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Travel behaviours and health outcomes during travel: Profiling destination-specific risks in a prospective mHealth cohort of Swiss travellers

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ABSTRACT

Background: We used a mobile application to determine the incidence of health events and risk behaviours during travel by country and identify which health risks are significantly elevated during travel compared with at home.
Method: TOURIST2 is a prospective cohort study of 1000 adult travellers from Switzerland to Thailand, India, China, Tanzania, Brazil and Peru, planning travel of ≤4 weeks between 09/2017 and 04/2019. The incidence rate ratio (IRR) in each country was calculated.
Results: All countries had significantly higher incidence of health events than at home. The most elevated symptoms were sunburn, itching from mosquitoes, and gastrointestinal disorders (e.g. vomiting, diarrhoea), corresponding with universally high food/drink risk behaviours. Peru had the highest incidence of both overall negative health events and severe health events (172.0/1000 travel-days). Traffic accidents were significantly higher in Peru (IRR: 2.4, 1.2, 4.7), although incidence of transportation risk was highest in India and Thailand. In Tanzania, incidence of negative mental health events was significantly lower than at home, although it was elevated in other countries. Sexual risk behaviours were high in Brazil.
Conclusions: Our study improves the understanding of the non-infectious disease related health challenges travellers face and provides evidence for more personalised traveller support.

1. Introduction

Technology has become a ubiquitous and crucial part of healthcare, and travel medicine is no exception [1,2]. A mobile health (mHealth) approach offers particular promise in the travel medicine setting, where patients are distant from familiar surroundings and healthcare providers [1,2]. Travel medicine practitioners give advice to prepare travellers for the health challenges they may face, but unlike other medical specialties, they have traditionally only rarely had the opportunity to follow up with their patients to see their health outcomes during their trips. Most travellers carry a smartphone and often already collect health data during their trips, providing an opportunity to change this paradigm by staying connected with their travel medicine practitioner [3]. Several applications have emerged that are taking advantage of this technology to provide real-time remote monitoring of infectious disease in travellers [4], provide advice virtually to travellers while abroad [5], support the pre-travel consultation [6], and study the effect of population mobility on spread of disease [7]. However, the use of mHealth in travel medicine remains underutilised [3].

In addition to bridging the communication gap between travel medicine practitioners and their clients facing emergent medical issues abroad, mHealth applications offer novel research opportunities to

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improve understanding in almost real-time of precisely what health issues travellers are facing, where and how these issues evolve, and how travellers respond to them. Travel medicine research has traditionally been limited to surveys administered on health symptoms and behaviours before and after travel, which are restricted by recall bias, especially in the fast changing environment of travel [1]. While surveillance networks such as GeoSentinel® provide important information on spread of infectious disease [8], without information on asymptomatic travellers there is no way to calculate the true incidence of health risks during travel, and very little is known about the risks of non-infectious diseases. The detailed timeline of health during travel and proven acceptability to users [9,10] offered by mHealth applications means that travel medicine research has started to move into the era of big data and expand beyond infectious diseases, providing detailed risk analyses to their travellers [2].

The TOURIST1 and TOURIST2 studies offer a new paradigm of using mHealth to track health during travel in a more comprehensive way, including health outcomes from infectious disease but also incidence of mental health outcomes both positive and negative, accidents/injuries, and risk behaviours [9–13]. In the TOURIST1 study in Thailand, we found that events associated with non-infectious disease were common, with 23% of the 75 travellers reporting an accident, 15% a bite or lick from an animal, and 35% reporting anxiety [11]. However, it remained unknown whether these results could be extrapolated to other travel destinations beyond Thailand, or larger groups of travellers. In addition, it is key to consider whether these risks are also high when at home, or whether they truly represent an elevated risk during travel. It is impossible to determine whether risks are elevated without comparison health data from the same travellers at home.

In the TOURIST2 study, we systematically tracked health at home in Switzerland and during travel to Thailand, India, China, Tanzania, Brazil and Peru, six popular travel destinations. By measuring the incidence of different health behaviours and symptoms both at home and during travel, this study can for the first time calculate how and whether the risk of specific adverse health outcomes is elevated during travel to different countries compared to at home. Specifically, we aim to (i) determine the overall incidence and severity of health events during travel by country, (ii) describe the overall patterns in health risks and health behaviours in each destination country, and (iii) identify which health risks are significantly elevated during travel versus when not travelling.

2. Methods

2.1. Study population and design

The TOURIST2 study aimed to recruit a prospective cohort of 1000 travellers from the Swiss travel clinics of Basel and Zurich to Thailand, India, China, Tanzania, Brazil and Peru. Travellers were eligible to participate if they were aged ≥18 years, intended to travel for ≤4 weeks, were able to use a smartphone during their trips, and were planning to visit one of the study countries between September 2017 and April 2019.

As part of the study, travellers were asked to (i) complete a pre-travel questionnaire with basic demographic, medical, travel, and risk-taking information, (ii) install the study smartphone application either on their own phone or a phone borrowed from the study, (iii) complete a daily electronic questionnaire via the application on their health events and risk behaviours during the past 24 h during their trip, for 10 days at home prior to their trip, and for 14 days at home after their trip, and (iv) complete an electronic post-travel questionnaire on their health and experience with the application. Participants were also informed that the study smartphone application would automatically collect data on their itinerary and location during their travels. Travellers were considered participants in the study when they submitted at least one survey during travel and did not withdraw consent.

