to normal life (signifying their motivation for behavior change) has been growing stronger among populations after the hit of the pandemic on all aspects of people's daily activities and well-being (USAToday, 2020). Furthermore, there is a renewed, and probably increased, mass recognition of parks' contribution to physical and mental health when recreational opportunities are limited, which motivated park visits as a safe and much-needed respite for those who suffered in early lockdown (Geng et al., 2021; Moore and Hopkins, 2021; Volenec et al., 2021; Yin et al., 2023). Even though we could not find an elevated non-pandemic level of park visiting frequency as in Volenec et al. (2021), this study highlights that parks are valuable natural assets and continue to provide crucial health benefits particularly in stressful times. More importantly, the decline of park visit frequency is reversible, if appropriate policies are devised.

Similar to the non-pandemic time (Li et al., 2019; Rossi et al., 2015), travel distance is a key predictor of park visitation behaviors during the pandemic (Heckert and Bristowe, 2021; Lin et al., 2023). This study reveals explicitly that visitors tend to shorten their travel distance after the pandemic. It is reasonable as longer travel distance means more inter-person interactions and thus a higher risk of viral transmission, and on the other hand mobility restrictions induced by relevant containment policies might have also narrowed the available travel modes (particularly public transit) and potential travel distance to access parks (Heckert and Bristowe, 2021). As observed in Kanazawa, Japan (Ueno et al., 2022), Stockholm, Sweden (Samuelsson et al., 2021), Oslo, Norway (Venter et al., 2020), Helsinki, Finland (Korpilo et al., 2021), and Wuhan, China (Zhang et al., 2022), people preferred parks at relatively closer distances during the pandemic. Especially, those parks in close proximity with high vegetation cover density, diverse facilities, and large size have received more attention from visitors and policymakers during the pandemic (Curtis et al., 2022; Ueno et al., 2022; Ugolini et al., 2020; Yap et al., 2022). In connection with travel distance during the pandemic, a recent study across a total of nine American cities reported that disadvantaged groups traveled much shorter distances to visit parks than more privileged groups (Sevtsuk et al., 2022), which further worsened environmental inequity as disadvantaged groups commonly have limited greenspaces and parks in their living environments and close proximity (Curtis et al., 2022), who might be greatly affected by the pandemic and also have a greater demand for the freely available health benefits provided by parks (Labib et al., 2022; Slater et al., 2020). However, in this study, we could not include the socioeconomic characteristics of park visitors in the analysis due to data limitation to investigate how these factors would influence park visitation behaviors, which have to remain a subject of future research.

Spending time in parks and engaging with nature are associated with numerous health benefits (Hartig et al., 2014). For instance, forest bathing has been demonstrated to reduce anxiety significantly (Robinson et al., 2021). Especially during the pandemic, spending more time in greenspaces/parks (spaces with natural vegetation) is significantly associated with lower depression and anxiety scores (Reid et al., 2022). By comparing the duration of time spent in parks before and during the pandemic, this study revealed that on average visitors in the United States slightly reduced their length of stay in parks throughout the whole year of 2020, even though the time decrease became less in the last two periods (P4 and P5) and in several weeks the length of stay surpassed the value observed in the non-pandemic period (Fig. 3). This finding is consistent with empirical evidence in the UK (Burnett et al., 2021), China (Chen et al., 2022), and Saudi Arabia (Addas and Maghrabi, 2022). In contrast, a survey of a total of 993 individuals in the UK suggested that people spent more time in nature as a result of the pandemic, even though some overcrowding sites were avoided (Robinson et al., 2021). The differences in research findings across empirical studies might be attributed to several factors, including the pandemic seriousness, containment policy stringency (particularly whether park visits are allowed or not), and the potential crowdedness in parks (Reid et al., 2022).

### 4.2. Local vs. non-local parks

Empirical evidence suggests that local parks close to people's homes are preferred and receive more visits during the pandemic, primarily for convenience reason (Korpilo et al., 2021; Ueno et al., 2022; Ugolini et al., 2020), while several studies have also documented that large parks with diverse and dense vegetations attracted more visitors due to low risk of viral transmission, despite their relatively remote location (Lu et al., 2021; Venter et al., 2020). The findings of this study corroborate the latter empirical observation. We found that local parks received shape drops in visit count, while non-local parks received insignificant drops, from the outbreak of the pandemic till the end of 2020 in the United States. This further confirms the higher attraction of large non-local parks during the pandemic.

