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ORIGINAL ARTICLE

Impact of social distancing on the transmission of COVID-19 in the state of Espírito Santo

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Open acess

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Abstract

Introduction: in Brazil, non-pharmacological measures were put into practice to reduce the transmission of SARS-CoV-2.

Objective: evaluate the effect of Social Distancing on the incidence of COVID-19 in the municipalities of Espírito Santo.

Methods: ecological study by regional aggregate to evaluate the effect of SD by the Work Mobility on the adjusted municipal incidence rate of COVID-19 in Espírito Santo from March 2020 to December 2022.

Results: Covid incidence rates were positively associated with Work Mobility (β:0,028; IC: -0,010; 0,047). When stratified by health region and density tertiles, only the South region and the tertile with the highest demographic density maintained the association.

Conclusion: the adoption of Social Distancing measures should incorporate demographic density as a vulnerability criterion in future epidemiological risk situations.

Keywords: social distancing; SARS-CoV-2, COVID-19, public health.

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Authors summary

Why was this study done?
The study was conducted to assess the effects of social distancing (SD) practices on municipal COVID-19 incidence rates in Espírito Santo, Brazil.

What did the researchers do and find?
The authors developed an ecological study by regional cluster using panel models of the time series of municipal incidence rates correlated with labor mobility rates covering the years 2020 to 2022.COVID-19 incidence rates in Espírito Santo showed a weak association with labor mobility. When stratified by health region and density tertiles, only the South region and the tertile with the highest population density maintained the association. The findings showed that social isolation maintained an association with reduced incidence rates only in the health regions with the highest population density tertile.

What do these findings mean?
Our findings demonstrate that SD measures should incorporate population density as a vulnerability criterion in future epidemiological risk situations.

Highlights
This study demonstrates that social distancing (SD) had different effects depending on population density, being more effective only in denser urban regions of Espírito Santo, such as the south of the state and in the highest density tertile. The results suggest that public policies to combat epidemics should consider regional variations, prioritizing strict SD measures in populated areas, while in less dense regions, other strategies may be necessary, as reducing mobility did not have as significant an impact on COVID-19 incidence rates.

INTRODUCTION

In Brazil, social distancing measures were implemented based on guidelines from the Ministry of Health (MS), endorsed by the National Health Council (CNS) in its recommendation No. 036, dated May 11, 2020. In addition to social distancing as the first measure adopted by the MS, mandatory mask use was recommended[1].

In Espírito Santo, the spectrum of non-pharmacological measures to mitigate the transmissibility of SARS-CoV-2 encompassed actions known as social distancing, which included guidelines to avoid crowds, maintain a distance of at least one meter between people, and work remotely[2]. These measures would contribute to reducing the speed of transmission of the COVID-19 epidemic, allowing the healthcare system to obtain the structural and human resources necessary for adequate and timely treatment. Social distancing measures were proposed by the State Department of Health (SESA) in an ordinance dated May 23, 2020: SESA Ordinance No. 94[3]. Social distancing measures were also recommended by Decree No. 4,593-r of March 13, 2020[4], establishing a health emergency in Espírito Santo, establishing measures to contain the spread of SARS-CoV-2 infection. These measures included the suspension of classes in schools, universities, and daycare centers, restrictions on events and gatherings, the recommendation of remote work, and the closure of non-essential businesses.

For your information, the first confirmed case of COVID-19 in the state occurred on March 5, 2020, in a resident of the municipality of Vila Velha, Metropolitan Region, who had returned from a trip abroad. As of March 14, 2020, Espírito Santo had recorded 156 reported cases of coronavirus, with 54 cases ruled out, 98 under investigation, and 4 confirmed. This marked the first cases resulting from local transmission[5].

In potential epidemiological scenarios, significant challenges remain regarding the mutagenicity of respiratory viruses, such as COVID-19 infection. Therefore, future health protection initiatives must consider lessons learned in addressing potential epidemics. In this sense, this study will contribute to the analysis of the progress of COVID-19 preventive measures in general and in the state of Espírito Santo in particular. Therefore, the objective is to analyze the effect of social distancing measures, measured through the work attendance index, on the COVID-19 incidence rate in municipalities within the state of Espírito Santo.

METHODS

This is an ecological panel study, with regional aggregation, that analyzed COVID-19 incidence rates in municipalities in the state of Espírito Santo from 2020 to 2022.

