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ORIGINAL ARTICLE

Suicide and meteorological factors in São Paulo, Brazil, 1996-2011: a time series analysis

Daniel H. Bando,[1,2] Chei T. Teng,[3] Fernando M. Volpe,[4] Eduardo de Masi,[2,5] Luiz A. Pereira,[2,6] Alfésio L. Braga[2,6]

[1]*Universidade Federal de Alfenas (UNIFAL), Alfenas, MG, Brazil.* [2]*Grupo de Estudos em Epidemiologia Ambiental, Laboratório de Poluição Atmosférica Experimental Faculdade de Medicina, Universidade de São Paulo (USP), São Paulo, SP, Brazil.* [3]*Departamento e Instituto de Psiquiatria, USP, São Paulo, SP, Brazil.* [4]*Fundação Hospitalar do Estado de Minas Gerais (FHEMIG), Belo Horizonte, MG, Brazil.* [5]*Coordenadoria Regional de Saúde Sul, Secretaria Municipal da Saúde, Prefeitura de São Paulo, São Paulo, SP, Brazil.* [6]*Grupo de Avaliação de Exposição e Risco Ambiental, Programa de Pós-Graduação em Saúde Coletiva, Universidade Católica de Santos, Santos, SP, Brazil.*

Objective: Considering the scarcity of reports from intertropical latitudes and the Southern Hemisphere, we aimed to examine the association between meteorological factors and suicide in São Paulo.
Method: Weekly suicide records stratified by sex were gathered. Weekly averages for minimum, mean, and maximum temperature (°C), insolation (hours), irradiation (MJ/m^2), relative humidity (%), atmospheric pressure (mmHg), and rainfall (mm) were computed. The time structures of explanatory variables were modeled by polynomial distributed lag applied to the generalized additive model. The model controlled for long-term trends and selected meteorological factors.
Results: The total number of suicides was 6,600 (5,073 for men), an average of 6.7 suicides per week (8.7 for men and 2.0 for women). For overall suicides and among men, effects were predominantly acute and statistically significant only at lag 0. Weekly average minimum temperature had the greatest effect on suicide; there was a 2.28% increase (95%CI 0.90-3.69) in total suicides and a 2.37% increase (95%CI 0.82-3.96) among male suicides with each 1 °C increase.
Conclusion: This study suggests that an increase in weekly average minimum temperature has a short-term effect on suicide in São Paulo.

Keywords: Suicide; meteorological factors; São Paulo; time series; epidemiology

Introduction

Suicide is a worldwide public health problem, accounting for 50% of all violent deaths in men and 71% in women. It is the second leading cause of death in the 15-19 age group.[1] From 1980 to 2006, suicide rates in Brazil increased significantly from 4.4 to 5.8 per 100,000 inhabitants, a change associated with the male population.[2] In the city of São Paulo, trends for men presented a significant increase of 2.5% per year from 2002 onwards, and the increase for younger men (25-44 years) was significant at 8.6% per year from 2004 onwards.[3] A recent epidemiologic survey provided the first empirical data on the prevalence of mental disorders in the adult population of the São Paulo metropolitan area. Mental disorders were notably prevalent, and the estimated prevalence of severe cases (10%) indicates that more than one million adults in this area had impairment levels indicating special need for mental health care.[4]

Correspondence: Daniel Hideki Bando, Universidade Federal de Alfenas (UNIFAL), Av. Jovino Fernandes Sales, 2600, CEP 37130-000, Alfenas, MG, Brazil.
E-mail: danielhban@gmail.com
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Many risk factors for suicide have been identified. Risks linked to the community and relationships include stresses of acculturation (e.g., in indigenous peoples and displaced persons), discrimination against subgroups within the population (e.g., bullying, refugees), and psychosocial stressors (e.g., work-related problems, family violence, parental separation, social isolation, loss).[1] Risk factors at the individual level include mental disorders (e.g., depression, bipolar disorder), neurobiological disturbances (e.g., serotonin dysfunction), substance abuse (e.g., alcohol), genetic loading, chronic pain and illness (e.g., cancer, physical disability), and personality traits (e.g., impulsivity, aggression).[5] In the city of São Paulo, several specific sociodemographic risk factors have been identified, such as men aged 25-44, being single or divorced, being an immigrant,[3] and living downtown.[6]

Environmental risk factors for suicide include seasonality, with higher rates in the spring and summer.[7,8] Daily/weekly temperature and sunshine have also been directly associated with suicide.[9-12] In the 19th century, Guerry, followed by Morselli, Masaryk, and Durkheim, noted that suicides took place during the warm months in European countries.[13-15] Since then, review studies, most performed in the Northern Hemisphere in mid-latitudes and developed nations, have continued to describe this pattern.[7,8] In Brazil, Benedito-Silva et al.[16] found a seasonal distribution

of suicide, peaking in spring/summer, but only in the southern states. Specifically in the city of São Paulo, Bando and Volpe reported a significant circannual cycle peaking in spring/summer for both men and women from 1996 to 2010,[17] while Nejar et al.[18] did not find seasonality or any association between suicide and meteorological factors in São Paulo from 1996 to 2004.

