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Association between racial residential segregation and homicide mortality in municipalities in Minas Gerais, Brazil

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Abstract *This article aims to evaluate the association between racial residential segregation and homicide mortality in the state of Minas Gerais (MG), Brazil. We conducted an ecological study in which the units of analysis were municipalities in MG. The outcome was homicide deaths between 2008 and 2012 and the exposure variable was residential segregation measured using the racial interaction index, calculated using data from the 2010 Demographic Census. The covariables were per capita family income and the Gini index. The variables were presented in tables and thematic maps and associations were measured using Bayesian hierarchical models. The results of the model adjusted for per capita family income showed a negative association between the racial interaction index and homicide mortality (coefficient=-1.787; 95%CI=-2.459; -1.119). Homicide mortality was lower in municipalities with higher levels of racial interaction.*

Key words *Social segregation, External causes, Spatial analysis, Health disparities*

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Introduction

One of the social determinants of health that has drawn interest from researchers recently is residential segregation, which is the separation of people and exclusion of segments of society for economic, social, cultural, racial, ethnic, or other reasons[1]. The perception that individual factors alone do not fully explain the health-disease process generated interest in the study of the context in which people live. The study of neighborhood characteristics allows scholars to study this context because neighborhoods possess both social and physical attributes that are potentially determinants of health. An area of special interest is the study of social and racial inequalities in health, because place of residence is strongly patterned by social status position and ethnicity. To have an impact on living and working conditions, intersectoral health promotion initiatives should focus on the context in which people live[2]. Measures of local residential segregation have high sensitivity for detecting associations with health outcomes[3].

Residential segregation is a multidimensional phenomenon. While segregation measures show the extent to which groups are separated throughout a space, dimensions illustrate different aspects of this separation, although there may be a high degree of overlap between measures at an empirical level. The dimension "exposure" refers to the degree of potential contact between social group members within residential areas and one of the most widely used measures of exposure in the interaction index[4].

In Brazil, external causes are the third leading cause of death, with homicide and transport accidents being the most common external causes of death among the one to 49-year age group. Brazil has the third highest *homicide rate in South America*, with rates being up to 10 times higher than in middle and high-income countries[5].

Violence has a substantial impact on health systems, the economy and physical and emotional health. Homicide rates vary greatly across the country, with the highest rates being found in the North and Northeast. Mortality due to external causes disproportionately affects young men and is compounded in contexts of structural inequality and criminality[5,6]. There are also substantial spatial variations in homicide and violent crime rates in the state of Minas Gerais[7].

Despite the importance of this issue, we were unable to find any empirical studies in Brazil investigating the relationship between residential segregation and homicide mortality. Considering the importance of this cause of death and its relationship with social context, the aim of this study was to estimate the association between the racial interaction index and homicide rate in municipalities in Minas Gerais (MG), a large state characterized by substantial regional differences that reflect to some extent national differences.

Methods

We conducted a cross-sectional ecological study in which the units of analysis were municipalities in Minas Gerais (MG). The dependent variable (outcome) was the total number of homicide deaths in the period 2008 to 2012. This data was obtained from the Mortality Information System (SIM) via the website of the country's national health information system, DATASUS, accessed on 27/11/2019. We used a five-year period for mortality data to reduce small area-related random variation, because many municipalities have small populations and few deaths.

The exposure measure was racial interaction index (RII), which represents the exposure dimension of residential segregation[4]. The indicator, which ranges from a low of 0 to a high of 1, was estimated for each municipality using data from the 2010 Demographic Census. The data were downloaded from the statistics page of the site of the Brazilian Institute of Geography and Statistics (https://www.ibge.gov.br/estatisticas/downloads-estatisticas.html) on 10/11/2019. On this page, we selected the directory Census, followed by Demographic_Census_2010, Universe_Results, and finally Breakdown_by_Census_Tract. From the latter, we downloaded the compacted file "MG_20171016.zip", using the file "People03_MG.csv" to obtain the total number of residents by race/color (variables v001 to v006) in each census tract. The data were then aggregated into municipalities, because the calculation of the municipal racial interaction index requires data at both census tract and municipal level. Race/color was divided into two categories: "black" (total number of "black" and "brown" individuals); and "white". RII was calculated using the following equation[8]:

$$RII = \frac{\sum_i^n \left| \frac{b_i}{B} \times \frac{a_i}{t_i} \right|}{2}$$

Where: RII=racial interaction index; a_i=population of group A (white) in sub-area i; b_i=pop-

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ulation of group B (black) in sub-area i; B=population of group B in the larger area; t_i=total population in sub-area i; sub-area=census tracts; larger area=the municipality.