Study Setting Description

The state of Espírito Santo is in the Southeast region of Brazil, bordering Bahia to the north, Rio de Janeiro to the south, Minas Gerais to the west, and the Atlantic Ocean to the east. Comprising 78 municipalities, the state is highly urbanized, with 86% of the population residing in urban areas and 14% in rural areas. According to the 2022 Demographic Census, its population is approximately 4.1 million, with an average population density of 187 inhabitants per km². For analytical purposes, the regionalization proposed by the Regionalization Master Plan (PDR-2011) was adopted, which organizes the municipalities of Espírito Santo into four health regions — North (14 municipalities), Central (18), Metropolitan (20) and South (26) — based on epidemiological, geographic and accessibility criteria[6]. This division is widely used in planning, resource allocation and public health surveillance strategies in the state.

Study Population Characterization

Exposure data were based on federal and state decrees regarding social distancing measures for COVID-19, obtained from the Google Community Mobility Report (CGMR)[7], a tool used to develop the Home Stay Index (HTI), available at: https://www.google.com/covid19/mobility/, which contains the percentage change in the average time individuals spent in their

homes, workplaces, markets, pharmacies, parks, transit, and public transportation stations compared to the average time spent for each day of the week in the pre-pandemic period. The exposure variable was operationalized by the prevalence of presence at the workplace—Workplace Mobility (WM), which measures the degree of mobility in relation to one's workplace, obtained by dividing the number of people who were present at one's workplace by the total number of people who were at the same workplace in a previous period. For municipalities with unavailable information (totaling 16 units), data imputation was performed based on the municipalities belonging to the respective health regions (North, Central, Metropolitan, and South).

The Municipal Population Density (MDD) used was obtained from data available on the website of the Department of Information Technology of the Unified Health System (DATASUS) for municipal population estimates, and from the website of the Brazilian Institute of Geography and Statistics (IBGE) (https://www.ibge.gov.br/pt/inicio.html) for the respective municipal areas expressed in square kilometers[8]. The MDD was obtained by calculating the ratio between the municipal population and its respective territorial area in km^2, transformed into a natural log to measure its strength of association with COVID-19 incidence.

Data Collection

The outcome, COVID-19 incidence rate, was extracted from the "COVID-19 Dashboard" website maintained by the Espírito Santo state government[9]. To calculate incidence rates per 100,000 inhabitants, the inclusion criteria were laboratory-confirmed cases through serological testing, rapid testing, and PCR, imaging-confirmed cases through chest computed tomography, and clinical-epidemiological criteria.

Work frequency (WF) exposure measures the degree of mobility by dividing the number of people present at the workplace by the total number of people who were in the same location in a previous period. This variable was obtained from the RMCG, as previously described. The municipal population density (DDM) covariate was calculated from the ratio between the municipal population and its respective territorial area in km^2 transformed into a natural logarithm, obtained through data available on the website of the Department of Information Technology of the Unified Health System (DATASUS), for municipal population estimates, and on the website of the Brazilian Institute of Geography and Statistics (IBGE)[8]. All variables were used continuously.

Statistical Analysis

Descriptive data were presented as proportions and 95% confidence intervals (95% CI). To assess the association between work attendance and the outcome over time, we used panel data analysis. The use of panel data allows us to compare assumptions implicit in cross-sectional data analysis[10]. We used a balanced panel model, with similar numbers of observations for each municipal unit. The cross-sectional data units allowed us to verify cross-sectional variations (between units) versus longitudinal variations (over time) and to determine whether the expected effect would occur dependently on the explanatory variables[10, 11].

The necessary adjustments led to the use of the model using the Viable Generalized Least Squares (VLSS) technique, providing adjusted estimates for AR (1) autocorrelation and heteroscedasticity. After identifying the ideal model, stratification into density tertiles was adopted due to the presence of density interactions on municipal COVID-19 incidence rates.

Statistical significance was set at $p < 0.050$, and analyses were performed using Stata software, version 18.0. Considering the disease's natural affinity for older individuals, as well as age differences among municipal populations, the incidence rate was adjusted for the total population of each health region using the direct standardization method, thus allowing for comparability of intraregional incidence rates without the influence of age differences within the populations of each municipality.

Ethical and Legal Aspects

The study was approved by the Research Ethics Committee of the Health Sciences Center of the Federal University of Espírito Santo (UFES), approved on October 10, 2023, under opinion No. 6420869, CAAE No. 73831323.2.0000.5060.

