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Streaming data from a smartphone application: A new approach to mapping health during travel

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ABSTRACT

Background: New research methods offer opportunities to investigate the influence of environment on health during travel. Our study uses data from a smartphone application to describe spatial and environmental patterns in health among travellers.
Methods: A prospective cohort of travellers to Thailand used a smartphone application during their trips to 1) answer a daily questionnaire about health behaviours and events, and 2) collect streaming data on environment, itinerary, and weather. Incidence of health events was described by region and trip type. The relationship between environmental factors and health events was modelled using a logistic mixed model.
Results: The 75/101 (74.3%) travellers that completed the study answered 940 questionnaires, 796 (84.7%) of which were geolocated to Southeast Asia. Accidents occurred to 20.0% of participants and were mainly in the Thai islands, while self-rated "severe" mental health events (21.3%) were centred in Bangkok. The odds of a health event were higher in Chiang Mai (2.34, 95% CI: 1.08, 5.08) and on rainy days (1.86, 95% CI: 1.03, 3.36).
Conclusions: Distinct patterns in spatial and environmental risk factors emerged in travellers to Thailand. Location based tracking could identify "hotspots" for health problems and update travel advice to target specific risk groups and regions.

1. Introduction

The role of environmental factors on human health outcomes has become a key focus for health research and innovation in recent years, especially given the rapid rate of global environmental change [1]. While previous research has established factors in the home environment as playing a fundamental role in health, little is known about environment and health in the context of travel. Travel represents a unique opportunity to study how changes in environmental and societal exposures interact with individual demographics and behaviours to affect health outcomes. Travel medicine researchers have long recognised that travellers represent a special risk category for international infectious disease transmission and give recommendations for vaccinations and prevention based on destination [2]. But the data and methods have not been available to analyse geographical patterns in infectious disease among travellers within a destination or how other health risks are related to spatial and environmental risk factors during travel, and some health issues during travel, such as mental health, have been largely neglected despite evidence that they are an important risk for travellers [3,4]. Previous environmental studies have shown that exposure to air pollution is linked to increased mortality [5,6], that traffic accidents in developing countries vary widely according to spatial and regional risk factors [7,8], and temperature affects the rate of transmission of infectious disease [9], while altitude can acutely affect health during travel [10], but research has remained largely focused on the environmental risk factors of long term residents and the ability to extrapolate results to the short-term acute exposures of travellers is limited and little is known about who is most at risk for poor health outcomes during travel.

In recent years use of smartphones and other mobile devices during international trips has become ubiquitous, allowing itinerary and environment to be tracked more precisely than ever before. The capability to use remote sensing and streaming data to track exact location and the increased quality of environmental data collection even in remote

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destinations (e.g. weather, temperature, nearby venues) offer new opportunities for travel medicine researchers to ask nuanced and wide ranging questions about environment and health during travel.

In our study, we used a smartphone application to create a timeline of health, behaviour, and environmental exposures against actual location during travel to Thailand. In this initial cohort of travellers, we aimed to describe major spatial patterns in lesser known health events during travel, quantify incidence of health events and behaviours in environmentally distinct major tourist regions, describe key trends in health events by trip type, and identify the key environmental predictors of adverse health events during travel.

2. Methods

2.1. Study population and design

A prospective cohort of 100 travellers to Thailand was recruited from the travel clinics of Basel and Zurich (Switzerland) from January to June of 2015. Travellers were asked to complete 1) a pre-travel baseline questionnaire with basic medical history and demographics and 2) download the study smartphone application that collects location and itinerary data during travel, and 3) complete a daily electronic questionnaire about health events and behaviours during their trip and once before their trip.

Travellers were eligible for the study if they met the following criteria: age ≥18 years, planned travel to Thailand between January–October 2015, and planned travel time of < 5 weeks. A single travel destination was chosen to ensure comparability of health risks, environmental exposures, and available technological infrastructure between travellers; Thailand, one of the most popular international travel destinations for Swiss travellers, was selected for ease of recruitment and relevance to travellers as a common destination. Travellers were considered to have completed the study when they answered at least one survey during travel and did not withdraw consent.

