Recovering from the COVID-19 Mortality Crisis: Are Brazilian States Returning to Pre-Pandemic Levels and Causes of Death Structure?

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Introduction

Worldwide, more than 7.0 million lives were lost due to COVID-19 pandemic by the end of 2023 (World Health Organization, n.d.). Despite representing 13% of the world's population (United Nations, Department of Economic and Social Affairs, Population Division, n.d.), the Americas were the region hardest hit with more than 2.9 million COVID-19 deaths, accounting for 42% of global deaths (World Health Organization, n.d.). Brazil has the second highest number of COVID-19 deaths in the world, with more than 700,000 registered deaths, surpassed only by the USA (World Health Organization, n.d.). Overall, Brazil experienced three strong waves (Alcantara et al., 2022; Moura et al., 2022; Szwarcwald et al., 2022), which were responsible for 95% of all COVID-19 deaths and 81% of all reported cases (Ministério da Saúde, n.d.). However, from the start of the COVID-19 vaccination campaign in January 2021, nearly 80% of the population has been vaccinated, considerably reducing the number of COVID-19 deaths in the country (Moura et al., 2022).

The spread of the SARS-Cov-2 and the pandemic mortality peaks were not evenly distributed across Brazil, with strong regional disparities observed during the major pandemic waves (Alcantara et al., 2022; Moura et al., 2022; Szwarcwald et al., 2022). Some states in the North region, such as Amazonas, Pará and Amapá, experienced their strongest wave in 2020, while the South and Southeasts were hit hard in 2021 (Szwarcwald et al., 2022). This explains the greater loss of life expectancy in 2020 in the North and Northeast regions, which are the least developed and the most vulnerable regions (Baqui et al., 2020; Castro, Gurzenda, et al., 2021; Castro, Kim, et al., 2021; Rocha et al., 2021). All of these factors highlight the persistent regional heterogeneities in Brazil, disparities that remained during the COVID-19 pandemic. Therefore, regional inequalities underscore the need for subnational analysis when studying the impact of the COVID-19 pandemic in Brazil.

In Brazil, in addition to regional disparities, mortality disparities by age and sex are also important in studying the impact of the COVID-19 pandemic (Castro, Gurzenda, et al., 2021). Men and people of older age were at higher risk of dying by COVID-19 (Baqui et al., 2021; Bhaskaran et al., 2021; De Souza et al., 2021; Williamson et al., 2020). However, the high prevalence of chronic conditions at younger ages in several low- and middle-income countries, as in the case of Brazil, rejuvenated the age-structed of COVID-19 deaths. This resulted in a higher concentration of death within the population younger than 60 years old, different from what we observed in some European countries (Nepomuceno et al., 2020). That was particularly the case of Brazil, where the less developed states and the most vulnerable social groups were more affected (Szwarcwald et al., 2022; Baqui et al., 2020, 2021; Baptista et al., 2022; Castro, Kim, et al., 2021; Santos, Siqueira, Atienzar, da Rocha Santos, et al., 2022; Martines et al., 2021; Rocha et al., 2021).

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The COVID-19 pandemic had an impact on other causes of death (Castro et al., 2023; Riou et al., 2023). First because the COVID-19 had a "harvesting effect" (Schwartz, 2000) as it anticipated some of the deaths that might have occurred due to other causes of death, particularly of the individuals with chronic conditions that are increasing risk factor for COVID-19 (Castro et al., 2023; Riou et al., 2023). Second, the pandemic affected people's access to the diagnosis, preventive care and treatment of non-COVID-19 diseases (e.g., cardiovascular and cancer care) as it disrupted the health services and systems (Andrade et al., 2023; Dale et al., 2023; Han et al., 2023; Riera et al., 2021; Wichmann & Moreira Wichmann, 2023). Third, the mortality risk of some external causes (e.g., from traffic-related accidents and injuries) changed during the pandemic due to lockdowns and social distance measures (Nivette et al., 2021; Tanaka & Okamoto, 2021; Yasin et al., 2021). Fourth, the pandemic also affected people's health behaviors and wellbeing (Dos Santos et al., 2022; Shalitin et al., 2022). Fifth, the health outcomes of the post-COVID syndrome (e.g., fatigue, cognitive dysfunction, sinus tachycardia and etc.) at the population level are not completely know yet (Aranyó et al., 2022; Fedorowski et al., 2024; Goldstein, 2024; Mogensen et al., 2023).