The covariables per capita family income and Gini index in 2010 were used in the analyses to control for confounding. This data was also obtained from the 2010 Demographic Census.

The statistical distribution of the variables was presented in tables. We also created thematic maps showing the distribution of indicators across quintiles and estimated global Moran's I, which is a measure of general spatial correlation[9].

We estimated standardized mortality ratios (SMR) by dividing the number of observed deaths (O_i) by the number of expected deaths (E_i) in each municipality[9]. To account for the differences in age structure between municipalities, expected deaths were estimated based on the total expected deaths in each age group obtained by multiplying the age-specific rates for the state ($r_j^{(s)}$) by the population of the specific age group in each municipality (n_j):

$$E_i = \sum_{j=1}^{m} r_j^{(s)} n_j$$

Where: E_i=expected deaths in each municipality i; r_j=mortality rate for each specific age group j; n_j=population in each specific age group j.

To determine the association between RII and homicide deaths, we ran Bayesian hierarchical models, estimating unstructured random effects (to adjust for overdispersion and capture the effects of unmeasured factors) and structured spatial random effects (to adjust for spatial dependence between observations). The spatially structured component was modelled with the conditional autoregressive (CAR), which smoothes the data according to a certain adjacency structure given by a neighborhood matrix that specifies two areas are neighbors if they have a common boundary[10].

Expected deaths (E_i) were used as an offset variable in the models so that SMR could be estimated for each municipality, calculated by dividing observed deaths (O_i) by expected deaths (E_i) and adjusted by the covariables. Bayesian estimation was performed using the Integrated Nested Laplace Approximation (INLA) approach with the INLA library (http://www.r-inla.org/) of the R program (https://cran.r-project.org/). We stipulated a non-informative prior distribution, which is used when data is expected to exhibit dominance in the adjusted models. We ran models with and without the covariables (per capita income and Gini index). The tables present the means and 2.5 and 97.5 percentiles of the posterior distribution (95% credible interval - CI95%) for each coefficient. The deviance information criterion (DIC) was used to select the final model. The model is expressed as follows:

$$y_i | \varphi_i, \upsilon_i \sim NB(\mu_i, \theta_i)$$

$$log(\mu_i) = log(e_i) + log(\rho_i) = log(e_i) + \beta_0 + \beta_1 x_{i1} + \varphi_i + \upsilon_i$$

$$\varphi_i \sim N(0, \sigma_\varphi^2)$$

$$\upsilon_i \sim CAR(\sigma_\upsilon^2)$$

$$SMR = \rho_i = e^{\beta_0 + \beta_1 x_{i1} + \varphi_i + \upsilon_i}$$

Where: y=observed response variable (deaths); μ=estimated mean of the response variable; θ=estimated model parameters; e=expected value for the response variable; SMR=ρ=estimated standardized mortality ratio; x=explanatory variable; β=coefficients estimated by the model; σ=variance; φ=unstructured random effect; υ=structured spatial effect.

The data were tabulated in TabWin 4.1.52 and all analyses were performed using R 3.5.2.

Results

The SMR for homicide ranged between 0 and 4.67 (median 0.50). Per capita family income ranged between R$ 168 and R$ 1,710 (mean R$ 482), while the mean Gini index was 0.48 (standard deviation 0.05). The mean racial interaction index (RII) was 0.43 (standard deviation 0.05). All the variables had positive spatial autocorrelation, with higher values for RII, per capita family income and SMR (Table 1).

All the indicators showed an uneven *spatial distribution*. The SMR was higher in municipalities in the north and center of the state, which were also areas with a lower racial interaction index and per capita family income (Figure 1).