To explain this observation, several hypotheses have been raised, including psychosocial,[11,13] physiological,[19,20] and neurobiological mechanisms.[12,21-23] Research conducted in Asia, Europe, and the Americas has explored a short-term association between meteorological factors and suicide.[10-12,18,24-27]

A time-series regression approach applying a generalized additive model (GAM) has typically been used in studies exploring the association between environmental factors and mortality[28,29]; however, there are few studies about suicide. A study performed in Korea using the GAM, adjusted for confounding factors, observed a 1.4% increase in suicide with each 1 °C increase in daily mean temperature.[11] A study performed in Japan used the same methodology, including nine geographical regions and a time period of 23 years. In five regions, increases of 0.3% (Okinawa) to 4.3% (Tohoku) were observed in suicide for each 1 °C increase in daily temperature.[10] In Brazil, only one study investigated this issue, in São Paulo, and found no association between weather conditions and suicide.[18]

Considering the lack of reports from intertropical latitudes on this issue, and the particular scarcity of GAM-based research, we aimed to examine the association between meteorological factors and suicide in the city of São Paulo, Brazil, to add further evidence to this matter.

Methods

Study site

The city of São Paulo is crossed by the Tropic of Capricorn (23° 32′ S; 46° 38′ W). It covers an area of 1,525 km^2 at an altitude of 720 to 850 m above sea level. Its population was estimated at 11.2 million by the 2010 National Census (Brazilian Institute of Geography and Statistics, IBGE),[30] and is mostly urban. It is also the major financial and economic center of the country.

Data sources

This is a time-series study using secondary data. Mortality data were extracted from the Programa de Aprimoramento das Informações de Mortalidade (PRO-AIM),[31] the official municipal health statistics program. PRO-AIM was created by the São Paulo municipal government in 1989 and aims to provide enhanced information for mortality and epidemiological surveillance and evaluation of health services since 1996. All deaths with suspicion of suicide undergo forensic autopsy and, when confirmed as suicide, are recoded according to the ICD-10. For the purposes of this study, we selected the codes corresponding to intentional self-harm (X60-X84) in death records of persons who were residing in the city of São Paulo and died in the city. To avoid bias, we restricted our search to data from 1996 onwards, which corresponds to the period of ICD-10 implementation.

Meteorological data were obtained from the Instituto de Astronomia, Geofísica e Ciências Atmosféricas, Universidade de São Paulo (IAG-USP). We computed weekly averages for minimum, mean, and maximum temperature (°C), insolation (hours), irradiation (MJ/m^2), relative humidity (%), atmospheric pressure (mmHg), and rainfall (mm).

Statistical analyses

Weekly records of deaths by suicide, stratified by sex, were gathered for the entire study period (1996-2011, a total of 757 weeks). The association between weekly suicide records and meteorological data was investigated with GAM, an extension of generalized linear models (GLM) that allow nonlinear effects. These models use a smooth function that is a nonparametric tool allowing control for potential nonlinear dependence of the variable of interest (in this case, number of suicide) on covariates (in this case, weather).[29] In a GAM, the dependent variable belongs to exponential family and the predictors are smooth functions of each covariate. In this context, the expected number of suicides (a Poisson random variable) was estimated as the sum of smooth and linear functions of the weather predictor variables. To remove long-term trends and seasonality and to minimize autocorrelation of residuals, a natural cubic spline function was chosen to adjust the time variable weeks. The optimal number of knots was chosen based on visual appraisal of the total suicide series. Four knots/year for total suicides, or 60 knots for the entire period, improved the model parameters (generalized cross validation [GCV] score, k-index). We tested and decided that 60 knots would be sufficient to estimate the smooth functions and control for seasonality in all models. The number of degrees of freedom was not fixed and was chosen by GCV score.[32]

