Short-term effects of ambient temperature on non-external and cardiovascular mortality among older adults of metropolitan areas of Mexico

Magali Hurtado-Díaz, Julio C. Cruz, José L. Texcalac-Sangrador, Eunice E. Félix-Arellano, Iván Gutiérrez-Ávila, Arely A. Briseño-Pérez, Nenetzen Saavedra-Lara, Aurelio Tobías & Horacio Riojas-Rodríguez

Abstract

Multi-city studies assessing the association between acute exposure to temperature and mortality in Latin American are limited. To analyze the short-term effect of changes in temperature (increase and decrease) on daily non-external and cardiovascular mortality from 1998 to 2014, in people 65 years old and over living in 10 metropolitan areas of Mexico. Analyses were performed through Poisson regression models with distributed lag non-linear models. Statistical comparison of minimum mortality temperature (MMT) and city-specific cutoffs of 24-h temperature mean values (5th/95th and 1st/99th percentiles) were used to obtain the mortality relative Risk (RR) for cold/hot and extreme cold/extreme hot, respectively, for the same day and lags of 0–3, 0–7, and 0–21 days. A meta-analysis was conducted to synthesize the estimates (RRpooled). Significant non-linear associations of temperature-mortality relation were found in U or inverted J shape. The best predictors of mortality associations with cold and heat were daily temperatures at lag 0–7 and lag 0–3, respectively. RRpooled of non-external causes was 6.3% (95%CI 2.7, 10.0) for cold and 10.2% (95%CI 4.4, 16.2) for hot temperatures. The RRpooled for cardiovascular mortality was 7.1% (95%CI 0.01, 14.7) for cold and 7.1% (95%CI 0.6, 14.0) for hot temperatures. Results suggest that, starting from the MMT, the changes in temperature are associated with an increased risk of non-external and specific causes of mortality in elderly people. Generally, heat effects on non-external and specific causes of mortality occur immediately, while cold effects occur within a few days and last longer.

Introduction

Latin America is the most urbanized region among developing countries. In 1950, around 42% of people in this world region lived in urban areas, and this number is expected to reach approximately 83% by 2030 (UNDESA Population Division 2015). Mexico is not an exception, in 1950, almost 43% of its population lived in urban settlements, and this proportion increased to 78% in 2010 (INEGI 2010).

It is known that urbanization influences local climate (Stewart and Oke 2012); differences in temperature between urban and rural environments are attributed to the heat island effect since urban areas absorb and retain radiation during the daytime and reradiate outgoing long waves more efficiently during the night (Heisler and Brazel 2019). The effects of climate conditions on public health have been associated with temperature and non-external mortality, and to a lesser extent, with specific mortality causes such as respiratory, cardiovascular, and cerebrovascular diseases (Analitis et al. 2008; McMichael et al. 2008). Regarding cardiovascular mortality, most of the studies have reported an increased mortality associated with changes in temperature, both increase (heat effects) (Barnett 2007; Basu 2009; Liu et al. 2013; Wang et al. 2013) and decrease (cold effects) (Khanjani and Bahrampour 2013; Mostofsky et al. 2014; Zhang et al. 2014) in temperature. Vulnerable populations to temperature variability such as children under 5 years (Joe et al. 2016) and the elderly people (65 years old and over) (Baccini et al. 2011; Barnett 2007; Basu and Ostro 2008; Son et al. 2011; Wang et al. 2013) have been identified as well as differences in temperature related risk by sex, being women at higher risk for mortality compared to men (Basu 2009).

Studies on climate and health have been mainly developed in areas between polar and subtropical climates such as Europe and the USA. In other climatic regions, specific causes of mortality and vulnerable groups lack of this evidence (Bunker et al. 2016; Sanderson et al. 2017; Song et al. 2017). However, researchers have recently started paying attention to countries with tropical and subtropical climates. Epidemiological studies have observed an association between changes in temperature and the increase in non-external mortality risk in Taiwan, China, Vietnam, Thailand, and Australia (Chan et al. 2012; Dang et al. 2016; Goggins et al. 2013; Guo et al. 2012; Lin et al. 2011; Ou et al. 2013; Xinchuang et al. 2016; Yu et al. 2011). Mortality due to cardiovascular, cerebrovascular, ischemic, and respiratory diseases has been reported too (Chan et al. 2012; Ou et al. 2013) in some of the previous countries and the Philippines (Seposo et al. 2016).