RESULTS

During the study period, 4,640,508 suspected cases of COVID-19 were identified, of which 1,314,321 (28.3%) were confirmed. The distribution was 21.22% in 2020, totaling 265,401 cases, reaching 26.9% in 2021 with 334,900 cases, and 51.8% in 2022, totaling 645,876 confirmed cases. The inter-regional distribution of cases shows a higher occurrence in the Metropolitan Region with 151,997 (57.7%) in 2020 and 177,323 (52.9%) in 2021 and 330,170 (50.9%) in 2022. However, over the years studied, it was the only health region with a decrease in the percentage of case incidence (11.0%). The other health regions showed an increasing incidence rate, with the North region showing the highest increase, at 64.0%, with 18,277 (6.9%) cases recorded in 2020, 35,126 (10.5%) in 2021, and 73,580 (11.4%) in 2022. The South health region showed smaller variations, with a 2.0% increase in the incidence rate, with 43,286 (16.4%) in 2020, 60,006 (17.9%) in 2021, and 108,268 (16.8%) in 2022 (Table 1).

In 2020, the average annual incidence rate for Espírito Santo was 25.7/100,000 population; (SD +- 37.48), whose highest values were observed in the municipalities of Cachoeiro do Itapemirim 165.57; Colatina 149.75 and Linhares 141.00. In 2021, the average rate for the state was 34.9/100,000 inhabitants. (SD +- 44.34), with the municipalities of Cachoeiro do Itapemirim with 165.57; Linhares with 141.81 and São Mateus 103.40 having the highest rates

Table 1: Case incidence, incidence rate, work attendance rate, and annual population density, 2020-2022

Municipality	COVID-19 Cases			Incidence rate*			Mobility to Work (%)			Population density (km²)		
Year	2020	2021	2022	2020	2021	2022	2020	2021	2022	2020	2021	2022
Afonso Cláudio	1.759	2.549	4.259	6.2	8.9	14.7	4.4	8.9	38.8	32.3	32.2	32.0
Água Doce do Norte	430	672	1.764	8.0	12.4	32.2	-5.0	13.2	42.6	21.1	21.1	21.1
Águia Branca	713	1.309	2.070	8.6	15.6	24.3	11.4	10.6	40.2	23.0	22.8	22.5
Alegre	912	2.652	5.748	10.8	31.1	66.8	6.8	9.2	37.4	396.0	394.6	393.2
Alfredo Chaves	1.395	1.457	2.715	16.5	17.1	31.5	-5.1	11.4	46.0	23.7	23.8	23.8
Alto Rio Novo	445	438	754	5.4	5.2	8.8	11.4	10.6	40.2	34.5	34.7	34.9
Anchieta	2.083	3.625	6.288	24.7	42.5	73.1	12.4	2.2	33.6	72.6	73.9	75.1
Apiacá	338	687	1.669	4.0	8.0	19.4	-4.7	12.7	36.3	38.9	38.8	38.8
Aracruz	8.586	8.349	21.707	104.2	99.7	255.3	10.7	10.7	44.0	72.5	73.8	75.2
Atilio Vivacqua	800	985	1.726	9.4	11.5	20.0	-6.8	8.8	14.7	51.9	52.6	53.4
Baixo Guandu	1.880	2.419	6.653	22.8	28.8	78.2	-1.9	10.4	36.9	34.2	34.3	34.5
Barra São Francisco	1.854	3.853	7.132	34.7	71.2	130.2	1.0	14.9	42.7	47.6	47.9	48.3
Boa Esperança	563	1.361	3.444	10.5	25.1	62.8	-4.1	15.7	26.3	35.2	35.3	35.4
Bom Jesus do Norte	610	672	1.760	7.2	7.8	20.4	-0.0	20.8	46.4	111.8	112.1	112.4
Brejetuba	753	1.091	1.338	2.6	3.8	4.6	-5.8	6.2	32.0	35.06	35.1	35.1
Cachoeiro Itapemirim	13.960	16.245	27.616	165.6	190.8	321.1	-5.3	8.6	32.6	243.5	245.4	247.2
Cariacica	18.136	22.802	51.322	64.8	80.1	177.6	-10.5	6.2	28.0	1.372.5	1.381.7	1.391.0
Castelo	3.183	3.831	7.884	37.7	44.9	91.6	0.3	16.2	48.0	56.8	57.2	57.52
Colatina	12.346	10.010	29.871	149.8	119.5	351.3	-5.9	11.6	30.1	88.2	88.8	89.5
Conceição da Barra	558	1.718	5.067	10.4	31.7	92.5	-3.7	5.4	37.6	26.4	26.6	26.8
Conceição do Castelo	721	1.078	1.721	2.5	3.7	5.9	-0.8	13.2	45.6	34.6	34.8	35.0
Divino São Lourenço	276	224	512	3.2	2.6	5.9	-4.7	12.7	36.3	24.5	24.3	24.1
Domingos Martins	1.978	2.973	7.300	7.0	10.4	25.2	-2.0	1.8	28.5	276.4	277.5	278.6
Dores do Rio Preto	378	461	922	4.4	5.4	10.7	-4.7	12.7	36.3	42.5	42.6	42.7
Fundão	1.154	1.985	4.213	4.10	6.90	14.50	-6.10	15.00	47.40	76.5	78.0	79.5
Gov. Lindenberg	940	1.434	2.732	11.4	17.1	32.1	11.4	10.6	40.2	35.7	36.2	36.6
Guaçuí	1.285	2.467	3.511	15.2	28.9	40.8	2.7	16.6	36.7	66.4	67.0	67.5
Guarapari	8.054	9.809	5.758	28.7	34.4	19.9	14.2	2.8	27.1	214.8	217.8	220.9
Ibatiba	1.461	3.445	3.081	5.2	12.1	10.6	0.8	12.4	48.1	109.9	111.3	112.8
Ibiraçu	1.050	982	2.888	12.7	11.7	33.9	23.6	20.6	56.3	62.5	63.1	63.6
Ibitirama	252	388	1.080	2.9	4.5	12.5	-4.7	12.7	36.3	26.7	26.6	26.6
Iconha	1.420	1.671	3.126	16.8	19.6	36.3	13.9	18.5	44.5	68.6	69.1	69.7
Irupi	665	1.210	1.641	7.8	14.2	19.0	-4.7	12.7	36.3	73.1	73.9	74.7

