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Effect of weather on pedestrian trip count and duration: City-scale evaluations using mobile phone application data

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ABSTRACT

We examined the association between meteorological (weather) conditions in a given locale and pedestrian trips frequency and duration, through the use of locative digital data. These associations were determined for seasonality, urban microclimate, and commuting. We analyzed GPS data from a broadly available activity tracking mobile phone application that automatically recorded 247,814 trips from 5432 unique users in Boston and 257,697 trips from 8256 users in San Francisco over a 50-week period. Generally, we observed increased air temperature and the presence of light cloud cover had a positive association with hourly trip frequency in both cities, regardless of seasonality. Temperature and weather conditions generally showed greater associations with weekend and discretionary travel, than with weekday and required travel. Weather conditions had minimal association with the duration of the trip, once the trip was initiated. The observed associations in some cases differed between the two cities. Our study illustrates the opportunity that emerging technology presents to study active transportation, and exposes new methods to wider consideration in preventive medicine.

1. Introduction

In all, more Americans are walking: the CDC found the number of adults who walk for transportation, fun, or exercise went up 6% over 5 years (Center for Disease Control and Prevention, 2012). Walking, as the most common form of adult physical activity (United States Department of Health and Human Services, 1996), is an important lifestyle component for improving long term health (Stephens et al., 1985). Walkability and pedestrian activity have become major topics of conversation in urban planning (Talen and Ellis, 2015) and public health, with new interest in improving pedestrian facilities, improving safety, and improving the public's general quality of life (Heath et al., 2006).

These efforts, however, are moderated by the relationship between human mobility behavior and climate—namely, weather and environmental conditions when trip initiation decisions are made (Hoogendoorn and Bovy, 2004). A few earlier studies have largely concentrated on adverse conditions (Cools et al., 2010), but little is known about the everyday experience of pedestrians. Meteorological effects could influence travel demand and route choice in various ways, including diversion to other trip modes or paths, or deferring and canceling of trips. The severity of different conditions may also affect the characteristics of a trip—potentially slowing individuals down during heavy rain or a hot day.

While previous studies were often constrained to small spatial units of analysis, the increasing ubiquity of mobile devices offers opportunities to obtain new data to understand human activity. Leveraging these data offers an unprecedented opportunity to understand human mobility patterns at a substantial temporal and spatial scale, with a level of detail heretofore unavailable.

Most studies of the relationship between weather and travel tend to focus on network performance, such as velocities or disruptions rather than travel behavior at an individual level—the choices made as part of peoples' everyday routines (Böcker et al., 2013). Various studies have observed that higher temperatures (up to a certain threshold) were positively associated with outdoor activities in various cities including San Francisco (Zacharias, 2004) and Chicago (Dwyer, 1988). In Flanders, Belgium, temperature had significant positive effects on walking, although to a lesser degree than precipitation effects. The effect of

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temperature may be mediated or confounded by a trip's purpose (Cools et al., 2010; Aaheim and Hauge, 2005).

In addition to temperature, precipitation and wind have also been reported to play a role in travel behavior. Similar to the literature on temperature, precipitation studies have largely focused on road network performance at a system level rather than micro-level (Böcker et al., 2013). Precipitation is one of the most important weather factors influencing the occurrence of physical activity (Burke et al., 2006), and particularly walking (Cervero and Duncan, 2003). With respect to wind, some studies among pedestrians have not shown significant effects on walking (Murakami et al., 2004), while others observed that wind deterred physical activity (Aaheim and Hauge, 2005). These conditions have an impact on the distance traveled as well; strong winds were associated with a reduction in average total travel distance as compared with normal wind (Sabir et al., 2010) and precipitation was also associated with shorter trip distances (Aaheim and Hauge, 2005).

Methodologically, previous studies of weather conditions and pedestrian mobility have usually relied upon self-report surveys or trip diaries (Lee and Moudon, 2006), for example). Such approaches tend to limit a study's spatial and temporal breadth, as recalled information may lose detail regarding travel modes and locations. Often, there is a loss of actual paths traveled, and a limited capability to collect precise data on travel start and end times, trip duration, and destination location (Murakami et al., 2004). Respondents may also omit trips because they do not consider them to be "transportation" or simply forgot to log them; individuals may consider some activities and short trips to be below the threshold of reporting (Agrawal and Schimek, 2007). Nikolopoulou and Lykoudis (2006)), to understand thermal comfort in key locations in 14 cities, focused their instrument to the felt experiences in specific spaces and a narrow set of questions to survey of 10,000 respondents.

Some studies have attempted to resolve this issue through technological means of data collection, including automated pedestrian counters in select points (Altman et al., 2010) or web-connected cameras, which have allowed for studies across multiple sites (de Montigny et al., 2012). These studies, while providing a more granular, but highly localized, alternative to survey methods, cannot readily infer trip purpose. The limited spatial resolution does not account for the microclimatological diversity that exists across a city outside of the sensors' range of view, and could not continually track the same individual longitudinally over time. As an understanding of the increasingly varied patterns of human activity becomes more important, longer periods of observation are needed (Lee-Gosselin, 2005).