The time structures of explanatory variables were modeled by polynomial distributed lag (PDL) applied to the GAM. The PDL is an estimation technique that forces the coefficients of each lagged variable of an equation to lie on a polynomial degree p. In the presence of high multicollinearity, the estimation of ordinary least square is not precise. Thus, the use of PDL increases the estimate's precision[33] and enables lagged dependency estimation among outcome and explanatory variables in a parsimonious fashion. Usually, PDL has been applied to social sciences studies and econometrics, and its use in epidemiology has been described in studies of the weather's effect on respiratory and cardiovascular deaths.[28,29,34]

Weather can influence suicide deaths not only in the same week but also on subsequent weeks.[12] Hence, the number of suicides in a given week will depend not only on the same-weather week effect, but also on the lagged effect of the previous weeks. To deal with this situation, a 6-week cumulative effect was estimated by the PDL applied to the GAM. This technique is called generalized additive distributed lag modeling.[29] According to the literature, long-term trends are related to months and

seasons, and short-term trends, with days and weeks.[7-9,11] Based on this and for the purpose of the study, we chose the period of up to 6 weeks to assess cumulative effect. To give enough flexibility to estimate a biologically plausible lag structure, control for multicollinearity better than in an unrestricted lag model, and impose minimal constraints, a third-degree polynomial was applied to PDL estimation, because these can adjust different curvilinear functions such as cubic and quadratic.[33]

Three independent models were estimated: one general and two stratified by gender. To fit the model, the GAM function from the Mixed GAM Computation Vehicle (MGCV) package in R software, version 2.15.2, was used.[35] The best-fitted model was selected in accordance with the dispersion parameter and explained variance and mean square error of prediction. Once the best-fitted model was selected, it was tested for overdispersion and residual autocorrelation using the GAM check command in R and the simple (autocorrelation function) and partial autocorrelation function plots. When working with Poisson distribution, overdispersion can be a problem. One general technique to deal with this problem is to use a quasi-likelihood method by specifying the variance function instead of giving a full probability model. R has a quasipoisson family in its GAM function to handle this situation.[10]

The models were built in several steps. First, to select the predictor variables, a correlation matrix was calculated. We considered correlation coefficients ranging from 0 to 0.19 as weak, 0.20 to 0.49 as moderate, 0.50 to 0.69 as strong, and 0.70 to 1 as very strong. All the independent variables correlated with suicide in a coefficient higher than 0.20 indicate a dependent relationship and were tested in a univariate model. We did not restrict the input variables much. To avoid multicollinearity, when two independent variables were strongly correlated ($r > 0.50$), only the better predictor was considered. Weekly averages of minimum, mean, and maximum temperature were very strongly correlated. In this case, the weekly averages of minimum temperature were the best predictor. Second, a univariate model was estimated for each weather variable. Finally, a multivariate model was built. The independent variables were entered one by one into the model according to association strength. After each estimated model, variables with p-values higher than 0.05 were removed, and the model was re-estimated. Third, the better model was checked for multicollinearity and residual autocorrelation. The residuals should be uncorrelated and follow a normal distribution according to a white noise process. In this way, the final general model obtained was as follows: Suicide ~ s(week, k = 60, bs = "cr," fx = FALSE) + temp0 + temp1 + temp2 + temp3 + insol0 + insol1 + insol2 + insol3 + rain0 + rain1 + rain2 + rain3, family = quasipoisson) – where Suicide is the number of suicide deaths; s is a natural cubic spline; k is the knot number; fx = FALSE indicates that the degrees of freedom will be chosen by GCV score; temp0 to temp3 are weekly averages of minimum air temperature in lag 0 to 3; insol0 to insol3 are cumulative weekly hours of insolation in lag 0 to 3; rain0 to rain3 are cumulative weekly rainfall in lag 0 to 3; and bs and family = quasipoisson are R commands for the MGCV package.

Results

São Paulo's tropical climate features monthly mean temperatures ranging from 22.3 °C in January to 16.0 °C in July, with a thermal amplitude of 6.3 °C (Figure 1). Precipitation is abundant (accumulated 1,500 mm/year). Seasons typically alternate between hot and humid (in spring and summer) and cold and relatively dry (in autumn and winter). Suicide is more frequent in spring and less frequent in the fall. Monthly suicide counts were highest in November (20.5 deaths) and lowest in April (16.6 deaths) (Figure 1). The mean annual suicide rate for the period was 4.2 per 100,000 population (6.8 for men, 1.9 for women).

