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The effect of air temperature on mortality from cerebrovascular diseases in Brazil between 1996 and 2017

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Abstract *Cerebrovascular diseases (CVD) are one of the leading causes of mortality globally. Air temperature is one of the risk factors for CVD; however, few studies have investigated the relationship between air temperature and mortality from these diseases in Brazil. This time series study investigated the relationship between air temperature and CVD mortality in 10 microregions located across Brazil's five regions during the period 1996 to 2017 using mortality data from the national health information system, DATASUS and daily mean temperature data. The association between mean air temperature and mortality from CVD was measured using generalized additive models with Poisson distribution and relative and attributable risks were estimated together with 95% confidence intervals using distributed lag non-linear models and a 14-day lag. There were 531,733 deaths from CVD during the study period, 21,220 of which (11,138-30,546) were attributable to air temperature. Minimum mortality temperatures ranged from 20.1ºC in Curitiba to 29.6ºC in Belém. Associations between suboptimal air temperatures and increased risk of death from CVD were observed in all of Brazil's five regions. Relative risk from the cold was highest in Manaus (RR 1.53; 1.22-1.91) and Campo Grande (RR 1.52; 1.18-1.94), while relative risk from heat was highest in Manaus (RR 1.75; 1.35-2.26) and Brasília (RR 1.36; 1.15-1.60).*

Key words *Stroke, Mortality, Temperature, Climate*

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Introduction

Cerebrovascular diseases, principally strokes, are one of the leading causes of death worldwide[1]. Understanding the risk factors for these diseases is vital to reducing morbidity and mortality. Recent studies have shown associations between air temperature and mortality from cerebrovascular diseases[2-7]. The potential health effects of the climate have become such an important issue that temperature extremes were added to the list of leading risk factors for morbidity and mortality globally in the latest edition of the Global Burden of Disease (2019)[8].

The pathophysiology of the relationship between air temperature and cerebrovascular diseases is multifactorial. Low temperatures stimulate peripheral skin receptors, which causes vasoconstriction and circulatory overload due to the release of catecholamines. In addition, exposure to cold can induce a hypercoagulable state, which can contribute to the development of these diseases[9]. In contrast, high temperatures can cause local and systemic inflammation, resulting in the release of pro-inflammatory interleukins, which can give rise to atherosclerotic plaque instability and endothelial dysfunction. In addition, dehydration due to heat causes hemoconcentration, inhibition of the fibrinolytic system, and activation of the pathway of coagulation, which are determining factors for acute vascular events[9].

In light of the above, understanding that air temperature is an important risk factor for cerebrovascular diseases is crucial for the development of effective health measures and public policies. Extreme cold and heat warning systems have been shown to be effective in encouraging individuals to protect themselves against temperature extremes, particularly among vulnerable groups[10,11].

The aim of this study was to provide new evidence of the relationship between air temperature and mortality from cerebrovascular diseases in 10 micro regions in Brazilin order to draw the attention of the public and health professionals and managers to the need to develop measures to address the health effects of extreme temperatures.

Although various countries possess epidemiological data on the effects of air temperature on mortality from cerebrovascular diseases, data in Brazil are scarce and generally limited to specific regions or shorter time intervals. The present study therefore intends to contribute to the body of knowledge on this issue by discussing the effects of air temperature on deaths from cerebrovascular diseases across Brazil's five regions over a 21-year period (1996-2017).

Methods

Study population

We conducted a time series study to investigate the effect of variations in daily mean temperature on mortality from cerebrovascular diseases. We selected the two largest cities in each of Brazil's five regions, which correspond to the micro regions defined by the Brazilian Institute of Geography and Statistics (IBGE), except in the Center-West, where the second largest city (Goiânia-GO) was discarded due to its proximity to the largest city (Brasília-DF). The following 10 micro regions were selected, representing the country's different social and climatic realities: Porto Alegre-RS (South), Curitiba-PR (South), São Paulo-SP (Southeast), Rio de Janeiro-RJ (Southeast), Brasília-DF (Center-West), Campo Grande-MS (Center-West), Salvador-BA (Northeast), Recife-PE (Northeast), Manaus-AM (North), and Belém-PA (North). The study period was January 1996 to December 2017 (21 years).