All travellers received a standard pre-travel consultation prior to their trips. As an incentive to participation, participants received a free travel medicine consultation and a SIM card that would provide free internet on their smartphone during travel to the study country. The methods and design of the TOURIST2 study have been described in detail elsewhere [9], and are an extension of the methods of the earlier, smaller TOURIST1 study that enrolled 100 travellers to Thailand [10]. All participants provided informed consent electronically.

2.2. Data collection with the TRAVEL smartphone application

The TRAVEL (Tracking Risks Abroad on Vacation with Electronic Localisation) smartphone application was developed during the TOURIST1 study in partnership with the Wearable Computing Lab of the Swiss Federal Institute of Technology (ETH Zurich, Switzerland). The application collected data both actively and passively. The active data collection was through an electronic close-ended questionnaire (with selected open field questions to explore e.g. psychological health) that users were prompted to answer daily via a push notification. The passive data collection of environmental data (i.e. location, weather, pollution, and social media data) was conducted automatically every 15 min via GPS fix and connection to open source application programming interfaces (APIs).

The daily electronic questionnaire was developed in conjunction with travel medicine experts and previous travellers [10]. It collects information on six health event domains (accident/injury, mental health, gastrointestinal symptoms, respiratory/flu-like symptoms, skin infections or rashes, and body aches or pain) and nine 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, see Table 1). Each health event was rated for its severity by using a Likert sliding scale ranging from one (mild) to four (severe). A moderate or severe health event was defined as one that was rated a three or four by the participant.

Once the application was installed on the participant smartphone, a search for location was automatically initiated every 15 min. If internet access was available, either through Wi-Fi or the study SIM card, the participant's location was identified through triangulation of nearby Wi-Fi access points or cell phone towers via web-based lookup. If no internet access was available, localisation was obtained through a GPS fix via satellite connection. If GPS connection was not available (usually indoors or in densely populated areas), Wi-Fi or cell tower localisation was used instead, with a corresponding loss in geographical precision of 50 m to a kilometre. To allow for filtering inaccurate location data when appropriate, an error estimation of the positioning has been recorded. Location and new questionnaire data were transmitted to study servers every hour. If a connection to the study servers was unavailable, the transmission was retried hourly until it was successful.

Management of the baseline demographic and health data was done using the Research Electronic Data Capture (REDCap) database software. Location and questionnaire data from the TRAVEL application were exported from the study servers via the web front-end as a comma delimited (csv) file and merged with the baseline data using the anonymous study pseudonym.

2.3. Statistical analysis

To calculate overall incidence of health events during travel to the different study countries, the number of days where the given health event was reported in that country was divided by the total number of geo-tagged survey-days in that country and multiplied by 1000 to obtain the incidence per 1000 travel days. To calculate the incidence of moderate or severe health events during travel in each country, the number of health events self-rated 3 (moderate) or 4 (severe) was added up for each country and similarly divided by the total number of geo-tagged survey-days in that country and multiplied by 1000 to obtain the

Table 1
Nine risk domains and items measuring risk or compliance behaviours from the daily electronic questionnaire.

Risk domain	Q1	Q2	Q3	Q4	Q5	Q6
Food	Raw salad/ vegetables/ unpeeled fruit	Raw meat/fish	Food from a street vendor	Food from a buffet	Leftover food	Unpurified tap water
Mosquito protection compliance	Insect spray used on skin	Insecticide used in room or on clothing	Covered arms and legs	Socks or closed toe shoes	Mosquito protection overnight (e.g. mosquito net, screen, or air conditioning)	
Alcohol/drug	Felt drunk/ intoxicated	Consumed marijuana	Consumed other drug			
Medical visits	Bought medication in a pharmacy	Bought medication from a street vendor	Bought medication from another person	Consulted a local doctor	Visited a local hospital	Contacted Swiss medical personnel
Sports	Watersports (e.g. swimming, diving, snorkeling)	Boating (e.g. river rafting, kayaking)	Adventure sports (e.g. skydiving, bungee jumping, zip-lining)	Jogging	Hiking/trekking	Other sports
Animals	Dog	Bat	Other furry animal (e. g. cat, monkey)	Snake		
Transportation (… riding a bicycle, motorcycle, moped, tuk-tuk, Bajiji, mototaxi …)	Without a helmet	Without seatbelt	After dark	On unsecured streets (e.g. under construction)		
Sexual (… sex without a condom …)	With another tourist (not partner)	With a local	Paid sex			

incidence per 1000 travel days.

To calculate the incidence rate ratio (IRR) in each country, the incidence of the given health event in that country was divided by the incidence of the given health events while at home in Switzerland. Incidence of health events both before and after travel was included as part of the health events "at home." The IRR was reported along with its corresponding 95% confidence interval (CI).

To calculate the incidence of risk behaviours by health domain in each country, the number of health behaviours within was summed up within each domain (see Table 1 for behaviours measured) by day and traveller. The total number of behaviours within each domain was then divided by the total number of geo-tagged survey-days for that country and multiplied by 1000 to obtain the incidence per 1000 travel days. All analyses were conducted with R version 3.6.1 [14].