In Latin America, associations between changes in temperature and mortality by cardiorespiratory disease and non-external mortality have been found in cities of Brazil (Pinheiro et al. 2014), Argentina (Carreras et al. 2015), Chile (McMichael et al. 2008), and México (O’Neill et al. 2005). In Mexico, however, most of the studies have been focused on respiratory outcomes even though cardiovascular disease is the first cause of mortality. Little is known about the association between short-term exposure in regions of Mexico. In 2010, cardiovascular disease was the leading cause of mortality in Valle de Mexico, Monterrey and Guadalajara, the main metropolitan areas of Mexico, with mortality rates of 141, 151, and 137 per 100 thousand inhabitants, respectively. Within this broad mortality cause, deaths by ischemic heart disease ranged from 61.7 to 76.0 per 100 thousand inhabitants, while deaths by cerebrovascular disease ranged from 30.1 to 33.8 per 100 thousand inhabitants in the above-mentioned metropolitan areas (DGIS 2016). The main objective of this study was to evaluate the association between short-term effects of temperature and non-external and cardiovascular causes of mortality in people 65 years old and over in 10 metropolitan areas of Mexico.

Methods

An ecologic time series study was conducted with daily mortality and meteorological data collected from 1998 to 2014 from 10 metropolitan areas of Mexico with at least one million inhabitants and meteorological monitoring systems (Fig. 1). Each city has specific orographic and climate conditions (INEGI 2017).

figure1

Metropolitan areas of Mexico with at least 1 million inhabitants and meteorological monitoring system

Data collection

Mortality records were provided by the Mortality Epidemiology and Statistics Sub-System of the Minister of Health (SSA by its acronym in Spanish) through the dynamic data information system from the General Direction of Information on Health (DGIS by its acronym in Spanish). Mortality records were categorized using codes from the International Classification of Diseases 10th revision (ICD-10). The daily mortality counts included non-external (A00-R99), cardiovascular (I00-I99), and the following subcategories of cardiovascular mortality: ischemic heart (I20-I25) and cerebrovascular (I60-I69). The main age-specific analyses were performed for all ages and 65 years old and over; however, since mortality for vascular disease happens to young adults, an analysis for adults aged 45 years old and over was performed (Campos-Nonato et al. 2018). Valle de Mexico hourly meteorological records were collected at the Meteorology and Solar Radiation Network (REDMET by its acronym in Spanish) of Mexico City (REDMET 2017). Data from the remaining 9 metropolitan areas included in this study were collected from the National Air Quality Monitoring System, meteorological stations at the airports, and National Meteorological System (SMN by its acronym in Spanish) from the National Water Commission). The SMN includes Automatic Meteorological Stations reporting average data every 10 min and Meteorological Observatories, which transmit meteorological information in real time. For each metropolitan area, daily minimum, maximum, 24-h average temperature, and relative humidity were estimated. We included data from stations with at least 50% of information sufficiency during the study period. Only days having at least 75% hourly measurements (18 h) were included. When data from meteorological stations were incomplete, linear interpolation from neighboring days was used for days with missing values.

Where air pollution data was available, hourly concentrations of ozone (O3), and particulate matter (PM10 and PM2.5) were obtained from the National Air Quality Monitoring System from the National Institute of Ecology and Climate Change (INECC by its acronym in Spanish). Twenty-four-hour average PM10 and PM2.5 concentrations and maximum 8-h moving average O3 levels were calculated for each station with at least 75% of hourly data.

Statistical methods

In the first stage of the analysis, standardized time-series data were analyzed to estimate the effect of temperature on mortality in each metropolitan area. Average daily temperature was used because according to literature, it was identified as the best predictor for mortality (Guo et al. 2012). The minimum mortality temperature (MMT) (Gasparrini et al. 2015), at which the risk of mortality is at its minimum, was calculated for each metropolitan area following the methods described by Tobias et al. (2017). The MMT for non-external mortality was used as a reference to estimate the relative risks (RR) and corresponding 95% confidence intervals (95%CI) for specific causes of death, contrasting the MMT with ambient temperature values. These values were defined as cold and hot temperatures (5th and 95th percentiles of local temperature distributions, respectively), and extreme cold and extreme hot temperatures (1st and 99th percentiles of local temperature distributions, respectively). The analysis was conducted through a regression model, assuming a quasi-Poisson distribution due to an over dispersion of the mortality outcomes, combined with non-linear distributed lag models (DLNM).