Data

Data on mortality from cerebrovascular diseases (Codes I60 to I69 of the ICD 10) were obtained from the national health information system, DATASUS[12]. Daily mean temperature was calculated using data from model equations[13] produced by the European Centre for Medium-Range Weather Forecasts (ECMWF). Reanalysis systems consist of a combination of weather forecasting models and systems that assimilate meteorological data obtained from different platforms, such as ships, aircraft, radiosondes and satellites. Because these observations are unevenly distributed across space and time, the data is assimilated to combine all available information with a weather forecasting model and generate a new analysis of the state of the atmosphere at a specific moment in time[14]. We calculated daily mean air temperatures at points on a uniform horizontal grid spaced at a distance of 13 km, using the points within each of the micro regions to obtain the daily mean temperature. Despite variations in temperature within each

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micro region, daily mean temperature provides a good representation of temperature trends[4] and is widely used by studies addressing the relationship between health and climate[15]. The performance of the model equations used by the ERA-Interim reanalysis is satisfactory when compared to meteorological data, showing a correlation of equal to or greater than 96% in the state of Rio Grande do Sul[16]. These data are publically available, meaning that, in accordance with National Health Council Resolution No. 510, the present study did not require ethical approval.

Statistical analysis

The statistical distributions of daily mean air temperature and daily deaths from cerebrovascular diseases by micro region were presented in tables. Boxplot charts showing the monthly distribution of the frequency of deaths and mean temperature were used to visualize differences in the variables in each region.

The association between mean air temperature and mortality from cerebrovascular diseases was measured using generalized additive models with the negative binomial distribution. Time was modelled using a natural cubic spline with eight degrees of freedom per year to adjust for long-term trends and seasonality. Day of the week was included in the models to adjust for days in which mortality from cerebrovascular diseases was higher, such as weekends for example. Non-linear and time interval effects were estimated using distributed lag non-linear models (DLNM)[17]. Widely used in time-series studies investigating associations between climatic factors and health outcomes[18], DLNM allow researchers to detect non-linear and time lag associations using cross-basis functions. We selected a natural spline with five degrees of freedom for the exposure–response function and a polynomial function with one intercept and four degrees of freedom for the lag-response function to provide greater model flexibility. Maximum lag was set at 14 days. The analyses were performed with the software R, version 4.1.0 using the packages dlnm, mgcv, splines and ggplot2.

The model is represented by the equation below:

$$Y_t \sim \textit{Negative binomial}\ (\mu_t)$$
$$log(\mu_t) = \alpha + \beta Temperature_{t,\mathrm{lag}} + NS(time,gl) + \gamma Day_t$$

Where Y_t is the number of deaths observed on day t; α is the intercept; $Temperature_{t,lag}$ is a matrix of variables derived from the transformation of temperature into a cross-basis object where β is its vector of coefficients and lag is in days; NS (time, df) is the natural spline of time in days, where df is degrees of freedom per year to control for long-term trends and seasonality.

Cumulative relative risk (RR) of mortality from cerebrovascular diseases was calculated for each micro region for predetermined temperature percentiles (P) relative to minimum mortality temperature - MMT (reference), with a 14-day lag. Percentiles 2.5 and 10 represent extreme and moderate cold, respectively, while 90 and 97.5 represent moderate and extreme heat. Finally, we calculated risks attributable to the temperature intervals between these percentiles: (a) Attributable risk (AR) of extreme cold (between the lowest temperature and percentile 2.5); (b) AR of moderate cold (between percentiles 2.5 and 10); (c) AR of mild cold (between percentile 10 and MMT); (d) AR of mild heat (between MMT and percentile 90); (e) AR of moderate heat (between percentiles 90 and 97.5); (f) AR of extreme heat (between percentile 97.5 and the highest temperature).

Results

Daily mean air temperatures were highest during the summer months and lowest in the winter across all micro regions except Manaus and Belém, where temperatures were highest in the spring, during September and November (Figure 1).

The highest daily mean air temperature was observed in Fortaleza (Northeast), while the lowest was in Curitiba (South). The North and South showed the highest and lowest mean temperatures, respectively (Table 1).

The variation in mean daily temperatures was highest in Porto Alegre (standard deviation 4.6°C) and lowest in Fortaleza (standard deviation 0.9°C). (Table 1).

A total of 531,733 deaths from cerebrovascular diseases were analyzed in this study. The number of daily deaths ranged between 0 and 60 across the regions. The largest and smallest number of deaths were recorded in Rio de Janeiro and Campo Grande, respectively (Table 1).