Continuation - Table 1: Case incidence, incidence rate, work attendance rate, and annual population density, 2020-2022

Municipality	COVID-19 Cases			Incidence rate*			Mobility to Work (%)			Population density (km²)		
Itaguaçu	958	941	3.711	3.4	3.3	12.8	-5.1	10.2	39.5	26.2	26.1	26.0
Itapemirim	2.469	2.542	5.937	29.2	29.8	69.0	-6.5	8.5	42.3	629.3	634.7	640.3
Itarana	731	1.044	2.533	2.6	3.6	8.7	-5.8	6.2	32.0	35.5	35.3	35.1
Iúna	1.108	2.533	3.261	13.1	29.7	37.9	-4.7	16.6	44.3	63.5	63.8	64.1
Jaguaré	1.812	2.980	4.600	33.9	55.1	83.9	-1.4	9.8	44.7	47.0	47.8	48.7
Jerônimo Monteiro	552	1.168	3.564	6.5	13.7	41.4	-4.7	12.7	36.3	69.1	69.5	69.9
João Neiva	1.354	1.647	4.018	16.4	19.6	47.2	14.8	29.5	71.3	58.7	58.9	59.1
Laranja da Terra	283	1.016	2.440	1.0	3.5	8.4	-5.8	6.2	32.0	238.5	238.2	237.9
Linhares	11.691	18.208	27.937	141.8	217.4	328.5	-5.5	16.1	40.6	50.5	51.4	52.3
Mantenópolis	467	645	1.452	5.6	7.7	17.0	-1.4	10.6	40.2	48.2	48.7	49.1
Marataízes	3.287	4.439	7.021	38.9	52.1	81.6	-5.1	8.8	35.2	298.4	301.3	304.3
Marechal Floriano	1.793	2.219	3.698	6.4	7.8	12.8	0.2	16.1	49.9	59.2	60.0	60.8
Marilândia	1.198	1.135	4.154	14.5	13.5	48.8	15.8	14.3	52.3	39.5	39.9	40.3
Mimoso do Sul	1.551	2.156	3.832	18.4	25.3	44.5	-6.0	20.2	63.8	30.0	30.0	29.9
Montanha	688	1.292	3.806	12.8	23.8	69.5	-9.4	20.9	55.3	171.9	172.4	173.0
Mucurici	291	387	1.046	5.4	7.1	19.1	-5.0	13.2	42.6	10.1	10.1	10.0
Muniz freire	996	2.307	2.441	11.8	27.0	28.3	-0.9	18.8	19.1	25.5	25.3	25.0
Muqui	714	1.779	2.253	8.47	20.8	26.1	-4.0	20.4	42.7	47.4	47.6	47.9
Nova Venécia	2396	4654	9840	44.89	86.07	179.7	5.34	8.66	39.1	35.03	35.25	35.48
Pancas	1040	1709	3135	12.61	20.41	36.87	7.15	7.48	29.89	27.82	27.96	28.10
Pedro Canário	760	1.898	3.501	14.2	35.1	63.9	13.4	18.9	56.8	60.8	61.3	61.7
Pinheiros	1.033	2.712	4.111	19.30	50.10	75.00	1.70	13.81	46.1	28.0	28.3	28.6
Piúma	1.376	1.707	4.175	16.3	20.0	48.5	18.3	8.7	44.4	297.8	302.3	306.9