The model used in the analysis is described by:

LogE[Yt]=α+βTt,l+βRHt,l+NS(Time,n/year)+DOWt+Holidayt+APt

Briefly, E (Yt) denotes the expected number of deaths on day t; α is the intercept; β is the coefficient; Tt,l is the “cross-basis” of temperature, l indicates the lag days; RHt is the cross-basis of daily relative humidity on day t; NS is the natural spline function; Time represents the long temporal trend; n describes the degrees of freedom (df) assigned to time per year for the best model fit; DOW stands for day of the week on day t; Holidayt is a dummy variable where 1 indicates that day t was a public holiday; and AP refers to air pollutants on day t where available. More details can be found in Gasparrini et al. (2010, 2015).

Evidence suggests that temperature not only has effects on mortality on the current day of exposure, but it also influences mortality days after the exposure occurred (lagged effect); this association is not linear (Guo et al. 2012). For these, DLNM models were used to examine the non-linear and lagged effect of temperature on mortality. This approach allowed us to estimate the cumulative effect of each lagged period (Gasparrini et al. 2010; Guo et al. 2012). A quadratic b-spline function with 3 df was used to explore the non-linear effect of temperature on mortality; the same function was assigned for relative humidity. Temperature effect on mortality was estimated for lag 0–21 days and its cumulative effects, since previous studies have suggested that cold temperatures have long-term effects on mortality, while the effects of hot temperatures can be acute (Braga et al. 2002; Guo et al. 2012; Tong et al. 2014). The knots for splines were placed equidistant in the temperature range and in equal intervals on a logarithmic scale for the lag periods. Sensitivity analyses were conducted by changing the df for each year (df 5, 8, and 10) to control the effect of seasonality and long-term trends, and by varying the exposure period from 3 up to 21 days. Diagnostic plots were used to check the fit of the model. Analyses were conducted using R (Version 0.99.486 – © 2009–2015 RStudio, Inc.) and the “dlnm” package (Gasparrini et al. 2010).

Meta-analyses

In the second stage of the analysis, meta-analyses were conducted to pool the magnitude of the association between mortality outcomes and temperature among metropolitan areas (RRpooled). Meta-analyses were applied to RR of mortality for each of the causes under study at 5th and 95th as well as 1st and 99th percentiles of temperature and lags 0–3, 0–7, and 0–21 days with random effects, using Restricted Maximum Likelihood as the estimation procedure. To assess heterogeneity across metropolitan areas, residual heterogeneity with Cochran Q test and I2 statistic was tested (Higgins and Thompson 2002; Higgins et al. 2003), and it can be interpreted as the percentage of the total variability in effect sizes among metropolitan areas.

Results

Descriptive statistics

During 2010, people 65 years old and over represented between 4 and 6% of the total population; meanwhile, people aged 45 years old and over represented between 17.7 and 24.2%. From 1998 to 2014 (6209 days), 3,288,254 deaths occurred in the metropolitan areas under study; on average, 530 persons died per day for all non-external causes in all ages. Most of these deaths occurred in Valle de Mexico, the most populated metropolitan area in Mexico. Table 1 presents descriptive statistics for the cardiovascular mortality subcategories in people 65 years old and over. Cardiovascular mortality in people 45 years old and over is shown in the online resource 1.

Table 1 Characteristics of population 65 years old and over and summary statistics of daily mortality counts

The average daily temperature among all metropolitan areas ranged from 13.9 to 23.3 °C, and relative humidity from 39.14 to 70.73%. The lowest and the highest temperatures were found in Juarez (0.4 °C and 35.3 °C, respectively), which shows a large intra-annual seasonal temperature contrast with hot summers and cold winters. Toluca has the highest altitude above the sea level (2701 masl).

In terms of air pollution, Monterrey had the highest PM10 daily concentrations (78.24 μg/m3), while the lowest was observed in Puebla-Tlaxcala (40.64 μg/m3). Regarding PM2.5, Toluca had the highest daily concentrations (32.72 μg/m3) and Puebla-Tlaxcala the lowest (18.97 μg/m3). In addition, the O3 highest daily value of 8-h moving average concentration was observed in Valle de Mexico (85 ppb), and the lowest in San Luis Potosí and Tijuana, both with 40 ppb. Air pollution data from San Luis Potosí was not included in further analysis since it did not meet the information sufficiency requirements. The distribution of orographic and climate conditions and daily air pollution concentrations of each metropolitan area is presented in Table 2.