Risk of mortality from cerebrovascular diseases was higher on days with extremet emperatures (both cold and hot) across Brazil's five regions (Table 2 and Figure 2). Increased risk of mortality was associated with extreme cold in seven of the 10 micro regions, extreme heat in six of the regions, and moderate temperatures in five of the regions.

Relative risk (RR) of death from cerebrovascular diseases was highest in Manaus foreach of the four percentiles analyzed by this study. RR of extreme cold was also high in Curitiba (South) and Campo Grande (Center-West), while RR of extreme heat was highest in Manaus (North), followed by Porto Alegre (South), and Brasília (Center-West). Belém was the only micro region not to show increased RR for the temperature percentiles analyzed by this study.

Attributable fractions were highest in Manaus and the micro regions in the South and Center-West in each of temperature percentiles. A significant proportion of deaths in Manaus and Curitiba were attributable to mild cold and mild heat. The proportion of deaths attributable to mild cold and mild heat was higher than that attributable to extreme temperatures because the proportion of days with mild temperatures was

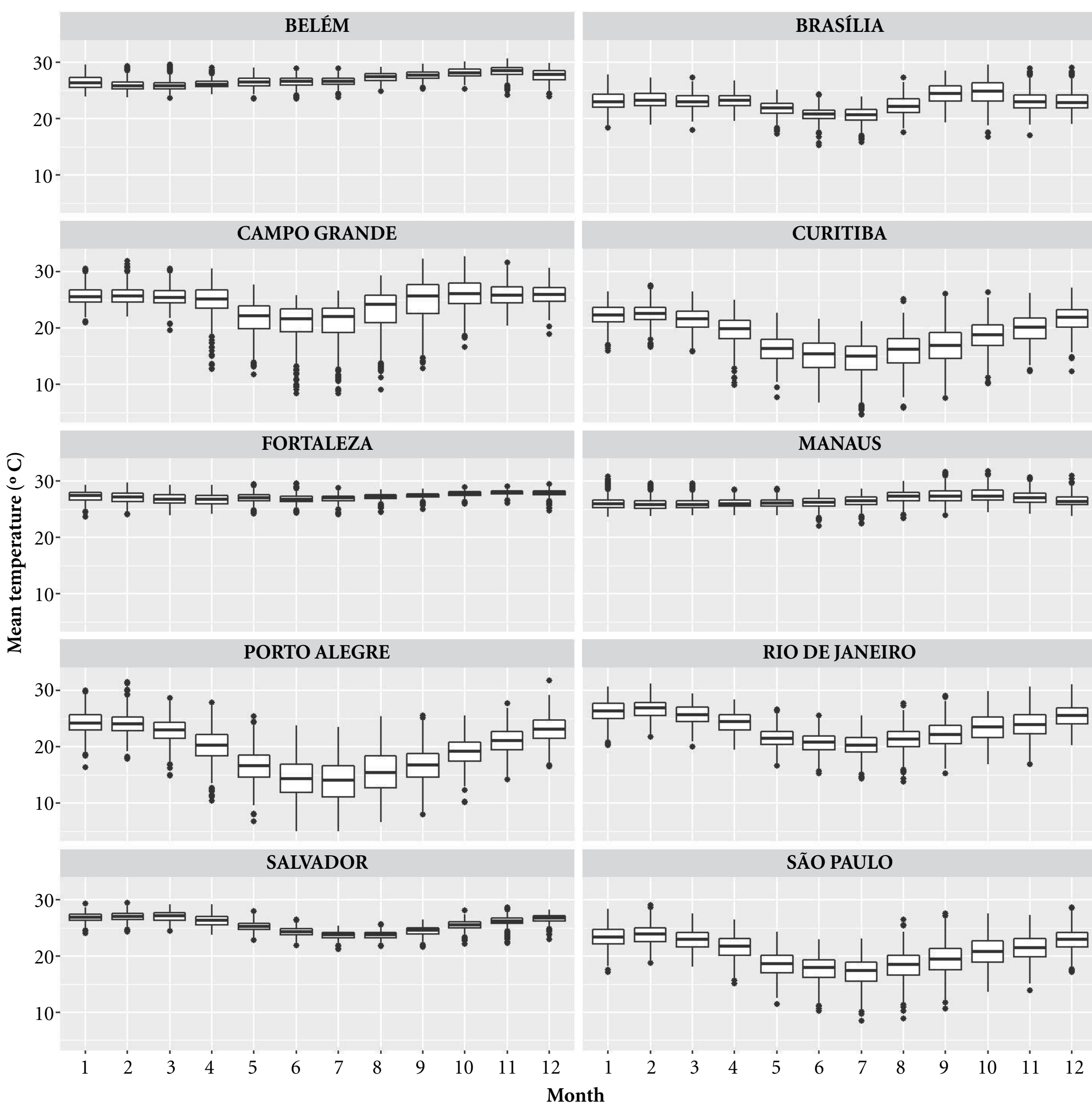

Figure 1. Boxplot charts showing variations in mean temperatures in each micro region by month (1996-2017).

Source: Authors.

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generally greater. Despite not having the highest attributable fractions in any of the temperature percentiles, São Paulo and Rio de Janeiro showed the highest number of attributable deaths because they are the most populous cities.

It is estimated that around 1,218 deaths from cerebrovascular diseases per year were attributable to temperatures above or below the MMT (Table 3).

Table 1. Distribution of daily mean temperatures (ºC) and daily deaths from cerebrovascular diseases in the 10 micro regions (1996-2017).

Micro region	Min	Q1	Q2	Q3	Max	Mean	SD	Total
Mean temperature								
Belém	23.5	26.1	26.9	27.9	30.7	27.0	1.2	-
Manaus	22.0	25.7	26.5	27.3	31.8	26.6	1.2	-