The study was approved by the Ethics Commission of the Canton of Zurich (KEK-ZH-Nr. 2014–0470, BASEC-Nr. PB_2017–00412). The TOURIST2 study is registered with clinicaltrials.gov under the identifier NCT03262337.

3. Results

3.1. Study population

Of the 1000 eligible travellers recruited, 793 completed the study (study design and recruitment described in detail elsewhere [9]) (Table 2). Study participants were a median of 34.0 years of age at enrolment (IQR: 28.0–50.0) and 54.5% female. Travellers planned trips of median 16.0 days (IQR: 14.0–23.0), with the longest trips in Peru (median 21.0 days) and the shortest trips in Tanzania (median 15.0 days). Travellers to Thailand and Peru had the youngest median age (30.0 years (IQR: 25.0–37.5) and 31.0 years (IQR: 26.0–41.5), respectively), while India and Tanzania had the oldest travellers (37.0 years (IQR: 28.0–53.0) and 37.0 years (IQR: 28.0–51.0), respectively). Most travellers were tourists (78.7%). Brazil had the highest number of business travellers (13.1%), followed by India (9.7%). India had the highest number of travellers visiting family and friends (8.3%).

Further study population characteristics are described in detail elsewhere [9].

Table 2
Baseline study population characteristics [n (%) or median (IQR)]. Some travellers visited more than one study country and all travellers were requested to fill out surveys while at home in Switzerland; therefore some travellers are represented in more than one destination cohort.

	Overall study	Thailand	India	China	Tanzania	Brazil	Peru	Switzerland (not travelling)
Number of travellers	793	135	145	35	225	183	95	750
Number of survey-days	19341	1688	1917	397	2353	2184	1134	9668
Age	34.0 (28.0–50.0)	30-0 (25.0–37.5)	37.0 (28.0–53.0)	34.0 (31.5–48.5)	37.0 (28.0–51.0)	35.0 (29.0–50.0)	31.0 (26.0–41.5)	34.0 (27.0–50.0)
Female sex	432 (54.5%)	84 (62.2%)	73 (50.3%)	15 (42.9)	123 (54.7%)	89 (48.6%)	57 (60.0%)	411 (54.8%)
Planned trip days	16.0 (14.0–23.0)	20.0 (15.0–29.0)	17.0 (13.0–24.0)	20.0 (15.0–29.0)	15.0 (12.0–19.0)	16.0 (14.0–23.0)	21.0 (16.5–27.0)	16.0 (14.0–23.0)
Reason for travel								
Holiday	624 (78.7%)	124 (91.9%)	96 (66.2%)	32 (91.4%)	186 (82.7%)	123 (67.2%)	82 (86.3%)	593 (79.1%)
Business	57 (7.2%)	2 (1.5%)	14 (9.7%)	2 (5.7%)	14 (6.2%)	24 (13.1%)	4 (4.2%)	49 (6.5%)
Volunteering	28 (3.5%)	3 (2.2%)	7 (4.8%)	0	15 (6.7%)	1 (0.5%)	4 (4.2%)	28 (3.7%)
Visiting family and friends	63 (7.9%)	0	12 (8.3%)	0	7 (3.1%)	1 (0.5%)	4 (4.2%)	59 (7.9%)
Missing	21 (2.6%)	0	16 (11.0%)	0	3 (1.3%)	2 (1.1%)	1 (1.1%)	21 (2.8%)

3.2. Overall incidence and severity of health events during travel in the study countries

Overall, the highest incidence of health events during travel was itchiness due to mosquito bites (IRR: 156.1 events of itchiness due to mosquito bites per 1000 survey-days), nasal congestion (IRR: 124.5), headache (IRR: 106.6), sunburn (IRR: 103.0), and diarrhoea (IRR: 102.8). The incidence of health events varied widely by country (Fig. 1). Peru had the highest incidence of muscle ache, headache, shortness of breath, nasal congestion, throat or ear pain, cough, vomiting, dizziness, nausea, bite/scratch/lick from an animal, and traffic accidents. India dominated in limb pain, joint pain, fever, stomach pain, and other accidents/injuries. China had the highest incidence of itchiness (not from mosquitoes), constipation, exhaustion, being positively excited, anxiety, and a wound or cut. Brazil had the highest incidence of sunburn, restless thoughts, sports accidents, and falls or sprains (along with Thailand). Thailand dominated in itchiness from mosquitoes, rash, and falls or sprains (along with Brazil). Tanzania had the highest incidence of diarrhoea (although it was close with Peru and China) and injury from sea animals.

The highest percentage of moderate or severe health events (self-rated three or four out of a four point scale) reported during travel were for vomiting (16.9% of vomiting events were moderate or severe), nausea (12.5%), feeling positively excited (12.1%), exhaustion (10.5%), and falls or sprains (9.5%). In contrast, the highest percentage of moderate or severe health events at home were for feeling positively excited (15.0%), feeling anxious (10.6%), and exhaustion (9.7%). Of the negative health events reported during travel (e.g. excluding being positively excited about the day), 7.4% (n = 974/13,118) were self-rated as severe. Overall incidence of moderate or severe negative health events was 100.7 events per 1000 travel-days. Incidence of severe negative health events was by far the highest in Peru (172.0/1000 travel-days). Tanzania (IRR 99.4), Thailand (IRR 96.0), Brazil (IRR 86.1), China (IRR 85.6), and India (IRR 84.0) all had similar incidence of severe negative health events. The incidence of moderate or severe negative health events was lowest at home (IRR 58.4).