Table 2 Summary statistics of meteorological conditions and air pollution concentrations in metropolitan areas of study

Regression results

Overall, non-linear associations in an inverted “J” shape were found for most of the metropolitan areas, except for Tijuana, which showed a “U” shape. The estimated MMT showed a range from 19.3 (95%CI 18.6–20.6) to 23.9 °C (95%CI 0.5–35.2). In general, the estimated MMT for each metropolitan area represents approximately the 75th percentile of the local temperature distributions (Fig. 2). In Toluca and San Luis Potosí, the 75th percentile of temperature distribution was used as the reference temperature due to the lack of data for MMT estimation.

figure2

Minimum mortality temperature and overall cumulative exposure–response associations in metropolitan areas of study

Both cold and hot temperatures showed statistically significant associations with mortality. In metropolitan areas like Valle de México, Toluca, Tijuana, and La Laguna, cold temperatures yielded to a higher risk of mortality than hot temperatures. In general, the cumulative RR [RR (95%CI)], for cold temperatures showed a consistent relationship, peaking at lag 0–7 days and ranged from − 0.8 (− 4.1, 2.54) to 28.9% (6.29, 56.3) for non-external causes; − 6.6 (− 10.5, − 2.5) to 43.5% (4.03, 98.1) for cardiovascular causes; − 34.2 (− 64.1, 22.0) to 20.3% (7.5, 33.1) for cerebrovascular causes; and − 9.6 (− 21.9, 4.4) to 62.2% (− 88.0, 135.2) for ischemic heart disease causes. Meanwhile, at lag 0–3, hot temperatures yielded to a higher risk of mortality, with RR ranging from 1.12 (0.8, 1.4) to 37.5% (20.7, 56.7) for non-external causes; − 14.0 (− 30.1, 6) to 29.5% (12.3, 49.2) for cardiovascular causes; − 4.1 (− 45.7, 69.0) to 112.9% (− 11.0, 409.6) for cerebrovascular causes; and − 19% (− 37.0, 4.1) to 32.8% (16.8, 50.8) for ischemic heart disease causes. Online resource 2 shows the RR and 95%CI estimated for each mortality cause and metropolitan area. Models for extreme temperatures (online resource 3), adults aged 45 years old and over (online resource 4), and adjusted by PM10 and O3 (Fig. 3) did not substantially change the results.

figure3

Effects of cold and hot temperatures adjusted by particulate matter and ozone in population 65 years old and over

Meta-analyses

Pooled associations between daily temperature and non-external and cardiovascular mortality were overall positive and similar, considering the lagged values of temperature associated more highly with mortality (at lag 0–7 and 0–3 for cold and hot, respectively). For example, cardiovascular mortality RR[RR (95%CI)] for cold exposure at lag 0–7 days was 7.1% (0.6, 14.0), whereas for heat exposure at lag 0–3 days was 7.1% (0.01, 14.7) (Fig. 4). The pooled analysis, using non-external and subcategories of cardiovascular mortality, showed a higher risk at hot temperatures and the association with ischemic heart disease was the strongest (online resource 5). Online resource 6 shows pooled relative risk for metropolitan areas of study and non-external mortality in population 45 years old and over. The I2 statistic showed values indicating moderate to low heterogeneity between metropolitan areas.

figure4

Pooled relative risk for cardiovascular mortality (random meta-analysis) in population 65 years old and over

Discussion

This is the first multi-city study in a single county performed in Latin America addressing the association between short-term changes in temperature and mortality using distributed lag nonlinear temperature terms, and a novel approach to identify MMT thresholds for the main metropolitan areas in Mexico. The main findings of our study suggest that both cold and hot temperatures are associated with increased risk of mortality for all specific cardiovascular causes in 65 years old and over. These associations remained statistically significant even after adjusting for air pollutants.

The observed effects of hot temperatures were more immediate, with a peak at lag 0–3 days, compared to cold temperature effects, where the peak was observed at lag 0–7 days. The highest RR were found in hot temperature conditions, indicating that the studied population could be more sensitive to hot temperatures.

Our findings differ from a previous study in Mexico, where O’Neill et al. (2005) observed a higher effect at low temperatures. In our study, we found similar associations with mortality at low and high temperatures using the same time-response that O’Neill et al. (2005). Other studies have reported greater risk for higher temperatures, particularly in countries with mild climates (Bunker et al. 2016; Sanderson et al. 2017; Song et al. 2017). Reports from mild-subtropical regions such as Australia, China, and the USA have also shown greater mortality rates during winter than in summer. This suggests that populations living in warm climates are more sensitive to the decrease in MMT (Dang et al. 2016).