Table 1 presents a summary of the variables used in the study for the entire period. Weather variables revealed interesting data. The coldest week of the year recorded 4.5 °C, and the hottest, 34.0 °C. Weekly mean temperatures ranged from 11.5 to 25.9 °C, with a thermal amplitude of 14.4 °C. This is a much broader range than the monthly thermal amplitude (6.3 °C). Irradiation and rainfall reached up to 26.8 MJ/m^2 and 33.6 mm per week, respectively. The total number of suicides from 1996 to 2011 was 6,600 (5,073 men and 1,521 women, yielding a male-to-female ratio of 3.3). The weekly mean suicide count was 8.7 (6.7 for men, 2.0 for women).

Figures 2 and 3 illustrate the lagged univariate effect of meteorological factors in men and women, respectively. Weekly averages of minimum temperature showed the highest association with suicide on lag 0. We observed a percent increase (PI) of 2.18 (95% confidence interval [95% CI] 0.86-3.51) in total suicide counts with each 1 °C increase in weekly average minimum temperature. The PI for men was 2.14 (95%CI 0.66-3.64). Suicide counts also increased with irradiation on lag 0 and lag 1, both overall and for men. Humidity was associated with suicide only on lag 3 overall and for men. Suicide risk decreased with insolation on lags 2 to 4. The suicide counts for women increased only with rainfall on lag 0 (PI 1.28, 95%CI 0.27-2.30).

Figure 4 presents the final multivariate model, the lagged association of weekly averages of minimum temperature on suicide according to gender, using third-degree polynomials ranging from lag 0 to lag 6. For total suicides and for men, associations were predominantly acute and

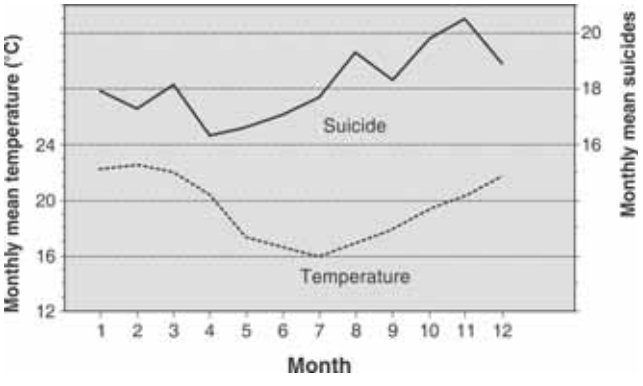

Figure 1 Monthly mean temperature and suicide counts in São Paulo, 1996-2011.

Table 1 Summary of suicide counts and meteorological factors used in this study. São Paulo, 1996-2011

Variables (weekly averages)	Mean (SD)	Min	Max	Week
Suicide counts				
Men	6.7 (2.6)	0	18	757
Women	2.0 (1.5)	0	7	757
Total	8.7 (3.1)	0	20	757
Weather				
Minimum temperature (°C)	15.2 (3.0)	4.5	21.1	757
Mean temperature (°C)	19.4 (2.8)	11.5	25.9	757
Maximum temperature (°C)	25.4 (3.3)	16.1	34.0	757
Insolation (hours)	5.3 (2.0)	0.6	10.0	757
Irradiation (MJ/m^2)	15.8 (4.0)	3.3	26.8	757
Pressure (mmHg)	926.0 (2.9)	919.4	934.4	757
Humidity (%)	80.2 (5.0)	59.1	94.1	757
Rainfall (mm)	4.2 (5.1)	0	33.6	757

Max = maximum; Min = minimum; SD = standard deviation.