Participants reported that they had moderate or severe problems carrying out their planned activities on 3.1% of travel-days (n = 302/9673). Participants reported being unable to do their planned activities at all that day only 0.9% of days (n = 90/9673). Travellers rated their travel-days as very or mostly good 89.0% of the time (n = 8605/9673). Participants rated their travel days as mostly or totally bad only 1.7% of the time (n = 161/9673). At home, participants rated their days as very or mostly good 82.1% of the time (n = 7942/9668) and rated their days as mostly or totally bad 2.2% of the time (n = 215/9668).

3.3. Country-specific relative risk of health events during travel as compared with at home

The risk of health events during travel as compared with staying home varied widely depending on the country, but each country was associated with significantly elevated incidence of health events (Fig. 2). The incidence of being itchy from mosquito bites was significantly elevated in every country as compared to at home, and incidence of sunburn was significantly higher in every country except China. Incidence of gastrointestinal problems such as diarrhoea, constipation, and stomach pain was also significantly higher than at home across all destination countries.

Compared to incidence at home, travel to India was characterised by the highest number of significant associations with incidence of negative health outcomes (n = 19 negative health outcomes), with symptoms spread across the accident/injury, gastrointestinal, respiratory, skin, and fever/pain domains. Aside from the health events typical of all travel destinations, travel to India had an elevated incidence of non-infectious disease health outcomes such as a wound or cut (IRR: 2.7, 95% CI: 1.9, 3.9), shortness of breath during exercise (IRR: 2.3, 95% CI: 1.8, 2.9), other accident/injury (IRR: 2.2, 95% CI: 1.3, 3.6), a bite, scratch, or lick through a wound by a mammal (IRR: 1.9, 95% CI: 1.0, 3.7), shortness of breath at rest (IRR: 1.8, 95% CI: 1.3, 2.5), joint pain (IRR: 1.5, 95% CI: 1.2, 1.8), headache (IRR: 1.4, 95% CI: 1.2, 1.6), itchiness (other than from mosquitoes, IRR: 1.3, 95% CI: 1.0, 1.7), and exhaustion (IRR: 1.2, 95% CI: 1.0, 1.4).

Travel to Peru was characterised by the second highest number of significant associations with incidence of negative health outcomes (18

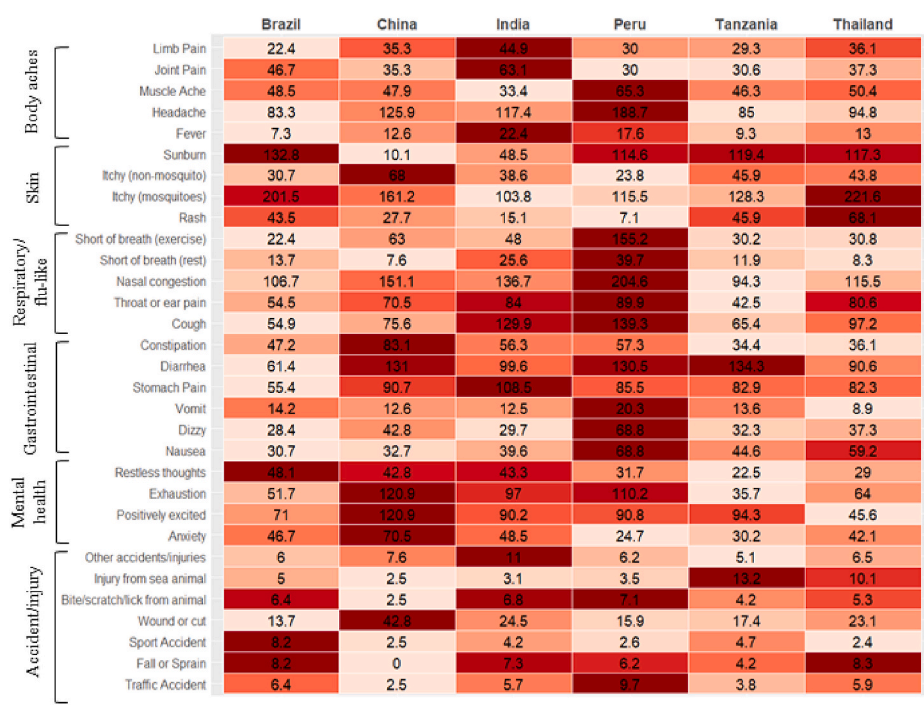

Fig. 1. Incidence of health events by country per 1000 travel-days. Darker red colour corresponds to higher incidence of health events in comparison with other countries. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