In Brazil, the COVID-19 pandemic increased the country's mortality level and reversed all gains in life expectancy observed at least since the 2010s. The Brazilian life expectancy decreased about 1.3 years in 2020 (Castro, Gurzenda, et al., 2021). The fact that the COVID-19 pandemic significantly reduced life expectancy is not new, but what we still do not know is whether all Brazilian states are returning to pre-pandemic mortality levels and at the same pace. Moreover, there is still a lack of knowledge about the impact that the COVID-19 pandemic has left on the cause of death structure. The goal of this study is to fill all these gaps in the literature. We calculate the change in life expectancies over time and states, considering the years of 2019, 2020, 2021, and 2022, and decompose these changes by age. Moreover, we show changes in the structure of the deaths by cause. In addition to show if the Brazilian states are returning to pre-pandemic mortality levels and causes of death structure, our study reveals if spatial disparities in mortality are increasing or not during the pandemic's recovery phase in Brazil.

Data and Methods

All three data sources used in this paper are derived from public and freely available data sources. First, the number of deaths by age, sex and cause of death from the Mortality Information System (Sistema de Informações sobre Mortalidade, SIM, in Portuguese), organized and distributed by the Brazilian Ministry of Health (Ministério da Saúde, MS, in Portuguese) (Ministério da Saúde, Departamento de Informática do Sistema Único de Saúde, n.d.). Second, the population projections by age, sex, projected by the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística, IBGE, in Portuguese) (Instituto Brasileiro de Geografia e Estatística, 2020). Third, the birth counts from the Live Births Information System (Sistema de Informações sobre Nascidos Vivos, SINASC, in Portuguese) (Ministério da Saúde, Departamento de Informática do Sistema Único de Saúde, n.d.).

The time series used includes the years 2019, 2020, 2021 and 2022. We used data for Brazil and all of its 27 federal units (Unidades da Federação, UF, in Portuguese), which correspond to the 26 states plus the Federal District, the country's capital (Distrito Federal, DF, in Portuguese).

We estimated the combined-sex period LE at birth (e_0) for Brazil and all states (UF), using the number of deaths from all causes that occurred in each of the four calendar years as the numerator. And as the denominator, we performed our analysis using the population projections adjusted for the excess deaths observed in 2020 and 2021, which affected the projections of the following years. However, for the population aged 0-1 years old we used the live births counts of each calendar year.

The period LE is a measure derived from a period life table (LT) that describes the survival probabilities of individuals at specific ages based on the mortality experience of a population over a given period of time (e.g., a calendar year) (Preston et al., 2001). We calculated combined-sex age-specific death rates by individual age, ranging from zero to the open interval ending in ≥ 90 (or 90^{+}). For the mean age of death of children in the first year of life (a_0) in a combined-sex LT, we applied the Andreev and Kingkade equations (Andreev & Kingkade, 2015) as suggested in the latest version of the Human Mortality Database Methods Protocol (Wilmoth et al., 2021).

The continuous decomposition method proposed by Horiuchi and colleagues (Horiuchi et al., 2008) was used to decompose the changes in life expectancy over time and by age for Brazil and its states. The estimated results show the contribution of each age group to the changes in total life expectancy at birth between 2019 and 2022.

We also analyzed the changes in the structure of causes of death in Brazil and its states during and after the COVID-19 mortality peak. And we try to understand both absolute and relative changes in the number of deaths by cause. We also estimated the age-standardized death risk ratios by causes of death and by age groups (0-29, 30-44, 45-59, 60-74 and 75^{+} years old). We used the 2019 Brazilian population structure as the population standard.

