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Spatiotemporal and demographic variation in the association between temperature variability and hospitalizations in Brazil during 2000–2015: A nationwide time-series study

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ABSTRACT

Background: Extreme temperature events are known to be adversely associated with a range of health outcomes, but little is known about the effect of less extreme, but more frequent fluctuation in temperature. We examined the spatiotemporal and demographic variation in the effect of temperature variability (TV) on nationwide hospitalizations in Brazil during 2000–2015.

Methods: Data on daily hospitalizations and weather variables were collected from 1814 cities, comprising 78.4% of Brazilian population. TV was defined as the standard deviation of daily minimum and maximum temperatures during exposure days. City-specific TV effect was estimated using a quasi-Poisson regression model, and then pooled at the national and regional level using meta-analysis. Stratified analyses were performed by sex, 10 age-groups, and 11 cause categories. Meta-regression was applied to city-year-specific estimates to examine the temporal change.

Results: The estimate of TV effect peaked on 0–1 days' exposure, contributing to 3.5% [95% confidence interval (CI): 3.1–3.8%] of hospitalizations nationwide, equalling 221 (95%CI: 200–242) cases per 100,000 population annually. The effect estimate varied across 11 cause categories, which was strongest for respiratory admissions. Males, particular those 10–49 year old were more affected than females but there was no sex difference for the attributable hospitalization rate. The attributable rate for the under-fives was twice as high as for the elderly, and five times higher than in adults. The majority of the most affected cities were located in the central west and the inland of northeast. The risk of hospitalization related to TV showed a significant increase over the 16-year period at the national level.

Conclusions: In Brazil, the effect of TV on hospitalization is acute, and varies by spatial, sex, age, and cause category. Given there is no evidence regarding TV adaptation, hospitalization burden associated with TV is likely to further increase and warrants consideration when developing future public health policies in the context of climate change.

1. Introduction

Climate change has been identified as posing the single largest threat for global health in the 21st century (Intergovernmental Panel on Climate Change, 2015). Most of the evidence regarding the relationship between temperature change and health outcomes has tended to focus on the adverse effect of extreme temperature events (e.g., heatwaves and cold spells) (Gasparrini et al., 2015; Guo et al., 2017; O'Neill and Ebi, 2009). By contrast, the influence of temperature variability (TV), representing weather instability within a few days, has been less investigated. To date, most studies have examined the mortality risk associated with either intra- (e.g., diurnal temperature range, DTR) or inter-day (e.g., difference of mean temperatures between neighbouring days) TV (Lee et al., 2018; Vicedo-Cabrera et al., 2016). However, these

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TV indicators may not fully capture the magnitude of recent temperature variations, because temperature change is a continuous process.

A novel and validated approach has been developed to assess the mortality effect of TV by combining intra- and inter-day temperature variations (Guo et al., 2016). Based on this new index, it has been estimated that 10 deaths per 100,000 population each year in Australia (1.7% of annual deaths) are attributable to TV exposure (Cheng et al., 2017). However, the actual disease burden associated with TV is likely to be much larger if the adverse effect on morbidity could be quantified. Hospitalizations have been used previously as a proxy measure for quantifying the non-fatal health burden associated with TV (mainly focusing on intra-day TV) but there are limited investigations on the relationship between TV with cause-specific outcomes. Moreover, there has been a marked decline in the disease burden related to extreme temperatures since the twentieth century, implying an evolved thermal adaptation in humans (Ha and Kim, 2013; Nordio et al., 2015; Vicedo-Cabrera et al., 2018). However, few studies have examined whether the strength of the association between TV and health outcomes has changed over time (Lee et al., 2018).

Most previous studies, conducted mainly in North America, Europe and Asia, have shown spatial heterogeneity in the relationship between TV and health outcomes (Gasparrini et al., 2015; Lee et al., 2018). By comparison, there are sparse data from South America, particularly from Brazil which covers nearly half the land mass of South America (Brazilian Institute of Geography and Statistics, 2016; Central Intelligence Agency, 2017). Brazil's wide range of climatic conditions and topographical types, as well as its unique location, suggest a varying distribution of TV and associated health outcomes (Alvares et al., 2013).

In this study, we use a national dataset to quantify the spatial and demographic variation in the association between TV and cause-specific hospitalizations in Brazil during 2000–2015. Further, by examining the temporal trend in the TV effect we will be able to determine to what extent humans have developed an adaptive capacity to variations in temperature.

2. Material and methods

2.1. Study area

Brazil is comprised of 26 states and one federal district with a total of 5570 cities. The country is subdivided into five regions according to geographic and socioeconomic differences: the north, northeast, southeast, south and central west (Brazilian Institute of Geography and Statistics, 2017).

