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Living in a pandemic: changes in mobility routines, social activity and adherence to COVID-19 protective measures

Lorenzo Lucchini[1,4]✉, Simone Centellegher[1,4], Luca Pappalardo[2], Riccardo Gallotti[1], Filippo Privitera[3], Bruno Lepri[1] & Marco De Nadai[1]✉

Non-Pharmaceutical Interventions (NPIs), aimed at reducing the diffusion of the COVID-19 pandemic, have dramatically influenced our everyday behaviour. In this work, we study how individuals adapted their daily movements and person-to-person contact patterns over time in response to the NPIs. We leverage longitudinal GPS mobility data of hundreds of thousands of anonymous individuals to empirically show and quantify the dramatic disruption in people's mobility habits and social behaviour. We find that local interventions did not just impact the number of visits to different venues but also how people experience them. Individuals spend less time in venues, preferring simpler and more predictable routines, also reducing person-to-person contacts. Moreover, we find that the individual patterns of visits are influenced by the strength of the NPIs policies, the local severity of the pandemic and a risk adaptation factor, which increases the people's mobility regardless of the stringency of interventions. Finally, despite the gradual recovery in visit patterns, we find that individuals continue to keep person-to-person contacts low. This apparent conflict hints that the evolution of policy adherence should be carefully addressed by policymakers, epidemiologists and mobility experts.

The COVID-19 pandemic has prompted many countries to implement a diverse set of Non-Pharmaceutical Interventions (NPIs) such as international travel restrictions, physical distancing mandates, closures of business venues, and stay-at-home orders to prevent the spread of the virus[1–7]. These policies have had a profound impact on numerous aspects of human life including employment[8,9], economy[10–13] and people's social behaviour[14–17].

In this context, mobile phone data offered unprecedented opportunities to capture the effects of the NPIs and to understand better their impact on the evolution of the epidemic[18,19]. Different technological and telecommunication companies have released analysis and data to help researchers estimate the epidemic spread[16,20–25], mobility reduction[16,26–29], physical distancing[30,31], physical activity[32], and informing on the efficacy of NPIs[25,33–36]. However, most of these works are based on aggregated data and focus their analysis on macro mobility indicators to inform epidemic models[16,31,34].

While the short term behavioural adaptation to NPIs and their impact on epidemic models is of paramount importance to promptly respond to the pandemic threat, an in-depth understanding of how individual behaviour adapted over time is still lacking. Understanding the long term behaviour in a condition of sustained epidemic threat represents an essential factor in facilitating policy adherence.

This paper studies the changes in the daily routinary behaviour of people, focusing on how individuals adapted their pattern of visits and social contacts over time. We combine Point Of Interest (POI) information extracted from OpenStreetMap (OSM) with privacy-enhanced longitudinal GPS mobility traces of more than 837,000 anonymous opted-in individuals, measured for nine months from 3 January 2020 to 1 September 2020. Our dataset has an average accuracy of 22 m and covers 16 hours of activity per day. This high precision and coverage allow us to examine human mobility at a fine spatial and temporal granularity while ensuring users' privacy (see SI Section S2-A for additional details). We analyse, model, and compare individual's mobility in four US states, including those with the highest and lowest values of daily COVID-19 death rate and NPIs stringency: Arizona (many deaths and low stringency), Oklahoma (few deaths and low stringency), Kentucky (few deaths and high stringency), and New York (many deaths and high stringency) (see SI Section S5 for details).

[1]Fondazione Bruno Kessler (FBK), Trento, Italy. [2]Institute of Information Science and Technologies, National Research Council (ISTI-CNR), Pisa, Italy. [3]Cuebiq Inc., New York, NY, USA. [4]These authors contributed equally: Lorenzo Lucchini and Simone Centellegher. ✉email: lorenzo.f.lucchini.work@gmail.com; work@marcodena.it

Figure 1. (A) From an individual's original GPS trajectory, we detect a stop whenever the individual spends at least 5 minutes within a distance of 65 meters from a given trajectory point. (B) We detect stop locations through a combination of the Dachesis[37] and DBSCAN algorithms[38]. (C) If present, we associate each stop location to the nearest Point Of Interest (POI) within a distance of 65 m.

Our results describe the disruption effect of the COVID-19 pandemic on human behaviour over time at an unprecedented level of detail. Overall, we find that people changed both how they visit places and how they experience them. They spend less time in venues, preferring simpler and more predictable routines. Individual patterns of visits to POIs are shaped by the strength of the NPIs policies, the pandemic's local severity and a risk adaptation factor, which increases the people's mobility regardless of the stringency of interventions. Finally, despite the gradual recovery in visit patterns, person-to-person contacts remained lower than expected given the increased time spent at venues.

Results

We explore and characterize human mobility from an individual's set of stop locations, defined as places where a person stays for at least 5 minutes within a distance of 65 meters. From the original GPS data (see Fig. 1A), we detect the stop locations of each individual through a combination of the Dachesis[37] and DBSCAN algorithms[38] (see "Methods" and Fig. 1B). As a result, stop locations are described as tuples (lat, lon, start-time, end-time), where an individual stays in a particular location with latitude (lat) and longitude (lon) from start-time to end-time. lat and lon are the mean latitude and longitude values of the GPS points found within the specified distance of 65 meters (we refer to the "Methods" and SI Section S3 for the details). Then, we focus on the home and work locations of people. To preserve privacy, the data provider obfuscates users' precise home and work locations by transforming it to the centroid of the corresponding Census Block Group. Thus, we identify the home census block group of users, from now on called Residential area, by looking at the most visited locations during the nights (from 8 pm to 4 am) with a moving time window of 28 days. Similarly, we also identify the Workplace defined as the most visited census block group during the week (from 9 am to 5 pm), which is not marked Residential. We refer to SI Section S4 for additional details.

Finally, we add semantic meaning to individuals' mobility trajectories associating each stop location to the nearest Point of Interest (POI), extracted from OpenStreetMap (OSM), whenever a POI lies within 65 m from the stop location (see Fig. 1C). POIs are commonly described as public locations that people may find interesting, for example, for business or recreational activities[40]. Since the OSM POIs taxonomy is not hierarchically organized, we create a human-curated mapping from the OSM taxonomy[41] to the Foursquare venue category hierarchy[42] (see "Methods" and SI Section S7 for details). SI Section S7-B shows the popularity of POIs in different states, highlighting the variety of the visiting behaviour in the US.

To validate the data provided by Cuebiq and our pre-processing, we compute the correlation of the time-series of visits to POIs, residential areas and workplace areas between our dataset, Google[26] and Foursquare data[43]. We report an average Pearson correlation in New York state of 0.91 and an average Pearson correlation of 0.8 in all four selected states (see SI Section S8).

Starting from the visits of each individual we analyse how people's lifestyle adapted during the pandemic.

Visits to POIs.

We begin our analysis by describing the impact of the COVID-19 pandemic on the visits to POIs over time. Overall, we observe that NPIs are associated with fewer visits to POIs confirming previous results obtained with similar datasets[26,32,34].

Figure 2 shows how the number of visits (panel A) to POIs and the duration of those visits change over time in the four selected US states. It also highlights the differences across states in which the epidemiological situation and the stringency of the enacted policies differed most (see Section S5 for more details). For example, the state of New York experienced the most significant drop in the number of visits to all types of POIs (for