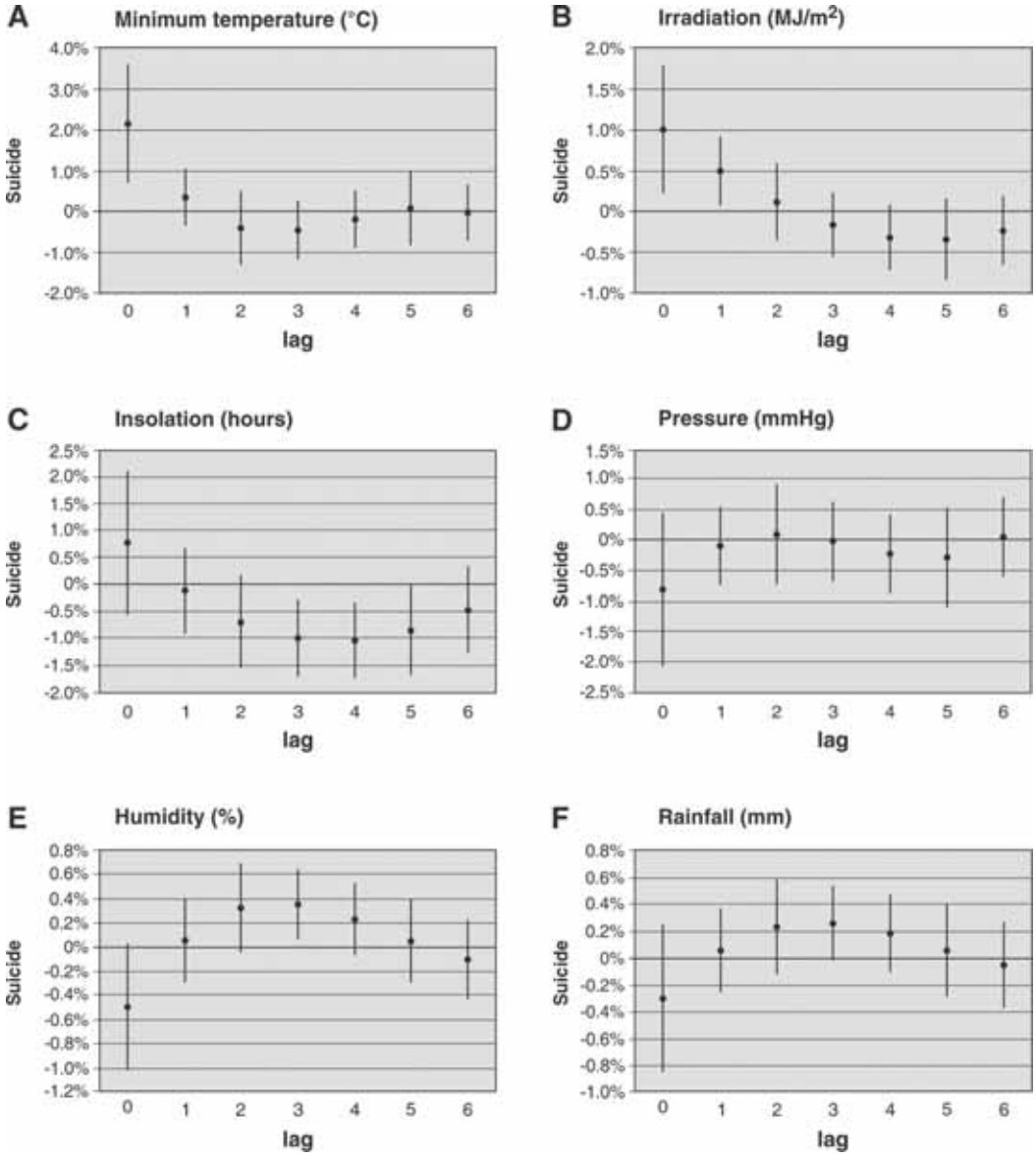

Figure 2 Generalized additive model (GAM)-estimated increase in male suicide (%) and 95% confidence interval for each meteorological factor modeled by polynomial distributed lag: A) minimum temperature; B) irradiation; C) insolation; D) pressure; E) humidity; F) rainfall.