2.2. Data sources

Between 1 January 2000 and 31 December 2015, data on daily hospitalizations in each city were collected through the Brazilian Unified Health System. The hospitalization records of some cities in early years were incomplete in the system, particularly for those in Northern Brazil. To examine the temporal change, 1814 cities with 16-year complete data, comprising 78.4% of the Brazilian population, contributed to the analysis. Fig. 1 shows the locations of each city and the population density of each region. Variables included patients' age, sex, date of admission, primary diagnosis [coded using the 10th version of the International Classification of Diseases (ICD-10)] and city of residence.

Daily data on weather conditions were extracted from a $0.25^{\circ} \times 0.25^{\circ}$ dataset that was interpolated using an inverse distance weighting method with data from 735 nationwide weather stations (Xavier et al., 2016). City-specific minimum and maximum temperatures ($Temp_{min}$ and $Temp_{max}$) were extracted from the grid overlaying the centre of each city. We followed the recommendation of the World Meteorological Organization (WMO, 2010) to define daily mean temperature ($Temp_{mean}$) as the mean value of the daily $Temp_{min}$ and $Temp_{max}$ due to the lack of data on actual $Temp_{mean}$.

Data on city-specific population were downloaded from the Brazilian Census 2000 and 2010 datasets (http://www.ibge.gov.br/censo/; http://www.censo2010.ibge.gov.br/). Data on standard population were collected from the World Standard Population Distribution (2000–2025) (Ahmad et al., 2001).

2.3. Data analysis

2.3.1. Definition of TV

In this study, TV was defined as the standard deviation (SD) of daily $Temp_{min}$ and $Temp_{max}$ during exposure days in order to properly capture the cumulative effect of both intra- and inter-day temperature fluctuations (Guo et al., 2016). For example, TV exposure for the current day and the preceding day one (TV0–1) was calculated as the SD ($Temp_{min\_lag0}$, $Temp_{max\_lag0}$, $Temp_{min\_lag1}$, $Temp_{max\_lag1}$).

2.3.2. Association between TV and hospitalizations

The association between TV and hospitalizations was quantified using a two-stage approach (Gasparrini et al., 2015; Guo et al., 2017; Hu et al., 2019). In the first stage, a quasi-Poisson regression model was performed on time-series data to obtain city-specific estimates of TV effect:

$$Y_{it} \sim poisson\ (\mu_{it});$$

$$Log\ (\mu_{it}) = \alpha + \beta TV_{it} + ns(\text{Time}, 7{\times}\text{year}) + cb(Temp_{mean}) + \gamma DOW_{it} + \delta Holiday_{it}$$

where Y_{it} is the daily number of hospitalizations in city i on day t; α is the intercept; TV_{it} is the linear function of TV because both previous studies and our initial analysis (see Fig. S1) have indicated that the relationships between TV and health outcomes are linear (Guo et al., 2016; Zhang et al., 2017); $ns(\text{Time}, 7 \times \text{year})$ is the natural cubic spline for time to control for the long-term trend and seasonality using 7 degrees of freedom (dfs) per year (Gasparrini et al., 2015); $cb(Temp_{mean})$ is the cross-basis function to estimate the nonlinear effect of $Temp_{mean}$ for up to lag 21 days, which could be an important confounder for assessing the TV effect (Gasparrini et al., 2015; Guo et al., 2014); natural cubic splines with 4 dfs are used for the mean temperature and the lags, respectively; DOW_{it} is a categorical variable for day of the week; $Holiday_{it}$ is a binary variable to control for public holidays.

We performed seven independent analyses by changing TV from the neighbouring two days (TV0–1) to eight days (TV0–7) to determine which exposure days were associated with the highest risk of hospitalization. The initial analysis indicated that the effect estimates associated with per 1 °C increase in TV were more heterogeneous than the results per interquartile range (IQR) increase in TV due to different ranges of city-specific TVs. Finally, the TV-hospitalization relationship was described as the percentage change in risk of hospitalization per IQR increase in TV [with 95% confidence interval (CI)].

In the second stage, the estimates of city-specific TV effect were pooled at the national and regional level using a random-effect meta-analysis with maximum likelihood estimation. Stratified analyses were performed by sex and 10 age-groups (i.e., 0–4, 5–9, 10–19, 20–29, 30–39, 40–49, 50–59, 60–69, 70–79, and ≥80 years). The various associations between TV and hospitalizations for 11 cause categories were also explored (classification of cause categories, see Table S1).

Sensitivity analyses were performed to check the robustness of the effect estimates by changing the maximum lag from 21 to 28 days and by changing the dfs for $Temp_{mean}$ from four to six. The confounding effect of relative humidity was evaluated using data from 265 weather stations provided by the Brazilian National Institute of Meteorology.