All travellers received standard pre-travel advice during their consultation. Study recruitment and design have been described in detail previously [11]. The study was approved by the Ethics Commission of the Canton of Zurich (KEK-ZH-Nr. 2014-0470).

2.2. Data collection tool: TRAVEL smartphone application

To create a new tool capable of capturing an accurate timeline of health during travel, the TRAVEL (Tracking Risks Abroad on Vacation with Electronic Localisation) smartphone application was developed in partnership with the Wearable Computing Lab of the Swiss Federal Institute of Technology (ETH Zurich, Switzerland). The application collects data in two ways: 1) an active electronic closed-ended questionnaire that participants are reminded to answer daily during travel, and 2) passive collection of environmental data via GPS fix, including location, weather, and social media data (Table 1, environmental data and sources).

The daily electronic questionnaire, designed to take 5 min daily, reported on 6 health event domains (accident/injury, mental health, gastrointestinal symptoms, respiratory/flu-like symptoms, skin infections or rashes, and body aches or pain) and 9 health risk behaviour domains (food, mosquito bite avoidance, transportation and accidents, alcohol and drugs, medication use and compliance, health care utilisation during travel, physical activity, animal contact, and sexual behaviour). Health events were self-rated by participants using a Likert scale ranging from 1 (mild) to 4 (severe). A severe health event was considered as an event self-rated as a 3 or 4. The development and testing of the questionnaire was previously reported in detail [11].

After participants had downloaded the application to their phone, a search for location was initiated every 15 min as long as location services were enabled. To maximise accuracy and completeness of passive environmental data collection and location mapping, participants were provided with a SIM card to provide internet access while in Thailand. This enabled the smartphone to (1) obtain location based on surrounding WiFi access points or cell phone towers through a web-based lookup, even while not having a GPS signal (e.g. indoors). If no internet connection was available, the location was estimated by (2) GPS only by attempting a satellite connection to obtain the coordinates. If this failed (normally indoors and in urban areas with bad GPS signal reception), (3) WiFi or cell phone tower localisation was attempted, which decreases the accuracy to 50 m, respectively up to kilometres. Location data was transmitted on an hourly basis to a server. If the attempt did not complete successfully, it was deferred to the next hourly slot until successful transmission. Once location has been received at the server, weather and semantic place data from the social media platform Foursquare were then collected for each captured location. For both services public application program interfaces (APIs) exist that allow programmatic queries based on parameters such as longitude, latitude, and time. Location and environmental data were stored in a noSQL database. A web front end allowed monitoring of the data collection and a data export for further analysis.

2.3. Statistical analysis

To be able to georeference health events and behaviours, all daily surveys were geotagged and timestamped when they were filled out. Survey data was similarly stored in the mobile's database together with the location data and transmitted to the server with the same hourly schedule. If the smartphone was not able to obtain a location update at the time of finishing the survey, the last known location was imputed together with the time difference of the survey and the last known location. If the last known location was > 3 days (72 h) from the survey timestamp, the survey location was recorded as unknown. Participants were not asked to answer questionnaires or leave GPS on while elsewhere in SEA, but may have sometimes spent part of the day in Thailand and part in another country, or uploaded multiple questionnaires from Thailand after arriving in another country, meaning they were instead tagged in the bordering country. Therefore surveys from countries bordering Thailand were included in this analysis. Baseline surveys filled out in Switzerland were omitted from this analysis.

Heatmaps of health events and behaviours were generated by mapping the GPS coordinates of the corresponding survey in which the event was reported; a 2D kernel density estimation was used to contour the regions with highest incidence. To quantify the incidence of health

Table 1
Environmental data and sources. Environmental data was collected passively in 15 min intervals beginning after download of the application onto the user's mobile device.

Data Type	Source	Description
GPS localisation	Satellite connection	Exact itinerary of each traveller
Weather	Connection to open source API	Daily maximum temperature, minimum temperature, average temperature, humidity, windspeed, precipitation, pressure
Social media (Foursquare)	Foursquare Open Source API	For places where the participant stayed > 30min: number of places visited per day, minimum/maximum/total density of nearby locations, number of nearby places by category (e.g. restaurant, nightlife, shops, outdoors & recreation)