Ponto Belo	255	512	1.653	4.7	9.4	30.1	-5.0	13.2	42.6	220.4	222.6	224.7
Presidente Kennedy	1.221	1.258	1.930	14.4	14.7	22.4	-6.6	-0.9	-5.3	19.6	19.7	19.8
Rio Bananal	1.067	2.364	3.069	12.9	28.2	36.0	19.2	3.5	40.7	30.0	30.2	30.4
Rio Novo do Sul	814	1.077	2.004	9.6	12.6	23.3	-3.7	8.0	7.1	56.8	56.8	56.9
Santa Leopoldina	473	882	2.149	1.6	3.1	7.4	-7.3	-3.6	3.4	16.9	16.9	16.9
Santa Maria de Jetibá	2.192	4.964	7.210	7.8	17.4	24.9	-2.5	-5.7	20.8	55.7	56.5	57.3
Santa Teresa	2.530	2.628	5.170	9.0	9.2	17.8	-6.5	4.8	34.7	34.7	34.9	35.1
São Domingos do Norte	655	1.028	2.454	7.9	12.2	28.8	11.4	10.6	40.2	290.9	292.5	294.1
São Gabriel da Palha	2.843	4.677	9.868	34.4	55.8	116.1	-9.9	-1.1	22.5	88.5	89.8	91.1
São José do Calçado	476	886	2.237	5.6	10.4	26.0	-4.7	12.7	36.3	38.5	38.5	38.4
São Mateus	5.519	9.818	22.436	103.4	181.6	409.7	-9.9	-0.1	23.6	56.5	57.3	58.2
São Roque do Canaã	1.008	1.140	3.013	12.2	13.6	35.4	19.4	-0.4	31.7	36.5	36.8	37.1

Continuation - Table 1: Case incidence, incidence rate, work attendance rate, and annual population density, 2020-2022

Municipality	COVID-19 Cases			Incidence rate*			Mobility to Work (%)			Population density (km²)		
Serra	35.207	39.314	69.280	125.8	138.2	239.8	-8.6	10.2	31.8	962.7	980.1	997.8
Sooretama	1.499	2.556	4.937	18.1	30.5	58.0	-3.3	15.1	52.2	52.2	53.2	54.3
Vargem Alta	1.165	1.579	3.415	13.8	18.5	39.7	0.1	19.8	55.3	516.8	521.3	525.8
Venda Nova Imigrante	2.307	2.588	4.857	8.2	9.1	16.8	-0.9	0.4	18.0	138.4	140.9	143.4
Viana	4.078	6.071	12.954	14.5	21.3	44.8	-7.2	9.7	37.0	254.5	258.5	262.5
Vila Pavão	427	896	1.592	8.0	16.5	29.0	-5.0	13.2	42.6	21.3	21.4	21.5
Vila Valério	1.039	2.385	3.146	12.6	28.4	37.0	-10.8	0.3	13.6	29.9	29.9	29.8
Vila velha	30.107	33.124	69.037	107.6	116.5	238.9	-14.1	4.7	26.3	2.384.7	2.419.5	2.454.9
Vitória	37.322	36.800	68.139	133.4	129.4	235.8	-18.7	-1.9	19.2	3.766.9	3.804.8	3.843.2

Note: * Incidence rate per 100,000 inhabitants.