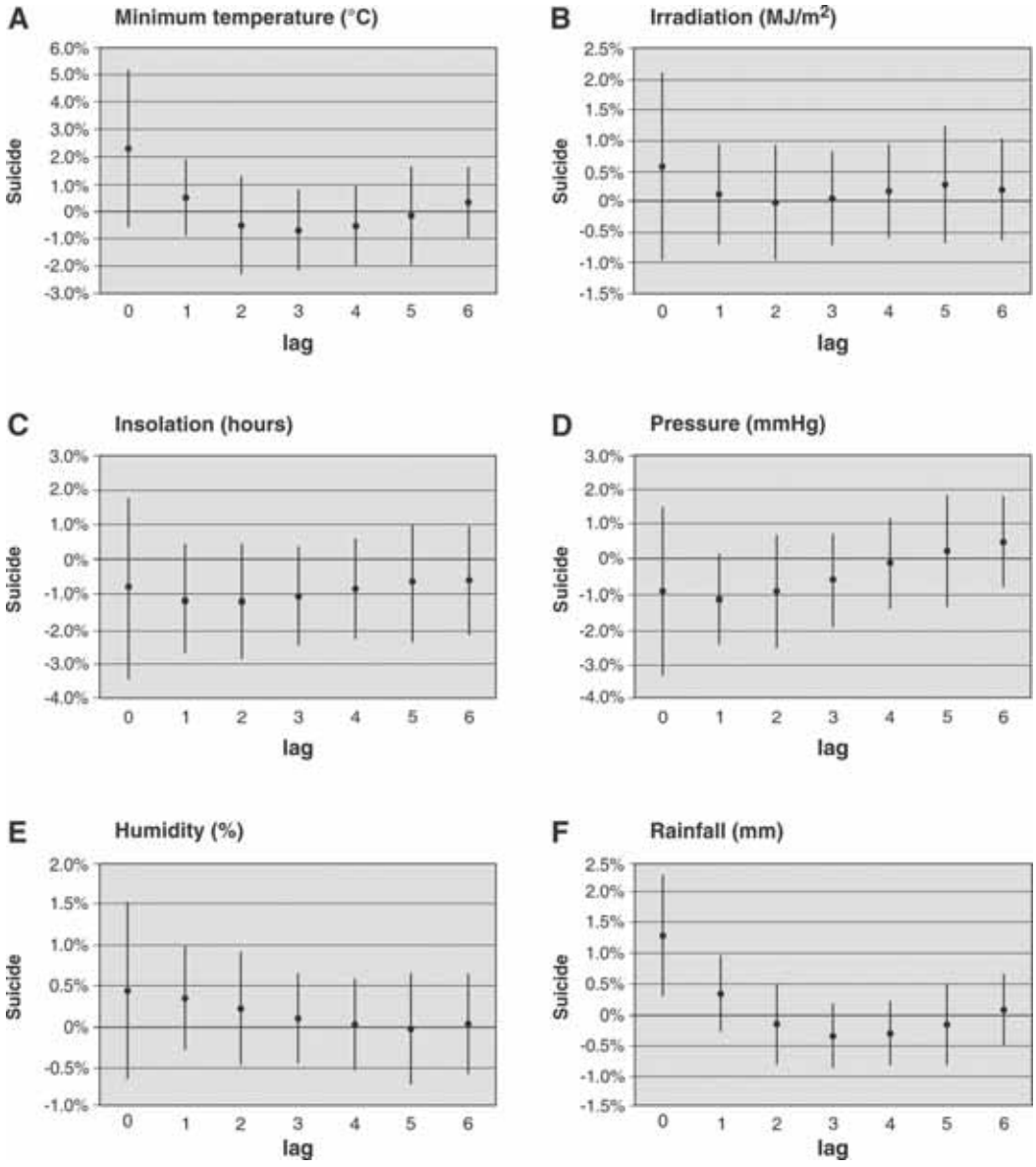

Figure 3 Generalized additive model (GAM)-estimated increase in female suicide (%) and 95% confidence interval for each meteorological factor modeled by polynomial distributed lag: A) minimum temperature; B) irradiation; C) insolation; D) pressure; E) humidity; F) rainfall.

statistically significant only at lag 0. There was a 2.28% increase (95%CI 0.90-3.69) in suicide with each 1 °C increase in weekly average of minimum temperature; men had a 2.37% increase (95%CI 0.82-3.96). The association among women was not significant. The residuals were uncorrelated and followed the normal distribution according to a white noise process. The sum of the residues was -0.2270. Overdispersion was not observed (dispersion parameter 1.0715), which means that the Poisson model was appropriate.

Discussion

We found a significant association between suicide and weekly averages of minimum temperature. The associations were acute and statistically significant at lag 0 and suggest a short-term association, within the same week. Time-series regression analysis showed a 2.28% increase in total suicide counts with each 1 °C increase in weekly averages of minimum temperature. The association was higher among men (2.37% increase) and nonsignificant among women.

In São Paulo, men had more than threefold risk of dying by suicide than women. In general, men tend to choose more violent means (e.g., hanging, shooting), and women, less violent methods (e.g., poisoning).[5] This pattern holds true in São Paulo.[3] A recent review considering environmental suicide risk factors such as seasonality confirmed a peak in spring/summer, mainly among men and by violent methods.[7] Short-term environmental suicide risk factors have long been reported to include a direct association with