Meanwhile, it is interesting to find that visitors' travel distance to local parks has increased significantly, and visitors' dwelling time in both local and non-local parks decreased in similar magnitude during different periods of the pandemic. Taken together, this study hints that people's visits to local parks are reduced and those local parks located farther away are chosen when park visit is feasible. Obviously, in doing so, visitors could not only avoid crowdedness and cognate infection risk (associated visiting local parks in close proximity, like residential neighborhoods), but also very avoid long-distance travel to access non-local parks, which might induce more head-on interactions especially when using public transportation (Korpilo et al., 2021; Samuelsson et al., 2021; Csomós et al., 2023). Thus, this study reflected visitors' trade-offs when making park visit decisions, and highlighted the importance of local parks situated in peri-urban areas which might attract insufficient policy attention as they are not readily accessible and not frequently visited during the non-pandemic time (Žlender and Ward Thompson, 2017).

### 4.3. The dynamic impact of the pandemic on park visitations

While the pandemic had reshaped park visiting behaviors, the impact varied along with its progression. With regard to the severity of the pandemic as proxied by infection cases, the second wave period (P3, 16 June to 10 August 2020) witnessed the most serious impacts, causing significantly reduced visit frequency and shortened travel distance. In the earlier periods (P1 and P2) and later periods (P4 and P5), we found weakened adverse impact or even positive impact (P5) on visit frequency, and positive impact on travel distance and dwelling time in parks, thus a U-shape curve concerning the impacts of infection cases on park visitation characteristics. With the onset of the pandemic, people's negative emotions (such as fear, worry, uncertainty, and anxiety) toward viral transmission and fear of the unknown have been gradually built up and elevated in the earlier periods (Ciesielski et al., 2022; Li et al., 2021; Lwin et al., 2020), probably peaked with the hit of the second surge in new infection cases (P3 in this study), and then become diminished towards the end of 2020 and even largely reverted back to positive emotions when the rollout of large-scale vaccination brought positive view offsetting the negative emotions brought by the increase of infection numbers (Bendau et al., 2021; Li et al., 2021). Additionally, pandemic fatigue, a natural response of people to a prolonged public health crisis, emerged and continuously increased along with the pandemic progression (Du et al., 2022; Petherick et al., 2021). The changing pattern of people's emotions and psychological fatigue towards the pandemic led to motivational and behavioral changes (Du et al., 2022; Groot Kormelink and Klein Gunnewiek, 2022; Wu et al., 2023). Taking the aforementioned factors together with a renewed interest in nature during the pandemic (Berdejo-Espinola et al., 2021; Haase, 2021; Jay et al., 2022), people became reluctant to comply with containment policies (such as staying at home or avoiding gathering) and motivated to engage in outdoor activities including park visitation, as observed in this study a U-shape relationship between the number of infection cases and park visit frequency, travel distance, and dwelling time throughout the year of 2020.

Another key factor exerting significant impacts on park visiting behaviors is the stringency of restrictive policies that had been widely implemented across the world during the pandemic. This study found that policy stringency led to a significant reduction in park visiting frequency and travel distance, which is consistent with empirical evidence suggesting that non-pharmaceutical policy interventions (e.g., social-distancing policies, lockdowns, border restrictions) coping with the pandemic significantly restricted people's mobility, including park visitations (Geng et al., 2021; Heo et al., 2020; Nouvellet et al., 2021). In a global-scale analysis, Geng et al. (2021) found that the government stringency index is the most important variable in explaining park visitor numbers, which is significantly correlated with reductions in park visits. On the one hand, different periods of the pandemic were characterized by different containment policies and also different levels of restrictions. If policies like staying at home, lockdown, or closing parks were enforced, it is not possible for people to visit any parks (Ciesielski et al., 2022; Ding et al., 2022). Particularly, park visits tended to be more restricted than grocery/drugstore visits (Bargain and Aminjonov, 2020). On the other hand, some recreational facilities in parks (such as restrooms and playgrounds) may be closed and some parks were perceived to be crowded or with a high risk of viral exposure (Curtis et al., 2022). Comparatively, large parks with more vegetation in suburban areas might be perceived as less crowded and conducive to maintaining social distance (Lu et al., 2021; Venter et al., 2020). Thus, different policy measures and different stringency levels decreased access to different parks, and correspondingly, people reduced their park visit frequency and travel distance to varying levels during different periods of the pandemic.

Nevertheless, no evident pattern is revealed concerning the impact of policy stringency on park visitors' length of stay in this study. Even though it was believed that the coronavirus was rarely transmitted in outdoor environments, the risk of transmission is associated with physical distance and length of contact between park visitors, amongst other factors (Curtis et al., 2022). This study found both positive and negative impacts of policy stringency on dwelling time in parks, suggesting that this association tended to be specific for different periods of the pandemic, influenced by factors like the types of restrictive policies being enforced, weather conditions, park characteristics (large park with diverse vegetation/natural landscape might encourage long stay and high-quality nature exposure), visitors' time availability and park visit frequency (to get the same level of nature exposure and health benefits visitors could reduce visit frequency but spend longer time), and the opportunity of nature exposure in living environment (as intentional nature-seeking via park visitation would lapse to circumstantial nature exposure enabled by neighborhood level nature availability under the same level of policy stringency, according to Tomasso et al. (2021).