The selected regression model (the model with the lowest DIC) was model C2, which included the variables RII and per capita family income and unstructured random and structured spatial effects. There was a negative association between the RII and risk of death, where the greater the racial interaction at municipal level the lower the risk of death from homicide (Table 2). Exposure variable-adjusted SMR had

a similar distribution to the non-adjusted SMR, suggesting that the model effectively captured the distribution (Figure 2). Figure 3 presents the posterior distribution of the coefficients from model C2, with most of the distribution lying outside the null value, corroborating the significance of the effects.

Table 1. Statistical distribution and spatial autocorrelation (Moran's I) of the variables.

	Minimum	Q1	Q2	Mean	SD	Q3	Maximum	MI
Standardized mortality ratio	0.00	0.20	0.50	0.59	0.55	0.80	4.67	0.44
Racial interaction index	0.08	0.27	0.41	0.43	0.18	0.56	0.90	0.87
Per capita income (R$)	168	351	467	482	170	582	1710	0.55
Gini index	0.33	0.44	0.48	0.48	0.05	0.51	0.78	0.15

Q1: percentile 25. Q2: median. Q3: percentile 75. SD: standard deviation. MI: Moran's I; p-value<0.05 (obtained with 1,000 permutations).

Source: Authors.

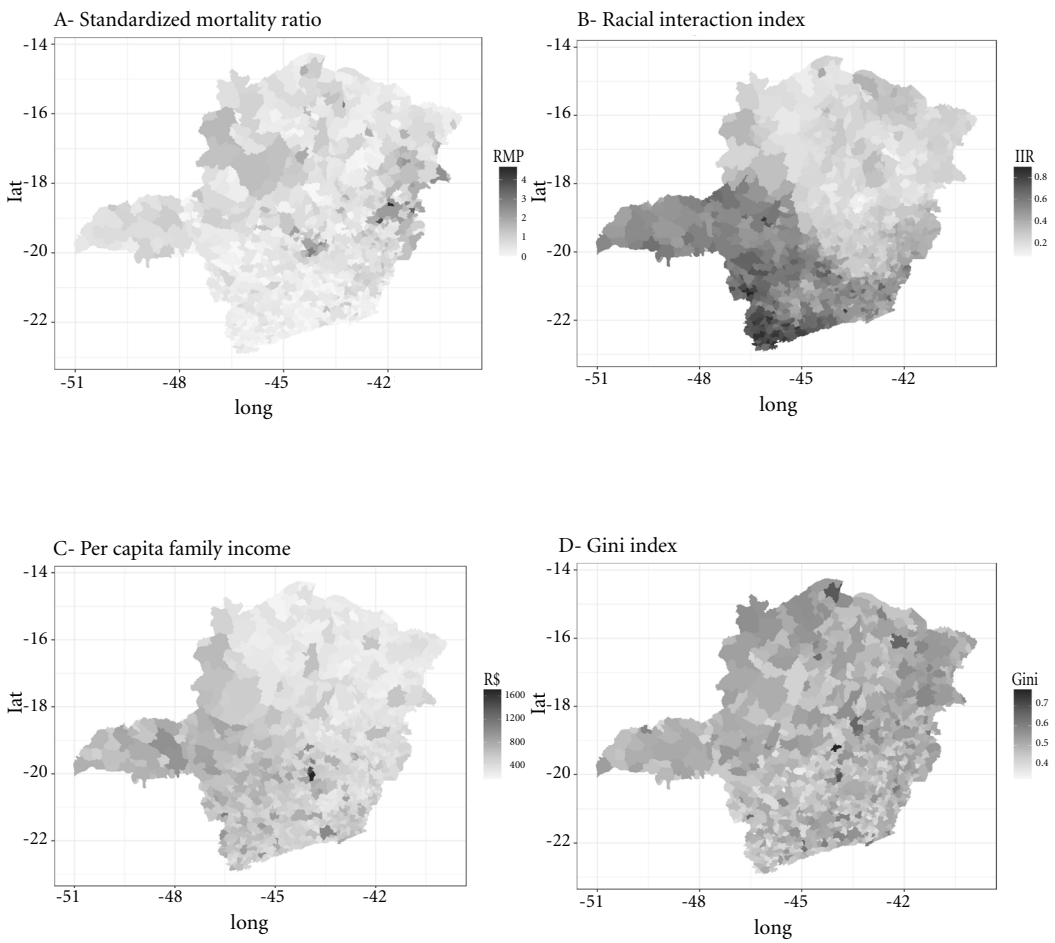

Figure 1. Spatial distribution maps of the variables in municipalities in Minas Gerais.