In 2022, the average rate was 68.1/100,000 inhabitants (SD ± 87.33), with the highest values observed in the municipalities of São Mateus 409.67; Colatina 351.29; and Linhares 328.54. In the panel analysis, an association between COVID-19 incidence and work attendance was observed in all municipalities. However, when evaluated by health region, a significant association was observed only between population density and COVID-19 in the Central and South regions (Table 2).

Table 2: Association of work attendance with the COVID-19 incidence rate in the health regions of Espírito Santo

Health Regions	Variables	β	p-valor	(CI 95%)
Total 1	Work Attendance	0.028	0.003	-0.010; 0.047
	Population Density	0.617	<0.001	0.492; 0.742
	Ft x Dd Interaction	-0.006	0.009	-0.107; -0.005
Northern Region	Work Attendance	0.011	0.629	-0.033; 0.055
	Population Density	0.177	0.376	-0.215; 0.568
	Ft x Dd Interaction	0.001	0.925	-0.011; 0.012
Central Region	Work Attendance	0.010	0.722	-0.046; 0.066
	Population Density	0.010	0.616	-0.288; 0.486
	Ft x Dd Interaction	-0.001	0.909	-0.015; 0.013
Metropolitan Region	Work Attendance	0.021	0.177	-0.010; 0.052
	Population Density	0.974	<0.001	0.801; 1.146
	Ft x Dd Interaction	-0.001	0.057	-0.015; 0.001
Southern Region	Work Attendance	0.030	0.079	-0.003; 0.063
	Population Density	0.631	<0.001	0.391; 0.870
	Ft x Dd Interaction	-0.005	0.208	-0.013; 0.003

Note: β – Regression coefficient for each term of the model: (FT; DD; (FTxDD), 95%CI – 95% Confidence Interval.

Analysis across Health Regions

When analyzing the possible interaction effect between work attendance and population density, we stratified into tertiles to determine whether fluctuations between groups are greater than would be expected by chance alone. We observed that in the second density tertile, work attendance was significantly associated with the COVID-19 incidence rate.

In the interregional analysis, an association between WGM and DD with the COVID-19 incidence rate was found only in the Metropolitan Region. In the South Region, COVID-19 incidence was associated only with population density. The equations for estimating the parameters found by health regions are shown in Table 3.

In the stratified analysis by density tertiles, we observed that labor mobility was associated with COVID-19 incidence in municipalities belonging to the second tertile. We sought to analyze the possible effect of WGM intra-regionally by stratifying regression coefficients (CR) into tertiles and establishing their variations between municipal rates and variations within health regions to determine whether the fluctuations between groups are greater than would be expected by chance alone. For the North region, an average increase of 180% was observed for the first tertile (1st Tertile) of the CR, for the second tertile (2nd Tertile) an average increase of 330% and 423%

Table 3: Regression coefficient according to population density tertiles

Population density	β	P Value	95% CI	
1º Tertile	0.003	0.337	-0.003	0.009
2 º Tertile	0.012	0.01	0.005	0.019
3 º Tertile	-0.007	0.087	-0.016	0.001

for the third tertile (3rd Tertile), however, the differences between the means were not significant with a p-value of (0.68 between 1st and 2nd Tertile; 0.130 between 1st and 3rd Tertile; and 1.00 between 2nd and 3rd Tertile). In the Central Region, an average increase of 192% was observed for the 1st Tertile, 171% for the 2nd Tertile and 224% for the 3rd Tertile, whose differences between the means were not significant with a p-value of 1.0 between 1st and 2nd Tertile; 0.59 between 1st and 3rd Tertile; and 0.39 between the 2nd and 3rd Terciles. In the Metropolitan region, for the 1st Tercile, an average increase in the incidence rate of 259.5% was observed, for the 2nd Tercile 116.5%, and for the 3rd Tercile: 188%, the differences between which were not significant (p-value 0.38 between the 1st and 2nd Terciles; 1.00 between the 1st and 3rd Terciles; and 1.00 between the 2nd and 3rd Terciles). In the South region, an average increase of 237% was observed for the 1st Tercile, 151% for the 2nd Tercile, and 208% for the 3rd Tercile. However, the differences were also not significant (with a p-value of 0.47 for the 1st and 2nd terciles, 1.00 for the 1st and 3rd terciles, and 1.0 between the 2nd and 3rd terciles). Figure 1 presents the increase rates to identify the municipalities that presented the greatest increases in the period studied.