One approach to addressing these challenges is to leverage the increasing pervasiveness of mobile devices (Hazas et al., 2004). Location-based tracking from these devices has progressed forward our understanding where persons are in space and the description of their activities. These spatiotemporal data have created new opportunities to describe human mobility. While the use of anonymized call detail records from mobile phones has permitted improved analyses of individuals (Ratti et al., 2006), the inclusion of geolocation capabilities with active mobile-phone tracking permits a more granular level of analysis (Asakura and Iryo, 2007). GPS technologies, in the automated collection of activity data, have been found to provide high-resolution spatial and temporal records, enabling the mass participation of subjects and the collection of enormous amounts of data in the long term (Shoval, 2008). This has the added benefit of higher accuracy and reliability than when the user is asked to recall their past activities (Forrest and Pearson, 2005).

The newly-available breadth and depth of the empirical data present new research opportunities, and we set out to implicitly test the use of these locative, digital data as a means of describing human behavior in space. In particular, to our knowledge this study is unique to evaluate these effects, concurrently, 1) over a one-year period, 2) at the city or regional scale rather than at a limited spatial scale such as an intersection or block, 3) longitudinally, with a population of specific users over time, and 4) across two cities. Hence, our study focused on evaluating the associations between meteorological conditions and pedestrian activity—count[1] and duration at the city-scale.

2. Methods

To understand general mobility patterns, trip data were collected from a free, commercially-available, proprietary activity-oriented mobile application (AOMA). This application utilized the devices' motion co-processor to record the time and movements of the phone. Generally, the AOMA assigned geographic information to those activities through the use of a device's geolocation services including assisted-GPS (A-GPS) which triangulates proximate Wi-Fi and satellite-based systems providing the highest precision with minimal battery draw; traditional satellite based GPS; and carrier-based signals, providing the coarsest resolution. A-GPS allows locationing even when full line-of-sight to sky is not available, such as in downtown areas. In the georeference data, we calculated the velocity between two points and changes in spatial resolution to further filter the data for errant records resulting in a loss of 8.81% Boston, and 16.06% of San Francisco records.

A new trip record was generated when the user moved outside of a geo-fenced area of approximately 10-meters radius from their previous location. Therefore, we defined a trip as departing one geo-fenced area and the user's journey until s/he remained in another location for a duration of time, thereby creating a new geo-fenced area using the application's own proprietary "stay-detection" algorithm and the device's motion coprocessor. As this process occurred in the background, information on the user's movement was passively recorded. The data were provided by the developer to the researchers as one historic dataset after censoring of the origins and destinations to preserve anonymity.

Boston, Massachusetts and San Francisco, California served as study sites. These cities were chosen for their general regional similarities in size, population numbers and density, and car-ownership rates. The Boston data collection area was bounded by 42.2284°N, 71.1895°W and 42.3979°N, 70.9852°W, which encompassed 317.06 km^2 and included Boston and Cambridge, and portions of Somerville, Brookline, Newton and Chelsea. The San Francisco area was bounded by 37.8064°N, 122.5444°W and 37.6016°N, 122.3472°W, which encompassed 394.38 km^2 and included San Francisco, Broadmoor, Brisbane, Daly City, Colma, South San Francisco and portions of Pacifica and San Bruno. In total, 246,814 trips from 5432 users were recorded in Boston and 257,697 from 8256 users in San Francisco. The average trip density was 778.45 trips per square kilometer in Boston and 653.42 in San Francisco. The average trip length was 889.11 m in Boston and 1017.7 m in San Francisco, with average durations of 1237.48 s and 1371.74 s, respectively. The data covered a period from May 15, 2014 through May 1, 2015.

To protect the privacy of the AOMA's users, the application developer assigned a hashed unique identifier to each individual. No biographical information was collected by the developer, and no personally-identifiable information was provided to the researchers. Further, a random distance of 0–100 m was removed from the start and end of each trip to mask a user's common locations to further anonymize the data.

Data were filtered to eliminate errant activity traces due to errors in the mobile phone's geo-locationing functionalities, which resulted in a loss of 8.81% of Boston, and 16.06% of San Francisco records. (This type of error creates incorrect trip details in the data due to the inherent errors of each locationing method; see Zandbergen and Barbeau, 2011). Further, periods from 01:00 am–05:00 am were excluded due to low or zero trip counts, which resulted in the omission of 2351 trips (0.9%) in Boston and 4052 (1.6%) trips in San Francisco.

[1] We use the terms "count" and "volume" interchangeably as a measure of the number of trip originations within a specified hour.