Source: Authors.

Discussion

This was the first study in Brazil to identify an association between greater racial interaction at municipal level and lower homicide mortality. In a literature review of the contextual causes of homicide, the studies analyzed showed that a wide range of social factors, including the Gini index, income and indicators of poverty, were associated with homicide rates, but none investigated indicators of residential segregation[11].

The social context in which people live and work is an important determinant of health. In her classic article, Schwartz pointed out how the methodological individualism in epidemiological studies led to a relative ignorance of the importance of this factor, consequently compromising the effectiveness of disease prevention and control measures[12]. In another classic work, Diez-Roux called for the development of disease causation models incorporating multiple levels of determination, include the structural factors influencing the health-disease process[13]. More recently, other authors have made considerations along the same lines, highlighting the need for epidemiological research to investigate the structures and networks of causes that underlie disease, rather than the isolated effects of single exposures[14]. The authors of a systematic literature review highlighted the recent growth in research on the effects of neighborhood context on health, focusing on areas such as mental health and violence[15]. Some studies have shown that socioeconomic and racial residential segregation is an important contextual factor causing health disparities[3,16-18].

The leading external cause of mortality in high-income countries is suicide, followed by transport accidents and falls. In contrast, the leading causes in middle and low-income countries in the Americas are homicide and transport accidents. Evidence suggests that poverty is a risk factor for external cause-mortality, manifested in the form of poor living, work and transport conditions[19]. Studies in the United States have observed that risk factors for violent death include belonging to minority groups, low community cohesion, criminality, and use of substances, primarily alcohol[20]. Another study found an association between residential segregation and increased fatal interactions with the police[21]. In addition, neighborhood factors such as criminality,

Table 2. Results of the regression models: mean and percentiles 2.5 and 97.5 of the posterior distributions of the model coefficients.

Models	IIR	Income	Gini	DIC
A1	-2.229			9543.68
	(-2.336; -2.123)			
A2	-2.930	0.728		8439.37
	(-3.052; -2.809)	(0.691; 0.765)		
A3	-3.612	1.370	-4.729	7818.15
	(-3.747; -3.479)	(1.307; 1.434)	(-5.093; -4.366)	
B1	-1.993			4106.45
	(-2.297; -1.690)			
B2	-2.576	0.988		4089.10
	(-2.936; -2.219)	(0.666; 1.312)		
B3	-2.563	0.977	0.100	4089.50
	(-2.951; -2.177)	(0.632; 1.323)	(-0.960; 1.164)	
C1	-1.427			4019.45
	(-2.080; -0.776)			
C2	-1.787	0.815		4001.63
	(-2.459; -1.119)	(0.520; 1.112)		
C3	-1.785	0.806	0.043	4002.39
	(-2.459; -1.113)	(0.427; 1.186)	(-1.065; 1.150)	

RII: racial interaction index. DIC: deviance information criterion. Models A: without random effects. Models B: with unstructured random effect. Models C: with unstructured random and structured spatial effects. Best model: C2 (lowest DIC).

Source: Authors.

low income and Gini index, high proportion of Afro-Americans and single parent families, and unemployment rate have a negative influence on criminality. In contrast, number of families living in their own home, social cohesion and informal participation have been shown to reduce violent crime[22]. In low and middle-income countries, income inequality was associated with homicide, self-reported assault and robbery[23]. A study of 10 Latin American countries, including Brazil, Colombia, Ecuador and Mexico, found that if deaths from external causes were prevent-