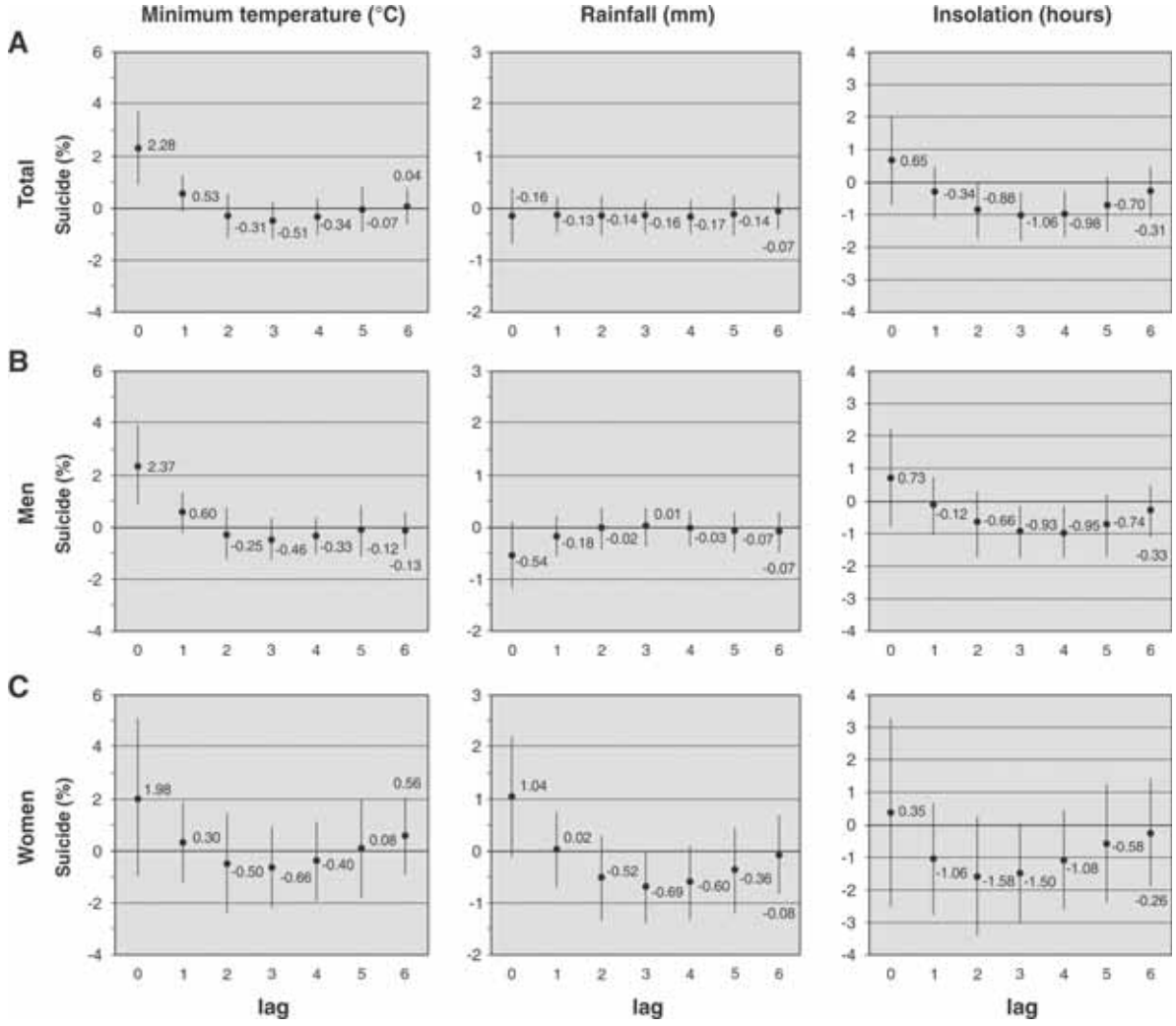

Figure 4 Lag effects of weekly minimum temperature, rainfall, and insolation on suicide counts (%) in the final multiple model: A) total; B) men; C) women.

temperature and sunshine, for the same group: men committing suicide by violent methods.[10,11,20,26,27] Therefore, this group should be a key component to understand the association of suicide with temperature in future research, at the individual level. Clinical practice can benefit from combining these outcomes with known psychiatric risk factors (e.g., mental illness, substance abuse)[5] and sociodemographic risk factors in the city of São Paulo (men aged 25-44, singles/divorced, Asians, immigrants,[3] and people who live downtown[6]), to monitor patients and intervene with greater accuracy.