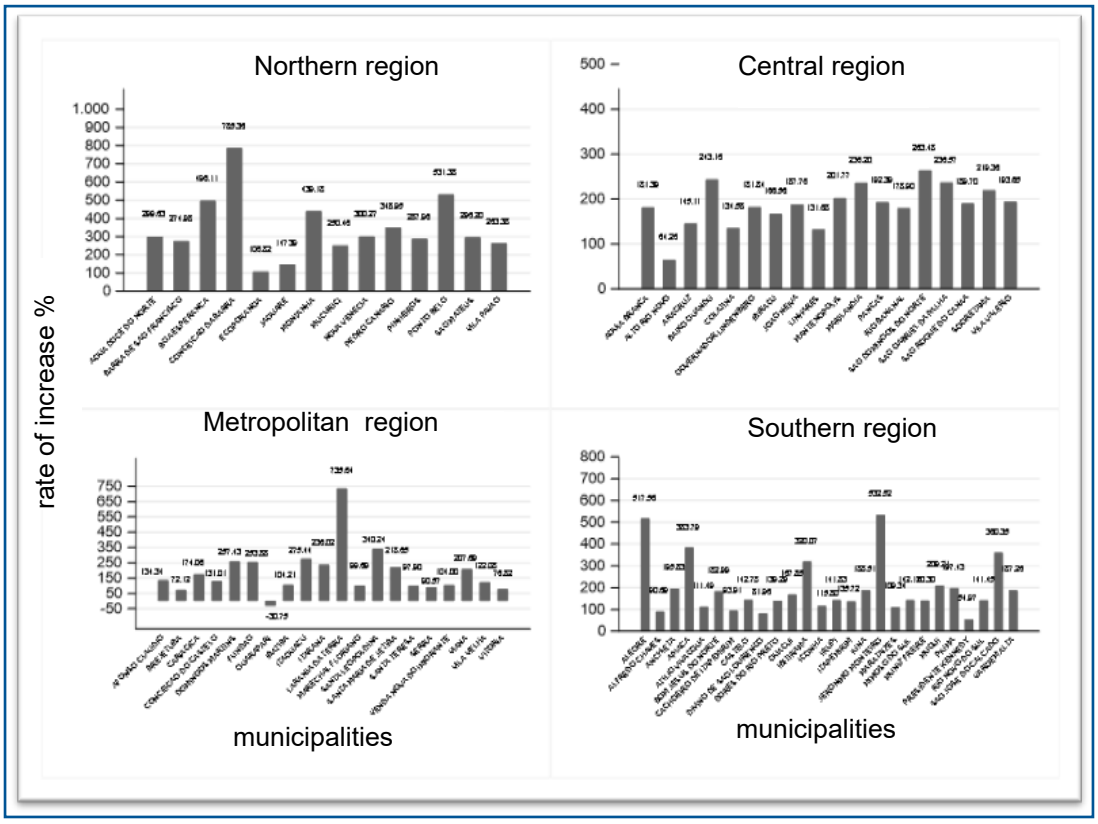

Figure 1: Incremental rates according to health regions

DISCUSSION

Data analysis indicates variations in the adoption of social distancing measures across municipalities.

In this study, monthly municipal COVID-19 incidence rates were positively associated with work attendance rates (%) assessed by the Labor Mobility Index. Our study showed that the heterogeneity in the adoption of non-pharmacological measures did not achieve the expected interruption of disease transmission at the municipal and intraregional levels. The impact of social distancing measures was expected to spread across municipalities and slow the progression of the incidence rate.

Estimates at the beginning of the COVID-19 epidemic period, in late 2019 and early 2020, indicated that population density could play a significant role in the impact of COVID-19. Our study found a positive association between population density and the municipal incidence rate in the South region, sparing the Metropolitan Region a larger population. Population density does not appear to have determined virus spread. However, in the models tested, the product of the interaction between population density and work attendance was also not associated with COVID-19 incidence rates.

The present study is like the findings of Moraes (2020)[13] in portraying the heterogeneity in the adoption

of non-pharmacological measures by the states of the federation, favoring the progression of the disease, such that "until February 2021, community transmission continued to occur." In line with this, Barberia *et al.,* (2021)[14] identified that the moderate intensity of the adoption of non-pharmacological measures by agents of the federated units may have favored the low population adherence in the reduction of mobility during the endemic period, despite the efforts made by the government of the State of Espírito Santo in adopting social isolation measures such as the prohibition of events, with the exception of churches (Decree 4,599-R)15 of 03/18/2020, total closure of educational units (Decree 4,597-R)[16] of 03/23/2020; institution of teleworking for employees belonging to risk groups (Decree 4,599-R of 03/18/2020)[15], isolation for employees who present mild flu-like symptoms (Decree 4,599-R of 03/18/2020)[15], suspension of the operation of gyms and shopping centers with in-person service (Decree 4,600-R)[17] 03/19/2020, suspension of service in bank branches (Decree 4,604-R of 03/20/2020)[18], suspension of the operation of commerce and restaurants for in-person service (Decree 4,605-R)[19].