Fortaleza	23.7	26.7	27.4	27.9	29.7	27.3	0.9	-
Salvador	21.3	24.4	25.7	26.8	29.5	25.6	1.5	-
Rio de Janeiro	13.8	21.2	23.4	25.7	31.3	23.4	3.0	-
São Paulo	8.4	18.4	20.8	23.1	29.0	20.6	3.2	-
Brasília	15.3	21.5	22.7	24.1	29.7	22.8	2.0	-
Campo Grande	8.3	22.8	24.8	26.5	32.7	24.3	3.4	-
Curitiba	4.5	16.1	19.0	21.7	27.6	18.7	3.8	-
Porto Alegre	4.9	16.0	19.8	23.0	31.9	19.3	4.6	-
Deaths								
Belém	0	1	3	4	11	2.7	1.7	21,629
Manaus	0	1	1	2	9	1.6	1.3	13,036
Fortaleza	0	2	4	5	14	3.8	2.1	30,733
Salvador	0	3	4	5	13	4.1	2.0	32,799
Brasília	0	1	2	3	11	2.4	1.6	18,894
Campo Grande	0	0	1	2	7	1.1	1.1	9,210
Rio de Janeiro	5	17	21	24	60	21.0	5.3	168,480
São Paulo	5	16	19	22	38	19.0	4.8	152,919
Curitiba	0	2	4	5	13	3.9	2.0	31,481
Porto Alegre	0	5	6	8	24	6.5	2.8	52,552

Min: minimum temperature. Q1: first quartile. Q2: second quartile. Q3: third quartile. Max: maximum temperature. SD: standard deviation. Total: total deaths recorded in the micro region during the period 1996-2018.

Source: Authors.

Table 2. Relative risk and 95% confidence intervals for mortality from cerebrovascular diseases in the 10 micro regions (1996-2017),

Micro region	Mean pop,	MMT (ºC)	Extreme cold	Moderate cold	Moderate heat	Extreme heat
Belém	2,047,823	29.6	1.14 (0.82-1.58)	1.12 (0.83-1.5)	1.08 (0.84-1.39)	1.03 (0.93-1.15)
Manaus	1,874,377	26.9	1.53 (1.22-1.91)	1.34 (1.11-1.63)	1.40 (1.14-1.72)	1.75 (1.35-2.26)
Fortaleza	3,181,555	26.6	1.21 (1.04-1.41)	1.04 (0.96-1.12)	1.08 (0.96-1.22)	1.10 (0.96-1.26)
Salvador	3,367,078	24.7	1.04 (0.89-1.21)	1.02 (0.91-1.14)	1.14 (0.99-1.3)	1.19 (1.01-1.4)
Brasília	2,411,607	23.3	1.13 (0.95-1.33)	1.07 (0.92-1.23)	1.24 (1.05-1.46)	1.36 (1.15-1.60)
Campo Grande	820,080	23.6	1.52 (1.18-1.94)	1.19 (0.96-1.47)	1.11 (0.92-1.34)	1.14 (0.91-1.43)
Rio de Janeiro	11,210,710	25.1	1.22 (1.15-1.3)	1.13 (1.08-1.19)	1.11 (1.07-1.16)	1.29 (1.22-1.37)
São Paulo	13,468,222	23.4	1.25 (1.17-1.34)	1.15 (1.09-1.22)	1.04 (1.01-1.06)	1.17 (1.11-1.24)
Curitiba	2,977,460	20.1	1.52 (1.32-1.74)	1.31 (1.16-1.47)	1.07 (0.94-1.22)	1.07 (0.93-1.22)
Porto Alegre	3,598,691	21.6	1.28 (1.14-1.43)	1.16 (1.05-1.28)	1.15 (1.05-1.27)	1.38 (1.24-1.54)

