Introduction

Respiratory pathogen seasonality can be viewed as a way to mitigate viral spread during low-transmission periods or prepare vaccination and intervention strategies to prevent illness during seasonal peaks. However, seasonality of influenza and other respiratory pathogens depends not only on environmental variables, but also the social behavior of hosts in highly susceptible populations. The lack of prior immunity to SARS-CoV-2 makes host social behavior even more important in preventing or increasing the likelihood of disease spread. Although environmental variables do play a role in the seasonality of respiratory pathogens, a key gap in our understanding of seasonality comes from a lack of understanding about indoor versus outdoor social interactions and interactions between environment and behavior.

Methods

We used mobile app-based data from the Safegraph Weekly Patterns datasets, which provides visit data weekly to over 5.5 million points-of-interest across the United States. We classified each point-of-interest as primarily indoor (e.g. stores, offices) or outdoor (e.g. playgrounds, parks), allowing for distinction between weekly visitor counts at indoor and outdoor locations. We aggregated visitor counts at the U.S. county level to assess spatiotemporal patterns of indoor and outdoor mobility. The metric we derived compares indoor and outdoor mobility using location data and visitor counts from 2019, before mobility patterns were affected by the COVID-19 pandemic. Indoor and outdoor visitor counts at the county level were divided by the maximum visitor count for that county throughout 2019 to reduce the effects of population size or device count differences between counties. To characterize seasonality in behavior, we defined for each county i at time t, $\xi_i(t)$, as the relative deviation from the county-specific mean proportion of indoor to outdoor mobility.

To analyze $\xi_i(t)$, we performed a time series clustering analysis that identified groups of counties that experienced similar seasonality in behavior.

Results

We find that the proportion of indoor to outdoor mobility in the baseline year (2019) is seasonal and displays a latitudinal gradient (**Figure 1**). In particular, there are four characteristic patterns of seasonal patterns that cluster latitudinally. The proportion of indoor to outdoor mobility is highest in the winter months across the country, reflecting winter weather conditions that limit outdoor mobility or non-essential outdoor activity. Northern latitudes displayed a stronger seasonality than other areas, consistent with longer, more severe winter weather at these latitudes.

Class A regions are predominantly in the northern United States and have strong seasonality. Indoor-outdoor mobility peaks in the early and late months of the year, during the winter, and reaches a minimum during summer months when the weather conditions are more suited to outdoor activities. Class B regions, mostly in the southern U.S., also display seasonality with indoor mobility highest in the winter, but the curve declines more rapidly and remains low for a longer period of time, consistent with a warmer climate with a longer summer season and milder spring and fall seasons. However, class B has more variation during the warmer months than class A. Class C regions, largely in northwestern counties, have a weaker seasonality with a smaller difference in indoor-outdoor mobility between seasons reflecting a

more temperate climate. Class D regions are sparse and spread out, but do not seem to have clear seasonality due to noise in the data or lack of information in less populated areas.

Comparing the baseline year (2019) with the pandemic year (2020), seasonality in indoor mobility was largely maintained. However, April 2020 diverged from 2019 trends as system shock, local lockdowns, and pandemic-related behavior changes spread across the U.S.

Figure 1. A) Indoor-outdoor mobility seasonality in the northern United States. B) Indoor-outdoor mobility seasonality in the southern United States. C) Indoor-outdoor mobility seasonality in the western and northwestern United States. D) Inconsistent indoor-outdoor mobility seasonality, possibly due to noise or counties with few locations or devices.