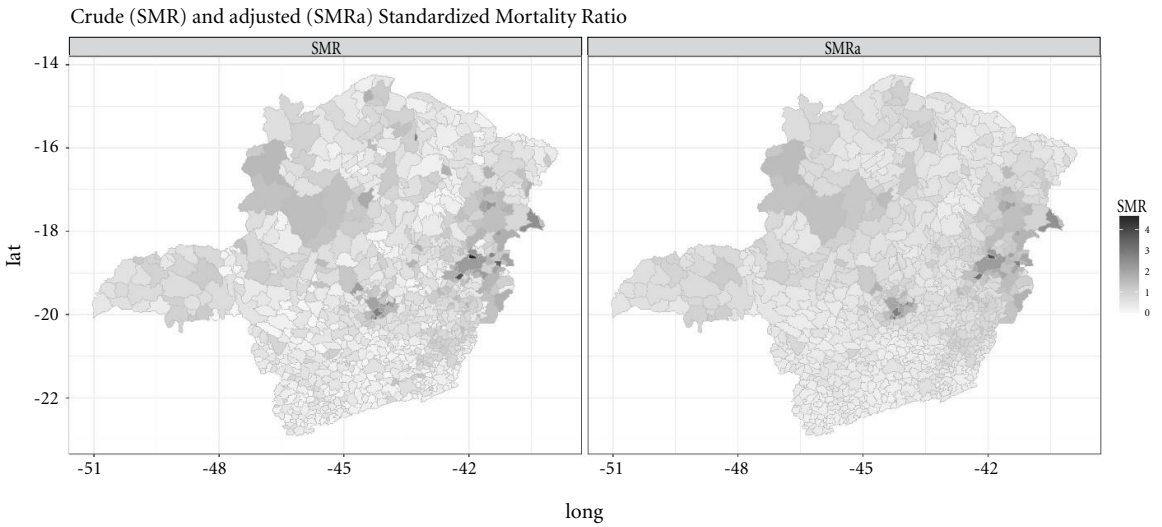

Figure 2. Spatial distribution maps of crude (SMR) and adjusted (SMRa) standardized mortality ratios in municipalities in Minas Gerais.

Source: Authors.

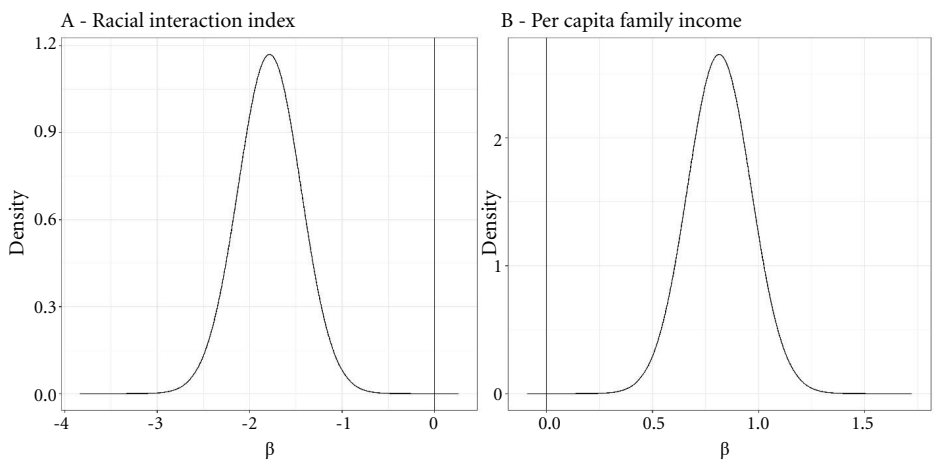

Figure 3. Posterior distributions of the coefficients from the C2 regression model.

Source: Authors.

ed, these countries would increase the number of years lived in adulthood in the future[24].

Various individual factors are associated with higher frequency of cases of violence and deaths from external causes in Brazil, including being male, young, black and single, having a low income and level of education, and poor living conditions. From a social context perspective, engagement in illegal activities such as drug trafficking, receiving stolen goods, and land invasion, and lack of state presence are some of the main factors responsible for increased rates of death form external causes in Brazil[6]. Residential segregation results in the formation of neighborhoods with high levels of poverty, contributing to an increase in mortality[25]. Other factors include intrafamily violence, unemployment, lack of public security, police violence, and urbanization. Living in *favelas* has also been associated with higher rates of homicide mortality, regardless of sex or age[6].

In addition, austerity policies, especially in a context of economic crisis, can affect outcomes related to external causes of death. In this regard, a study reported an increase in homicide mortality and suicide across Brazil during the financial crisis starting in 2014, with increases being more pronounced in the North and Northeast[26].