In the present study, we adopted PDL applied to GAMs to explore the relation between suicide and meteorological factors. Various statistical methods have been used to examine the association between weather and suicide. Logistic regression, GLM, and GAM have been the main techniques, applied with different procedures to control for the effect of seasonality. Two European studies, from Greece and Austria, used logistic regression and found significant associations of meteorological factors with suicide. The former found an association with sunshine during up to 9 days preceding suicide,[12] while Deisenhammer et al. found a positive association between daily high temperature and suicide in Tyrol, Austria.[24]

Studies using GLM in São Paulo[18] and in a northern province of Finland[27] revealed no association between meteorological factors and suicide. Possible explanations for the contradiction between findings and those of this previous study carried out in São Paulo include different time span (1996 to 2004), time unit (day), and statistical method (GLM).[18] Conversely, four GLM-based studies performed in mid-latitude nations (British Columbia, Canada; Toronto, Canada; Mittelfranken, Germany; England; and Jackson, Mississippi, USA) showed direct and acute effects of temperature on daily suicide counts.[9,25,26,36] Three other studies from mid-latitude nations used GAMs to estimate the association between suicide counts and meteorological variables. Two of these were performed in Japan and Korea and showed similar results compared with our findings: an acute, direct association of temperature with suicide.[10,11] Hanigan et al., using monthly data from New South Wales, Australia, found a positive association of suicide counts and

drought for rural men aged 30-49. Although the study used monthly data, its findings revealed the complexity of the phenomenon and possible interactions with environmental, biological, and socioeconomic factors.[37] The few studies that used GAM were from developed countries at mid-latitudes. These studies found a short-term and direct association between temperature and suicide. GAM is an extension of GLM that uses nonparametric smooth functions to estimate the relation between the outcome and each predictor, and suggests a more flexible alternative to exploring these associations.[34] The scarcity of reports using the same methodology in different regions of the globe warrants the promotion of new studies in this area.

Several hypotheses have been raised to explain the direct association between temperature and suicide, including that high temperature might increase the negative impact of body self-harm on the chance of surviving after a suicide attempt.[19,20] The Italian psychiatrist Morselli was among the first to point out that mood disorders could be influenced by temperature, and reported a notable parallelism between suicides and daily temperature in Italy from 1866 to 1874.[14] Higher temperatures are also associated with higher admission rates of patients with bipolar disorder to psychiatric hospitals.[38,39] A possible clue for an explanation of the role of ambient temperature in suicidal behavior could be the importance of the serotonin system in modulating both body thermoregulation and mood through serotoninergic neurons from the interfascicular part of the dorsal raphe nucleus (DRI).[40] These serotoninergic neurons are activated by thermosensitive proteins at peripheral structures like the skin and upper airways, and give rise to a majority of the median raphe forebrain bundle tract, traveling within the ventromedial part of the medial forebrain bundle to the prefrontal cortex, frontal, cingulate, and entorhinal cortices, hippocampus, and midline thalamus; most of these cerebral areas are associated with mood disorders. The activation of DRI neurons could explain the antidepressants effects of warm ambient temperature, in a mechanism similar to that of the serotoninergic antidepressants. Warm ambient temperatures are also associated with higher responsivity of the serotonin 5HT2A receptor,[41] which is associated with aggressive behavior and impulsivity,[22,23] especially in some polymorphic gene variants.[21] Nevertheless, the role of 5HT2A in suicidal behavior is still unclear.[21]

The present study has some limitations. The first is inherent to the ecological study design. The association observed between variables at the group level does not necessarily represent the association that exists at the individual level. Another limitation is the lack of information about mental disorders and socioeconomic conditions related to suicides in our dataset. Another limitation is the lack of more information about meteorological factors across the city, which would have allowed monitoring of local phenomena such as the urban heat island effect. The last one is related to data collection due to misclassification of suicide. Although PRO-AIM provides a complete, extensive record of mortality in the city of São Paulo, it still depends on medical diagnosis. For instance, relatives of a victim might compel the attending physician to substitute a an alternative diagnosis for one of suicide for several reasons (such as religious, familial resistance concerning the act itself, and insurance purposes). Different procedures, social practices, and values probably have various effects on death records and lead to misclassification of suicide. However, none of these limitations were consequences of systematic errors, and no overestimation of the effect was observed.

In conclusion, suicide is a public health problem and a multifaceted phenomenon. We found that an increase in weekly averages of minimum temperature was acutely associated with suicide mortality in São Paulo. This is an important step in continued efforts to improve the scientific basis of suicide prevention. The results observed in the present study could implicate a potential relevant role of ambient temperature on suicidal behavior. However, further investigations, possibly including different populations, meteorological conditions, and study designs, should be considered to add further contributions on this matter.

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