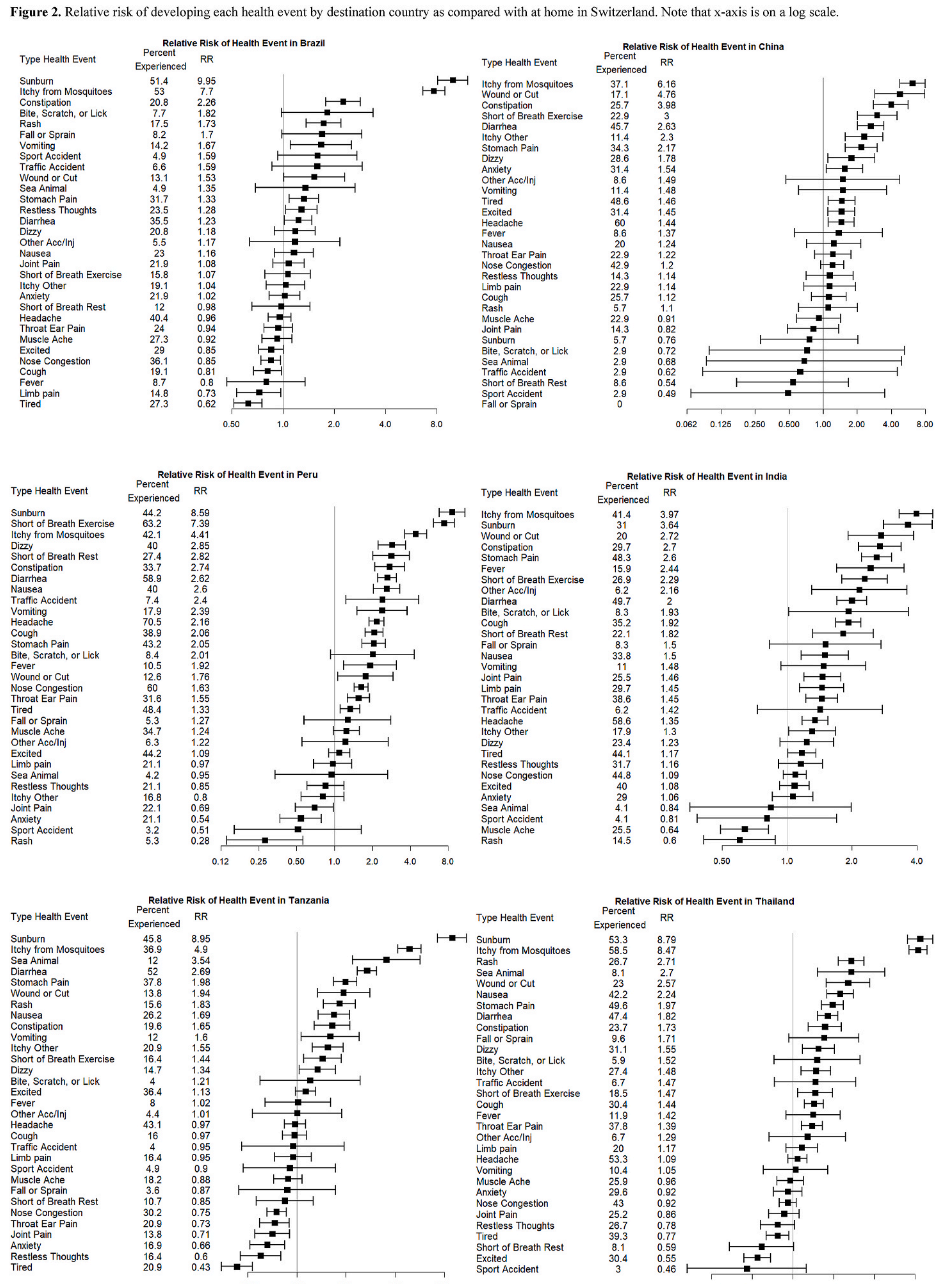

Fig. 2. Relative risk of developing each health event by destination country as compared with at home in Switzerland. Note that x-axis is on a log scale.

negative health outcomes were significantly associated with travel to Peru), with symptoms especially in the respiratory and gastrointestinal domains. Peru was the only country with a significantly higher risk of traffic accidents (IRR: 2.4, 1.2, 4.7) than at home in Switzerland. Many of the significantly higher negative health events in Peru were consistent with altitude sickness, such as incidence of dizziness, (IRR: 2.9, 95% CI: 2.2, 3.7), shortness of breath at rest (IRR: 2.8, 95% CI: 2.0, 3.9), nausea (IRR: 2.6, 95% CI: 2.0, 3.3), vomiting (IRR: 2.4, 95% CI: 1.5, 3.8), headache (IRR: 2.2, 95% CI: 1.9, 2.5), and exhaustion (IRR: 1.3, 95% CI: 1.1, 1.6).

Travel to Thailand was significantly associated with 14 negative health outcomes, with symptoms predominantly spread across the gastrointestinal, skin, respiratory, and accident/injury domains. Risk was significantly elevated for non-infectious disease risks such as injury from a sea animal (IRR: 2.7, 95% CI: 1.5, 4.8), rash (IRR: 2.7, 95% CI: 2.2, 3.4), a wound or cut (IRR: 2.6, 95% CI: 1.8, 3.7), shortness of breath during exercise (IRR: 1.5, 95% CI: 1.1, 2.0), and itchiness (other than from mosquitoes, IRR: 1.5, 95% CI: 1.2, 1.9). In contrast, the incidence of feeling positively excited was significantly reduced in Thailand (IRR: 0.55, 95% CI: 0.44, 0.69) as compared to at home in Switzerland.