In Brazil, external causes are the third leading cause of death[5]. The country witnessed a downward trend in homicides among men between 2005 and 2016, despite regional differences: stable rates in the North and Mid-West, increased rates in the Northeast, and reductions in the Southeast and South[27]. It is possible that public policies such as the Disarmament Statute have contributed to curbing the rampant growth in mortality from firearms in the country[28]. In contrast, however, the homicide rate among young people and number of female homicides increased between 2007 and 2017[29]. The country has witnessed a trend towards the "interiorization" of homicide mortality, with large cities in the Southeast like Rio de Janeiro and São Paulo seeing a substantial reduction, while inland states such as Minas Gerais have observed a rise, especially in smaller cities in the mid-north of the state close to the border with Bahia. Smaller municipalities have seen an increase in homicide rates, while those with more than 100,000 inhabitants have witnessed the opposite[30].

A study in three state capitals (including Belo Horizonte, the capital of Minas Gerais) investigated population distribution by race/color and level of education using the index of dissimilarity. The findings show that the population of urban peripheries was predominantly black, while the population of areas with better infrastructure in city centers was predominantly white. The study also reported that people who self-declared as black or brown were more likely to live in areas with poorer socioeconomic indicators and higher levels of segregation[31]. Another study comparing residential segregation by race in 40 of the country's biggest metropolitan areas reported that residential segregation between white and brown people and brown and black people reduced between 1980 and 2010, especially in areas with poorer housing. However, levels of segregation remain high in high-income groups, who have access to a wider variety of housing options[32].

Although we did not find publications addressing the association between residential segregation indices and homicide mortality in Brazil, there are studies investigating other health outcomes. One of these studies, which performed an analysis adjusted for other sociodemographic factors, reported an association between residential segregation and higher prevalence of hypertension and diabetes mellitus. The findings show that black and brown people were more likely to live in segregated neighborhoods than white people. According to the authors, residential segregation is a cause of income and racial health inequalities and has a negative impact on health, as segregation is not restricted to people, but also encompasses the segregation of infrastructure and health resources, limiting access to health services among the segregated population[18].

A study that explored the relationship between lethal police violence and socioeconomic development in São Paulo reported the existence of racial and social biases in this association. The findings demonstrate the existence of spatial clusters with high levels of mortality and different characteristics: the victims' place of residence tended to be located in areas with lower HDI, while the place of occurrence of violent events tended to be in areas with higher HDI[33].

Some studies have assessed the effect of public policies on residential segregation and its social and health consequences. Approaches focusing on early childhood interventions have demonstrated that starting early in local communities can have life-long positive impacts on health and the social determinants of health. The evaluation shows that poor and minority families respond to interventions and take advantage of real opportunities, resulting in an increase in income and improved safety and physical and

mental health[34]. On the other hand, housing policies can drive residential segregation, through the construction of more affordable housing in more isolated areas that tends to be bought by lower income groups. Improvements in infrastructure and transport in these areas commonly fail to be implemented, making the integration of populations living in these areas and those in more central regions even less viable[35]. Studies suggest that relocating people from their neighborhood is not the ideal policy. Rather emphasis should be placed on improving living conditions in poor areas.

The main limitation of this study is the use of secondary data that may have been subject to shortcomings in the data collection and/or processing stages. It is also possible that deaths were underreported, especially in municipalities located in poorer regions of the state. However, it is important to stress that the sources used were DATASUS and the Demographic Census, both of which are official government databases and widely used in epidemiological studies and subject to constant data quality monitoring. One of the advantages of using these sources is that they encompass the whole population of the state of Minas Gerais, thus reducing the likelihood of selection bias. Another limitation in that cross-sectional studies are limited in their ability to determine the cause-and-effect relationship between variables. In this regard, the associations found by the present study raise the hypothesis that there is a causal relationship. This relationship should be tested by future longitudinal studies.

This study observed the presence of racial residential segregation in municipalities in Minas Gerais and that segregation was associated with homicide mortality, showing that this factor should be taken into account in violence prevention and control polices in the state.

Collaborations

All authors participated in the conception, planning, analysis, interpretation and writing of the work, and approved the final version.

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