MMT: minimum mortality temperature (ºC), Mean pop,: mean population of the micro region between 1996 and 2017.

Source: Authors.

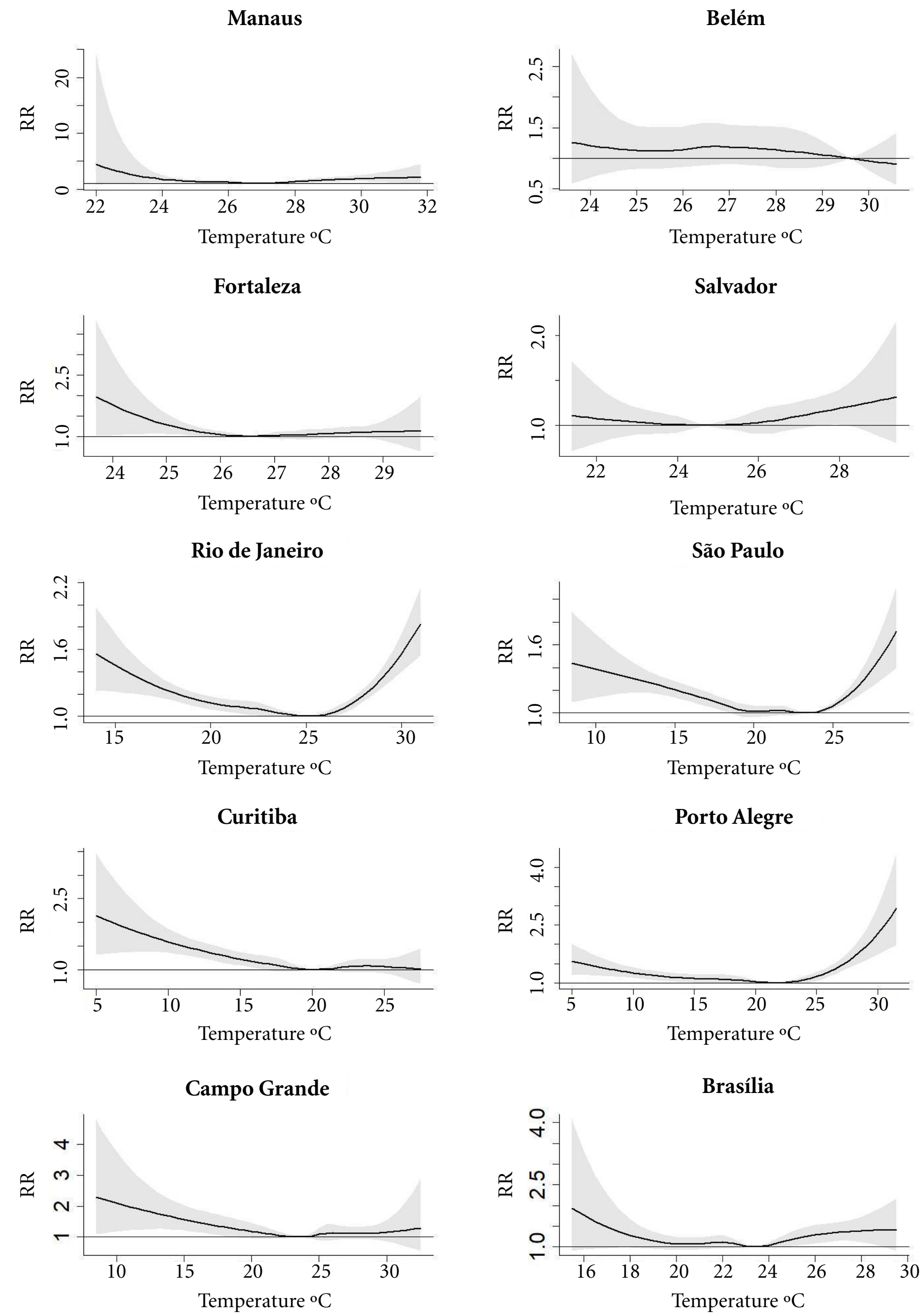

Figure 2. Relative risk and 95% confidence intervals for mortality from cerebrovascular diseases in the 10 micro regions (1996-2017).