Travel to Tanzania was associated with 12 negative health outcomes. Symptoms were predominately in the gastrointestinal, skin, and accident/injury health domains. Travel to Tanzania appeared to be protective against negative mental health outcomes (IRR anxiety: 0.66, 95% CI: 0.52, 0.85, IRR exhaustion: 0.43, 95% CI: 0.35, 0.54, IRR worrying thoughts: 0.60, 95% CI: 0.45, 0.80). There was a particularly high risk of injury from a sea animal (IRR: 3.5, 95% CI: 2.2, 5.7).

Travel to China was significantly associated with 11 negative health outcomes, with symptoms from all health domains. Of interest is the fact that anxiety (IRR: 1.5, 95% CI: 1.1, 2.2), exhaustion (IRR: 1.5, 95% CI: 1.1, 1.9), and headache (IRR: 1.4, 95% CI: 1.1, 1.9) were all significantly elevated in comparison to at home in Switzerland.

Travel to Brazil was significantly associated with the smallest number of negative health outcomes (n = 9), with symptoms from all health domains. In Brazil, it is of note that worrying thoughts (IRR: 1.3, 95% CI: 1.0, 1.6) were significantly elevated as compared to home.

3.4. Country-specific incidence of risk and compliance behaviours

Overall incidence of food risk behaviours during travel was universally high, with 97.9% of travellers engaging in at least one of the food risk behaviours during travel listed in Table 1. The incidence of these behaviours was 1117.4 per 1000 survey-days, indicating that on average travellers were performing more than one of these risk behaviours per day. On the positive side, the same is true for compliance with mosquito protective advice, with 93.3% of travellers performing at least one protective behaviour during their trip and an overall incidence of 1730.0. Around half (52.2%) of travellers participated in drug or alcohol risk behaviours (incidence: 157.6) or sports risk behaviours (52.6%, incidence: 166.3). Most alcohol and drug risk behaviours were related to alcohol, but 3.7% reported using marijuana and 1.5% another drug during their trips. A little less than half (41.2%) came into contact with an animal during their trip (incidence: 137.8) or participated in risky transportation behaviours (44.4%, incidence: 303.0). 17.0% of travellers made use of local healthcare services (incidence: 31.5). A small number of travellers participated in risky sexual behaviours (2.3%, incidence: 4.7).

Incidence of risk behaviours by health domain also varied highly by country (Fig. 3). Brazil had the highest incidence of sexual risk behaviours (10.1 risky sexual events per 1000 survey-days, see Table 1 for list of measured behaviours), animal risks (196.0), alcohol or drug risk behaviours (196.4), and food and drink risk behaviours (1,299.9). India had the highest incidence of transportation-related risk behaviours (675.0) and a similarly high number of medical visits to Thailand (44.9). Thailand had the highest incidence of sports-related risks (257.7). Tanzania had by far the highest incidence of mosquito protective behaviours (2603.5). China had overall the lowest incidence of all risk behaviours, although it did have a relatively high incidence of drug and alcohol risks (183.9, second highest after Brazil).

The greatest variation in incidence of risks across countries was in transportation risk behaviours (incidence 1318.1% higher in India versus Brazil), sports risk behaviours (incidence 581.7% higher in Thailand versus China), animal risk behaviours (incidence 270.5% higher in Brazil versus China), and mosquito protective behaviours (incidence 145.8% higher in Tanzania versus Peru).

Only 2.7% of travellers in Tanzania took malaria post-exposure prophylaxis and 1.1% of travellers to Brazil. However, around 8.4% of travellers to Peru reported taking an antibiotic during their trip, followed by 5.9% of travellers to Thailand, 3.3% of travellers to Brazil, 2.2% of travellers to Tanzania, 2.1% of travellers to India, and none of China travellers. Use of anti-diarrhoeal medications during travel was also high. 16.9% of Tanzania travellers took one, followed by 12.6% of Thailand travellers, 11.7% of India travellers, 11.6% of Peru travellers, 8.6% of China travellers, and 4.9% of Brazil travellers.

The use of healthcare services was higher in Switzerland than during travel (32.5% of participants used healthcare services while at home vs. 17.0% during travel). Of those who had a healthcare visit in Switzerland, 19.6% had a runny nose, 11.7% coughing, 10.2% stomach pain, 10.2% throat/ear pain, 9.6% diarrhoea, 3.2% fever, 1.1% a fall/sprain/sports accident, 1.1% were vomiting, 1.5% took an antibiotic, and 0.2% took a malaria medication.

4. Discussion

Our study provides evidence that certain health risks are significantly elevated during travel, and that these health risks are highly dependent on the destination country. As found in the earlier TOURIST1 study on travellers to Thailand [11], travellers faced diverse health threats, including non-infectious disease health events. Travellers self-rated 7.4% of these health events as moderate or severe. This variety of health challenges occurred even in a normal population of relatively young travellers (median age of travellers to all countries ranged between 30 and 37). Most health behaviours varied widely across countries, while some (e.g. alcohol/drug risk behaviours and food and drink