It is known that air pollutants, such as O3, particulate matter, along with nitrogen oxides, sulfur oxides, volatile organic compounds, and carbon monoxide, affect health and are correlated to ambient temperature (Ramanathan and Feng 2009; Romero-Lankao et al. 2013; Romieu et al. 2012). In this study, the association between temperature and mortality did not differ substantially even after adjustment for such confounders. In a study that analyzed acute mortality associated with short-term exposure to temperature in Mexico City and Monterrey, with 2 and 4 years of data, respectively, the authors found that controlling for PM10 and O3 affected their temperature-effect estimates in different directions. They were able to use a proxy for respiratory epidemics to adjust their analyses, which was not available to be included in our analysis (O’Neill et al. 2005).

We observed exposure-response profiles between temperature and mortality outcomes with an inverted J and U shape. Such patterns may be explained by differences on the local climate and socioeconomic conditions. For example, Tijuana showed a U-shaped graph and, among the cities of the study, it has the lowest altitude and highest relative humidity, which may contribute to extreme cold and hot temperatures (Pepin and Seidel 2005) (see Table 2); Valle de Mexico and Monterrey showed an inverted J-shaped graph, with increased risk at lower temperatures. In this matter, some authors suggest that due to adaptation to local climate, population living in tropical or subtropical regions are more sensitive to cold temperatures (Yu et al. 2012; Ma et al. 2014).

For physiologic mechanisms involved in human thermoregulation, it is known that extreme changes in ambient temperature may cause thermal stress and alter cellular function to adequately respond to toxic agents. This is especially true for vulnerable groups, such as the elderly. In addition, different preexisting health conditions may imply different levels of sensitivity to sudden changes in temperature, making difficult to study the biological mechanisms involved in adverse effects of thermal dysregulation (Kim et al. 2014; Li et al. 2015).

In general, an increase in temperature has been associated to adverse health effects leading to heat stress, inducing pathological effects due to heat accumulation in the human body. Under normal circumstances, the increase in body temperature activates mechanisms such as sweating and vasodilatation to release heat. When such mechanisms fail and the body experiences heat stress, damages to the central nervous system, kidneys, and liver are more likely to occur (Lucas et al. 2014).

On the other hand, deaths related to low temperatures could be explained because dry and cold air lead to vasoconstriction in veins and arteries, increasing blood viscosity and cardiac output. It also causes heat loss since blood pressure increases on the skin surface, leading to vasospasm, and in some cases to a break off from atherosclerosis plaque and blood clots (Li et al. 2015). There is also an overload on the blood supply system, decreasing metabolic activity, which affects the brain (Seltenrich 2015).

Our findings must be interpreted considering the strengths and limitations of our study. Among the strengths of our research are the following: the length of the study period, 16 years of daily observations (making it one of the longest time series in Latin America); over 1.6 million deaths of persons aged 65 years or more, which contributes to the statistical power to detect the associations between temperature and mortality; the novel statistical approach used to characterize the association between short-term exposure to temperature and mortality; and the spatial representativeness for almost the entire urban territory of Mexico.

One of the most important limitations in our research is the lack of adjustment by potential confounders in the statistical analysis (Gasparrini and Armstrong 2010). For instance, socioeconomic status is considered a modifying risk factor in this association. Some authors suggest that socioeconomic context may contribute to local climate adaptation through the use of technology. For example, air conditioning could be a protective factor for mortality in temperature increase, while having heating systems or insulation may reduce the risk of mortality due to a decrease in temperature (Bouchama et al. 2007; Dear and McMichael 2011; Guo et al. 2014). Because of the homogeneity of this variable at metropolitan area level, it was not included in the analysis.

Despite the differences between the availability of information for each metropolitan area, it is methodologically possible to compare the results among metropolitan areas since the same method of analysis was used.

Our results are the first approximation of the extent to which temperature has an effect on mortality rates in metropolitan areas of Mexico. Pooled estimates consistently showed an adverse effect for all metropolitan areas in both hot and cold temperatures.

We concluded that both cold and hot temperatures were associated with increased cardiovascular mortality in a vulnerable population group of 65 years old and over in 10 metropolitan areas of Mexico. Although differences in the effect size were observed among metropolitan areas, our results suggest that the studied populations were more sensitive to hot temperatures compared to the effects of cold temperatures. These findings are relevant for the development of public health policies and strategies to prevent mortality caused by changes in temperature.