Note: RR = relative risk. Shaded areas represent 95%CI.

Source: Authors.

Discussion

This is the first study in Brazil to carry out a comprehensive nationwide analysis of the relationship between mortality from cerebrovascular diseases and air temperature. The findings show an association between mortality and both low and high temperatures across all of Brazil's five regions. Nine of the 10 micro regions showed a high risk of mortality attributable to temperatures above or below the MMT. The findings show that 1,218 deaths per year could have been avoided in the 10 micro regions by adopting preventive measures to minimize exposure to temperature extremes. It is important to stress that this number is even more alarming when these results are extrapolated nationally, further reinforcing the hypothesis that air temperature is a major risk factor for cerebrovascular diseases.

Previous studies have shown an association between low and high air temperatures and increased mortality in different regions around

Table 3. Attributable fraction (%) and 95% confidence intervals, and temperature-attributable deaths from cerebrovascular diseases in the 10 micro regions (1996-2017).

Micro region	Extreme cold	Moderate cold	Mild cold	Mild heat	Moderate heat	Extreme heat	Total
Temperature-attributable fraction (%)							
Belém	-	-	-	-	-	-	-
Manaus	0.9 (0.4-1.3)	2.0 (1.0-2.8)	8.4 (1.9-14.3)	3.1 (0.9-4.9)	2.9 (1.6-4.0)	1.3 (0.8-1.8)	-
Fortaleza	0.6 (0.1-1.0)	-	-	-	-	-	-
Salvador	-	-	-	-	-	-	-
Brasília	-	-	-	2.1 (0.2-3.9)	1.8 (0.8-2.8)	0.7 (0.3-1.0)	-
Campo Grande	1.2 (0.7-1.7)	1.9 (0.3-3.2)	-	-	-	-	-
Rio de Janeiro	0.7 (0.5-0.9)	1.1 (0.8-1.5)	3.3 (1.2-5.2)	0.6 (0.1-1.1)	1.1 (0.8-1.4)	0.8 (0.6-0.9)	-
São Paulo	0.7 (0.4-0.9)	1.3 (0.9-1.7)	-	-	0.6 (0.4-0.8)	0.5 (0.4-0.7)	-
Curitiba	1.2 (0.8-1.5)	2.4 (1.7-3.1)	5.1 (0.6-9.4)	-	-	-	-
Porto Alegre	0.8 (0.5-1.1)	1.5 (0.8-2.2)	3.7 (0.0-7.0)	-	1.3 (0.88-1.9)	1.0 (0.8-1.2)	-
Temperature-attributable deaths							
Belém	-	-	-	-	-	-	-
Manaus	123 (62-167)	256 (124-373)	1.098 (167-1861)	398 (135-630)	376 (212-508)	174 (98-227)	2.425
Fortaleza	186 (31-296)	-	-	-	-	-	186
Salvador	-	-	-	-	-	-	-
Brasília	-	-	-	392 (12-714)	342 (120-515)	130 (56-189)	864
Campo Grande	114 (59-155)	179 (34-294)	-	-	-	-	293
Rio de Janeiro	1.108 (792-1411)	1.922 (1291-2477)	5.491 (2166-8747)	1.079 (178-1968)	1.852 (1353-2325)	1.286 (1034-1518)	12.738
São Paulo	1.005 (664-1293)	1978 (1393-2588)	-	-	891 (572-1211)	840 (585-1079)	4.714
Curitiba	374 (244-472)	766 (523-982)	374 (248-465)	1.615 (186-2906)	-	-	3.129
Porto Alegre	426 (239-584)	794 (410-1156)	-	-	708 (406-1002)	528 (406-637)	2.456

Blanks indicate micro regions where no association was found for the temperature interval.