### 4.4. Possible implications for future planning and management

The COVID-19 pandemic has notably altered people's behavior and perception towards nature. This study provides clear and comprehensive evidence of park visitation behavior change after the pandemic. Although it remains unclear whether these behavioral changes and new preferences will persist or revert to normal in the post-pandemic era (Pröbstl-Haider et al., 2023), we do need to learn from this experience and be adequately prepared for future epidemics or pandemics. We should not only take immediate actions to cope with such changes in park management in the short term but also develop new strategies and management concepts for urban green infrastructure planning in the long run. For example, more resilient management solutions could be adopted when facing the pandemic crisis rather than simply closing the parks to avoid overcrowding. The digital real-time visitor monitoring system, online booking systems, or other similar management aids could be developed to facilitate residents' travel decisions. This could mitigate people's fear of crowds when making a decision to visit parks. Moreover, the risk-management plans and training among managers to cope with the emergency circumstance could also be strengthened in the park management. In terms of urban green infrastructure planning, more attention should be paid to local parks situated in peri-urban areas as we discussed in Section 4.2. The accessibility of these parks could be further improved to get more visits.

### *4.5. Study limitations and strengths*

The main strength of this study pertains to a very comprehensive longitudinal study of park visitation behavior over different periods of the pandemic progress for the whole contiguous United States. And the comparison with the corresponding week and period in the preceding non-pandemic year allows us to mitigate the uncertainties associated with the seasonality of park vitiation (Ciesielski et al., 2022). As compared with the majority of existing empirical studies which cover commonly short periods and limited sampled cities, this study considers the pandemic as a dynamic progress and its impact on park visitation behaviors change along with the progression of the pandemic.

Another strength of this study is the use of a big dataset of SafeGraph park visiting data (based on millions of park POIs) covering about 10% of anonymous mobile devices in the United States, which avoids any potential risk of viral transmission associated with traditional data collection approaches, such as direct observations or interviews. And the representativeness of the whole population has been confirmed (Curtis et al., 2022; Jay et al., 2022), even though SafeGraph park visiting data has not yet been validated against traditional data sources (such as on-site surveys).

This study has several limitations. First, weather condition, which determines the feasibility of many park-based activities and thus park visitation decisions (Rice and Pan, 2021), is not considered in this study, even though the use of YOY observations might partly mitigate the seasonality factor. Any further modeling efforts should address the aforementioned issues, so as to tease out all major influencing factors and derive a more precise understanding of park visitation behaviors during the pandemic period. Second, an overall stringency index is applied to investigate whether and how the implementation of various restrictive policies might affect park visitation behaviors during different periods of the pandemic progression. Due to the data limitation, we cannot take into account the closure of parks (and facilities in parks) or the closure of indoor recreational facilities, which would prohibit or encourage park visitation directly (Curtis et al., 2022; Reid et al., 2022), even though these factors are considered in the calculation of the overall stringency index. Third, we are unable to assess the socioeconomic characteristics of park visitors and the activities they engage in parks, which could also affect people's park visiting behaviors during the pandemic (Tomasso et al., 2021). Fourth, although using a mixed effect model for our longitudinal analysis in this study could largely limit potential biases from time-unvarying variables such as the availability of facilities in parks, other park characteristics such as the quality of park amenities should be considered (Song et al., 2022). And fifth, we did not differentiate park visitation on weekdays and weekends due to the data unavailability. It would be another point deserving to be investigated in future studies if the data is available.

## 5. Conclusion

Using a big dataset comprising location-based mobile data, this study presented a comprehensive longitudinal study focusing on the long-term park visitation behavior change (terms of visiting frequency, travel distance, and time spent within parks) across the contiguous United States during different periods of the pandemic progression in 2020. Based on the analytical results, we can conclude that park visitations have been adversely affected by the pandemic. People visited parks less, shortened the travel distance to access parks, and also reduced dwelling time inside parks. While the largest negative impacts were detected during the second wave of the pandemic (16 June to 10 August), a rebound of park visitation has also been observed toward the end of 2020. Compared with non-local parks, local parks received much fewer visits, even though visitors traveled a longer distance to access some local parks located in peri-urban areas, thus putting these parks under the policy agenda. Overall, this study depicts a clear picture of park visiting behavior changes, and shed light on the varying impacts on park visitations in response to the dynamic social change along with the pandemic progress.

## CRediT authorship contribution statement

**Wu Xueying:** Conceptualization, Methodology, Software, Writing - Original Draft. **Lu Yi:** Conceptualization, Writing- Reviewing and Editing, Supervision. **Chen Y Wendy:** Writing- Reviewing and Editing, Validation. **Zhang Kai:** Writing- Reviewing and Editing, Supervision.

## 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.

## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ufug.2023.128154.

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