Aquino *et al.,* (2020)[2], in a narrative review, highlights that even after the adoption of non-pharmacological measures by the states of the federation, only a few "stand out for the proactive adoption of strict social distancing policies." Our study reaffirms this point, which corroborates the results found.

Talic *et al.,* (2021)[20] demonstrated in a meta-analysis of eight studies relative reductions in incidence of 25.0% (RR 0.75, 95% CI: 0.590;0.950) for physical distancing, 53.0% (RR 0.47, 95% CI: 0.290;0.750) for mask use, and 53.0% for hand washing (RR 0.47, 95% CI: 0.190;1.120)[20].

As demonstrated by Nepomuceno *et al*.[21] for Brazil, the findings confirmed the importance of including variables such as population density in assessing job mobility and its impact on COVID-19 incidence rates. Using both generalized linear models and panel data models, it was demonstrated that, in municipal and regional contexts, job mobility had a significant impact on COVID-19 incidence.

A strength of the study is the methodology used, as panel data analysis allowed us to control the autocorrelation and heteroscedasticity inherent in repeated measures data over time[22,23]. Thus, the results contribute to the customization of coping strategies in future scenarios, informing public policies at the state and municipal levels. They demonstrate the need to consider other variables, such as population density, in public health measures so that non-pharmacological interventions can have better effects on protecting against health events. Among the study's potential limitations, we can consider the occurrence of selection bias, given the lack of complete municipal data on work attendance. This necessitated the need for data imputation to continue the study, potentially distorting the true relationship between the variables studied. Another condition to be considered concerns the quality of the data generated from notifications by municipal epidemiological surveillance services, which may have underreported cases early in the pandemic. Another important point is the lack of correlations with seasonal and climatic variations, which were not addressed in this study, and which Hoogeveen[24] found to have a positive association with climatic variations in a study conducted in the Netherlands.

Thus, work mobility, used as a non-pharmacological measure at the local level in the state of Espírito Santo (state and municipal), negatively impacted COVID-19 incidence rates. The results expand knowledge in this area, incorporating the need to consider the population density variable in future decision-making scenarios by health authorities. Given the results found, it is indicated that the inclusion of other variables, such as population density, can maximize the results achieved in tackling health risk events.

Author Contributions

Romildo Luiz Monteiro Andrade was responsible for all aspects of the study: data adjustment and application of statistical techniques, data analysis and interpretation, and article preparation; Gabriela Callo Quinte was responsible for all aspects of the study: data adjustment and application of statistical techniques, data analysis and interpretation, and article preparation; Cristiano Dell'Antonio collected data analysis and interpretation, revised drafts, and critically reviewed the content; approved the final version; Anselmo Dantas collected data analysis and interpretation, revised drafts, and critically reviewed the content; approved the final version; Jose Geraldo Mill contributed to the study design and critically reviewed the content of the final version to be published.

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Conflict of Interest

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Resumo

Introdução: no Brasil, medidas não farmacológicas foram colocadas em prática para reduzir a transmissão do SARS-CoV-2.

Objetivo: avaliar o efeito do distanciamento social na incidência de COVID-19 nos municípios do Espírito Santo.

Método: estudo ecológico por agregado regional para avaliar o efeito do distanciamento social pela mobilidade para o trabalho na taxa de incidência municipal ajustada de COVID-19 de março de 2020 a dezembro de 2022.

Resultados: as taxas de incidência de COVID-19 apresentaram associação positiva com a mobilidade para o trabalho (β:0,028; IC:-0,010; 0,047). Quando estratificadas por região de saúde e tercis de densidade, apenas a região Sul e o tercil com maior densidade demográfica mantiveram a associação.

Conclusão: a adoção de medidas de distanciamento social deve incorporar a densidade demográfica como critério de vulnerabilidade em futuras situações de risco epidemiológico.

Palavras-chave: distanciamento social, COVID-19, SARS-CoV-2, saúde pública.