Source: Authors

the world[6,19-21]. A systematic review of 20 international studies investigating the relationship between stroke and both low and high temperatures published in 2015 corroborates our main findings. Lian *et al.*[2] concluded that, at high temperatures, a 1°C increase in temperature led to a 1.5% increase in death from stroke, while in the cold the increase was 1.2%[2].

Gasparrini *et al.*[20] collected data from the period 1985-2012 for 384 locations across all continents except Africa. The findings show that more deaths were attributable to cold than heat, with extreme cold and extreme heat accounting for 0.86% of total deaths from stroke. Studies in other regions, including China, Ireland, Iran and the US, found similar outcomes, with increased mortality from stroke being higher in the cold[4,7,22-24]. A study in Porto Rico[25] reported that stroke and cardiovascular diseases were the primary causes of death associated with high summer temperatures, while Royé *et al.*[26] showed that higher risk of mortality from stroke in Spain was associated with high temperatures[26].

A number of studies in China have addressed this issue[4-7,27-29], with elevated relative risk at non-optimal temperatures demonstrating that both hot and cold temperatures are risk factors for mortality from stroke in the country[4,5,7]. As in the present study, other studies in China found that that relative risk was higher at extreme temperatures[6,7]. However, moderate temperatures accounted for most deaths, followed by extreme temperatures[4]. This is also consistent with the findings of the present study and may be explained by the fact that the number of days with moderate temperatures was greater than the number with extreme temperatures. The results of a study in India show that attributable risk was higher for mortality from stroke and all other causes at moderately cold temperatures, reinforcing the need for health interventions to focus on both moderate and extreme temperature events[30].

Few studies in Brazil have investigated the relationship between air temperature and morbidity and mortality from cerebrovascular diseases. A time-series study in São Paulo of the period 2002-2011 found an association between mortality from stroke and air temperature, reporting increased risk at temperatures below 10°C[31], especially for hemorrhagic strokes. These findings are consistent with the results of the present study for this micro region. Another study with patients admitted to two different hospitals in São Paulo for strokes or heart attacks over a two-year period showed that 2.8% and 4.9% of admissions, respectively, were due to high temperatures and found associations between the outcomes and air pollution[32]. A time-series analysis of the period 1996-2013 in six micro regions distributed across Brazil's five regions found similar results to the present study, reporting a relationship between air temperature and mortality from heart attacks. The findings reveal increased risk at both low and high temperatures, particularly in the South and Southeast. Although this study analyzed mortality from heart attack rather than cerebrovascular diseases, comparisons can be made with the present study due to the major similarities between the pathology of these diseases[33].

Considering the diversity of this huge country, there are various plausible explanations for the findings of the present study, including the country's different climates. The climate of each micro region was defined based on the Köppen-Geiger climate classification[34].

In the North, an association was found in Manaus, but not in Belém. The two micro regions are part of the same homogeneous group when it comes to location and climate, as they are both located in the Amazon and have a humid equatorial climate[35]. Notable findings in these regions are the low number of mean daily deaths from cerebrovascular diseases and days with extreme temperatures. Another important factor in this region is health care. A survey of intensive care unit (ICU) bed numbers conducted by the Federal Council of Medicine in 2018 showed that the state of Amazonas (Manaus) has 2.40 beds per 10,000 inhabitants, compared to 4.51 in the state of Pará (Belém). This difference in ICU bed numbers may be a possible cause of the association found in Manaus, as cerebrovascular diseases are acute conditions requiring intensive care[36].

In the Northeast, associations were found in both Fortaleza and Salvador. In Fortaleza, extreme cold was associated with a relative risk of 1.21. Understanding the climate of this micro region can help explain the findings. Fortaleza has a tropical savanna climate with dry winter (Aw)[37] and showed the highest daily mean temperatures among the 10 micro regions and lowest variation in temperature (SD 0.9). It is therefore possible that exposure to extreme cold was the factor that most influenced mortality from cerebrovascular diseases, as the bodies of people living in this region are physiologically adapted to high temperatures and more susceptible to low temperatures. Salvador on the other hand showed an association with extreme heat. Despite both

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cities being located in the Northeast, the two micro regions have significantly different climates. Although Salvador has a tropical rainforest climate (Am)[38], mean air temperature is lower than in Fortaleza. Frequent episodes of mild temperatures associated with cold fronts may explain the findings in Salvador.