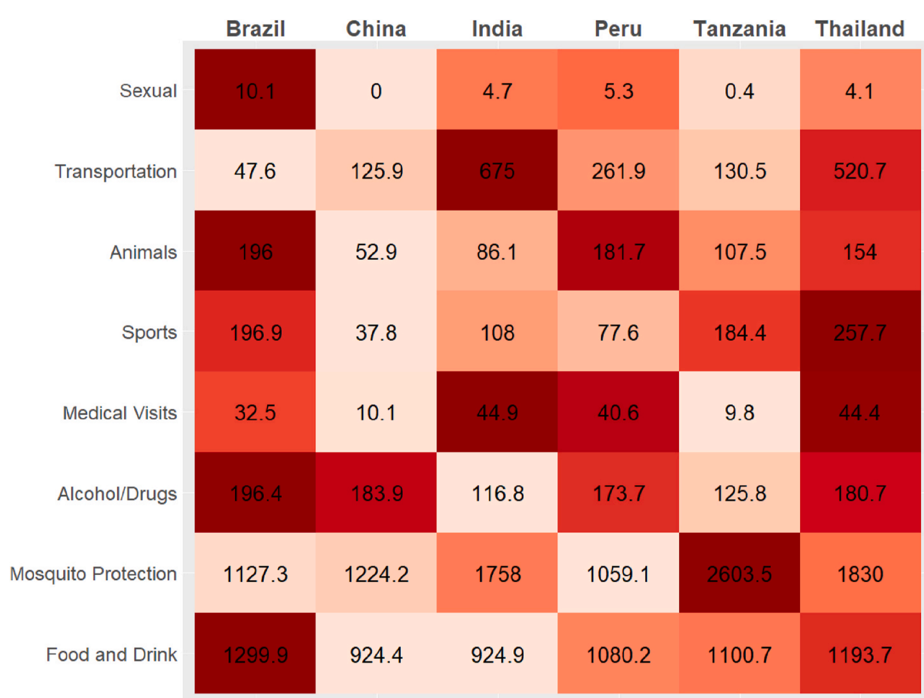

Fig. 3. Incidence of medical visits and health risk/compliance behaviours by domain and country per 1000 travel-days. Darker red colour corresponds to higher incidence of behaviours in comparison with other countries. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

risk behaviours) were universally high. Health risk behaviours did not always correlate with correspondingly high incidence of health outcomes, as seen by the relatively low incidence of transportation risk behaviours in Peru but its significantly higher incidence of traffic accidents.

Among the investigated countries, Peru and India appear to emerge as the riskiest destinations. Peru had the highest density of incidence of negative health events overall, by far the highest incidence of self-rated severe health events (172.0 severe negative health events per 1000 travel-days), and the second highest number of significantly higher associations with health risks compared to staying at home in Switzerland. Many of these ailments likely relate to altitude issues (shortness of breath during exercise and at rest, dizziness). The fact that 8.4% of Peru travellers took an antibiotic during travel is also concerning, especially given the potential role of travel in spreading antibiotic resistance [15]. Of particular interest are the high incidence of itchiness from mosquitoes, traffic accidents, and gastrointestinal ailments (constipation, diarrhoea, vomiting, nausea, stomach pain). The high incidence of negative health events in Peru did not correspond with higher incidence of health risk behaviours in any of the domains measured (Fig. 3). This may indicate either that Peru is a riskier place to travel independent of individual behaviour, or that important health risk behaviours relevant to Peru were not measured. However, other studies have suggested that consumption of non-recommended food and drink is not associated with increased risk of travellers' diarrhoea in Cusco [16]. The low compliance with mosquito protective behaviours corresponds with the significantly higher incidence of itching from mosquito bites, suggesting that travellers to Peru may be less aware of the need to protect against mosquito bites. More follow-up is warranted with Peru travellers.

India had the second highest density of incidence of negative health events overall, and the highest number of significant associations with incidence of negative health outcomes. Of interest and somewhat surprisingly, most of these significantly elevated negative health outcomes were linked with non-infectious disease risks (e.g. wound or cut, other accident or injury, a bite, scratch, or lick from an animal, joint pain, limb pain, throat/ear pain, shortness of breath during exercise or at rest). As might be expected, incidence of gastrointestinal ailments was also high (e.g. stomach pain, constipation, diarrhoea, nausea), along with fever and cough. As might be expected with the high risk of accidents/injuries and other health problems, incidence of transportation behavioural risks and medical visits was highest of all the destination countries in India. Travellers to India would benefit from increased advice about how to handle both non-infectious and infectious negative health outcomes during travel.

Other destinations emerged as hotspots for certain specific risks. Tanzania and Thailand were the riskiest for injury from a sea animal (usually jellyfish or sea urchin). China had the highest incidence of negative mental health events. Sports risk behaviours were especially high in Thailand, where there was also a significantly increased risk of sprains or falls. Brazil is clearly a destination where risky sexual behaviour is common (sex without a condom with someone other than a partner); this may be related to the similarly high incidence of drug and alcohol risk behaviours there. On the other hand, some health risks appeared to be universally elevated during travel. Travellers reported significantly increased incidence of wounds or cuts, itchiness from mosquito bites, stomach pain, diarrhoea, and constipation in all study countries compared with staying at home in Switzerland. Other health events, like sports accidents, were more likely to occur at home (which reflects that sports are a popular activity in Switzerland).

Gastrointestinal disorders (e.g. vomiting, diarrhoea) were overall the most elevated symptoms during travel, corresponding with almost universal disregard for travel medicine guidelines regarding recommended consumption of food and beverages. This is similar to the findings from TOURIST1 in Thailand, where 97.3% of travellers engaged in risky food/drink behaviours [11]. Of the study countries, incidence of travellers' diarrhoea is traditionally particularly high in Peru, Brazil, India, Thailand, and China [17], but the incidence of diarrhoea in our study is highest in Tanzania, China, and Peru, perhaps due to increased precautions in countries perceived as risky. However, while travellers were somewhat more compliant with food/drink advice in China and India, they were still consuming non-recommended food or drink almost daily. The low compliance with food hygiene advice was also reflected in the significantly higher incidence of diarrhoea across all travel destinations, a finding that corresponds with that of other studies showing the persistently high rate of travellers' diarrhoea over the decades since it began being measured [16]. The low compliance with food risk behavioural advice contrasts with the relatively high compliance with mosquito protection advice across all destinations; however, even with these precautions, itchiness from mosquitoes was significantly elevated in all countries. It is also clear that in some destinations travel medicine advice is simply harder to follow than in others: transportation risk behaviours were 1318.1% higher in India versus Brazil, despite the fact that travellers to Brazil were some of the greatest risk takers in terms of sexual and alcohol/drug risks. This differential adoption of travel medicine advice is interesting, and implies that certain advice is more important or difficult to follow than other advice while on the ground. A more pragmatic risk management approach to topics such as transportation safety depending on destination during the travel medicine consultation may help travellers identify ways to minimize negative risks while still successfully navigating their destination.

While travellers reported being happy with their travel days despite the high incidence of health events, Tanzania was overall the destination with the lowest risks and seemingly happiest travellers. Travellers to Tanzania even seemed to experience a protective effect against negative mental health events. While this may be due to the beach vacation and animal safari parts of the trip, this contrasts with Thailand, also a destination known for beach vacations. In Thailand, only the negative mental health event of exhaustion was significantly reduced, and being positively excited about the day was actually significantly lower than at home. These results are similar to those of the TOURIST1 study, where over a third of Thailand travellers reported negative mental health events during travel [11]. Tanzanian travellers also had by far the highest compliance with mosquito protection advice, suggesting that travellers take the risks of vector-borne disease more seriously there than in other destinations. Future analyses should investigate what elements of travel enhance traveller well-being.

This study has limitations. The IRR represents an overall calculation of elevated or reduced risk during travel as compared to at home, and is therefore not adjusted for the specific characteristics of the travellers that might be more likely to go to each destination. In addition, the calculation of the IRR may be biased due to unequal numbers of days reported by participants in Switzerland versus abroad, meaning that individual travellers may contribute more to the numerator than denominator or vice versa. These two groups may therefore not be perfectly comparable. However, the overall demographic characteristics of those who did fill out questionnaires in Switzerland are very similar to those of the overall study population (Table 2). In addition, so long as this bias is non-differential, it may be assumed that this would bias the IRR towards the null. For some health events like diarrhoea, incidence in Switzerland may be from an infection that during travel. In these cases, the IRR is a likely underestimate of the true incidence during travel. The sample size in some destination countries is quite small (especially China) and may not represent the entire range of travellers to each country, meaning that these results need to be interpreted with caution. Finally, these participants were recruited from travel medicine clinics and may be different from the general population of travellers that do not consult an expert before travel. However, as the aim of the study is to improve travel medicine advice, we believe that this is an appropriate sample for which to draw conclusions for this purpose. Finally, our analysis focuses only on country-specific patterns in health events and behaviours, and not the complex ways in which traveller characteristics may have interacted with country characteristics to produce these different health outcomes; while highly important, this analysis is beyond the scope of the current paper.

The TOURIST2 study uses mHealth technology to offer a new perspective on travel medicine research by enabling the calculation of incidence rates of health events during travel, providing much needed information about health risks in real-time in different destinations and at home. In addition, our study builds on the TOURIST1 study to expand the range of symptoms to include non-infectious disease events such as accidents or injuries. By finally providing a comparison group measuring incidence of the same health events in the traveller's home country, we provide evidence that certain health risks are higher during travel while exploring patterns in risk behaviours and corresponding health outcomes that characterise different destination countries. This new methodology allows researchers to quantify health during travel in an entirely new way and provides relevant health information for the medical practitioner giving advice to travellers to specific destinations. By using an mHealth approach to capture geo-located health data in almost real-time during travel, our study shows how digital data in travel medicine can be used to provide destination-based evidence and advice for the travel medicine consultation that is closer to the actual needs and risks of the individual traveller, ushering in a new era of personalized travel medicine.

Declaration of competing interests

The authors declare no competing interests.

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CRediT authorship contribution statement

Andrea Farnham: Conceptualization, Methodology, Data curation, Writing – original draft. **Vasiliki Baroutsou:** Data curation, Writing – review & editing. **Christoph Hatz:** Conceptualization, Supervision, Writing – review & editing. **Jan Fehr:** Writing – review & editing. **Esther Kuenzli:** Writing – review & editing. **Ulf Blanke:** Methodology, Data curation, Writing – review & editing. **Milo A. Puhan:** Methodology, Supervision, Writing – review & editing. **Silja Bühler:** Funding acquisition, Conceptualization, Methodology, Supervision, Data curation, Writing – review & editing.

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