In the Center-West, Brasília showed an association with extreme heat and moderate heat. The climate in the country's capital is classified as equatorial savannah (Aw)[37] and, due to its location in the middle of country and continentality, the city has higher temperatures, which may have been a more pronounced risk factor in this region. Another important factor in various state capitals in Brazil are the effects of urban heat islands. A study showed that these effects are particularly pronounced in Brasília due to an intense process of urbanization in satellite cities, deforestation and soil exposure[39]. Campo Grande, on the other hand, located further south in the Center-West region, showed an association with extreme cold. Despite having the same climate as Brasília[38], the capital of Mato Grosso do Sul has specific characteristics that can help explain the result observed for this city. While Campo Grande has a generally high mean temperature, temperatures in the winter can be very low, similar to those in cities in the South.

In Rio de Janeiro and São Paulo, the most populous state capitals in the Southeast, risk of death from cerebrovascular diseases was higher in both cold and hot periods. In both São Paulo, which has a humid subtropical climate (Cfa)[39], and Rio de Janeiro, which has a tropical wet-dry climate (Aw)[39], frontal systems and air masses are common, creating distinct trends in air temperature throughout the year. This results in higher variability in temperature, illustrated by a high standard deviation in the air temperature data. However, the climates of the two regions have significant differences. São Paulo has a greater daily thermal amplitude due to continentality. Polar masses have a pronounced effect, causing sharp cold spells. Rio de Janeiro on the other hand has a lower daily and annual thermal amplitude because it is on the coast, meaning that the population is also more susceptible to cold.

The micro regions with the lowest mean temperatures are located in the South, which has a humid subtropical climate (Cfa)[40]. Porto Alegre showed an association with both cold and heat, while Curitiba showed an association with extreme and moderate cold. A possible explanation for these differences is that mean maximum temperatures were much higher in Porto Alegre than Curitiba, which is partially due to the difference in altitude between the two cities. Curitiba has an altitude of 900 meters above sea level, compared to only 47 meters in Porto Alegre[39]. In addition, heat waves are more frequent and intense in Porto Alegre than in Curitiba[39].

Although the present study did not stratify the population data by age and demographic characteristics, evidence from other studies suggest that the groups that are most vulnerable to death from cerebrovascular diseases at non-optimal temperatures are older persons, women, and people with a low level of education[5,27,28]. A study in China showed that men and older persons were the most affected and that the proportion of temperature-related deaths decreased with decreasing latitude[4]. Another study in China also showed that people living in rural areas were more vulnerable to the effects of heat waves on mortality from stroke[29].

Study limitations include the fact that the use of secondary air temperature data ignores the presence of microclimates that can influence apparent temperature in each micro region. In addition, external air temperature does not necessarily correspond to the air temperature felt by individuals, which is influenced by air conditioning and other factors that affect internal ambient temperature. Finally, we did not distinguish between hemorrhagic and ischemic strokes, as some other studies did[5,31,41].

Given the significant impact of extreme and moderate air temperatures on cerebrovascular disorders among the Brazilian population, it is important to stress the importance of stroke prevention measures. In this regard, heat wave and cold spell early warning systems have been adopted in various regions around the world with the aim of reducing morbidity and mortality caused by variations in weather, especially among vulnerable populations[10,11,42-47]. These warnings allow individuals to prepare themselves and adapt their homes and daily activities to minimize exposure to extreme temperatures. Although only 9% of Brazilian homes have air conditioning[48], the use of these devices appears to be an effective strategy for reducing heat-related deaths[49] as they regulate internal temperatures and reduce heat stress[50]. In addition to warning systems, effective communication campaigns and education initiatives are needed to raise awareness about the health effects of climate[43-45,47].

Conclusion

The findings of this analysis of 10 micro regions located in Brazil's five regions show that both low and high non-optimal air temperatures are associated with increased risk of death from cerebrovascular diseases. Preventive and health education measures tailored to local demographic and climate characteristics, such as early warning systems, the provision of information on this problem to health professionals, and the use of air conditioning, should be adopted across different regions in order to reduce mortality from these diseases in Brazil.

Collaborations

MS Mascarenhas, DD Silva, MC Nogueira, CCM Ferreira and LCM Ferreira contributed to the study design; analysis and interpretation of data; writing the article and final approval of the version to be published. WCM Farias contributed to the study design; analysis and interpretation of data; relevant critical review of the intellectual content and final approval of the version to be published.

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