All quantitative analyses and plots were performed in R software. We used the R package "DemoDecomp", developed by Tim Riffe, to perform the continuous decomposition method proposed by Horiuchi and colleagues. The code and all input and output data will be hosted on GitHub.

Results

Changes in combined-sex LE at birth between 2019 and 2022

The estimated decline in combined both sexes life expectancy (LE) at birth (e_0) in Brazil during 2020 was of 1.43 years. In 2021 it was followed by a larger drop of 2.04 years. During the first two years of the COVID-19 pandemic the loss in e_0 for both sexes was of 3.46 years. In 2022 we estimated a bounce back in e_0 of 2.75 years, but still 0.72 years (or almost 9 months) bellow the pre-pandemic level.

Across the 27 Brazilian states, all of them exhibited a drop in combined-sex e_0 in 2020 except Rio Grande do Sul, which showed a small increase (of +0.02 yrs.). The decline was smaller than the country's estimative in seven states: Minas Gerais (−0.50 yrs.), Santa Catarina (−0.59 yrs.), Paraná (−0.84 yrs.), Mato Grosso do Sul (−1.18 yrs.), Rio Grande do Norte (−1.22 yrs.), São Paulo (−1.23 yrs.), Paraíba (−1.37 yrs.), and Tocantins (−1.43 yrs.). Among the states with larger drops than the country's estimative, the highest declines were observed in: Amazonas (−3.50 yrs.), Amapá (−3.32 yrs.), Roraima (−2.77 yrs.), Pará and Mato Grosso (−2.75 yrs.), Maranhão (−2.64 yrs.), Ceará (−2.48 yrs.), Distrito Federal and Rondônia (−2.21 yrs.), Acre and Pernambuco (−1.93 yrs.), Alagoas (−1.92 yrs.), Rio de Janeiro (−1.89 yrs.), Espírito Santo (−1.84 yrs.), Sergipe (−1.61 yrs.), Goiás (−1.54 yrs.), Bahia (−1.53 yrs.), and Piauí (−1.52 yrs.) (Figure 1).

The drop in combined-sex e_0 continued through 2021 and was observed in all states except in two, Pará (+0.05 yrs.) and Amapá (+0.03 yrs.). Twelve states exhibited larger drops than the country's estimative: Paraná (−4.07 yrs.), Rondônia (−3.62 yrs.), Mato Grosso do Sul (−3.57 yrs.), Rio Grande do Sul (−3.13 yrs.), Santa Catarina (−3.00 yrs.), Goiás (−2.81 yrs.), Minas Gerais (−2.75 yrs.), Tocantins (−2.72 yrs.), São Paulo (−2.67 yrs.), Mato Grosso (−2.44 yrs.), Roraima (−2.09 yrs.), and Amazonas (−2.06 yrs.). In thirteen states the decline in e_0 was lower than the country's estimative in: Maranhão (−0.33 yrs.), Sergipe (−0.42 yrs.), Alagoas (−0.43 yrs.), Pernambuco (−0.62 yrs.), Ceará (−0.70 yrs.), Bahia (−0.91 yrs.), Rio Grande do Norte (−0.92 yrs.), Rio de Janeiro (−1.18 yrs.), Piauí (−1.21 yrs.), Espírito Santo (−1.36 yrs.), Paraíba (−1.46 yrs.), Acre (−1.52 yrs.), and Distrito Federal (−1.62 yrs.) (Figure 1).

The bounce back in combined-sex e_0 in 2022 was observed across all the Brazilian States. The recovery was higher than the estimated value for the country (i.e., +2.75 yrs.) in: Amazonas (+5.27 yrs.), Roraima (+4.37 yrs.), Acre (+4.26 yrs.), Rondônia (+4.20 yrs.), Mato Grosso (+4.00 yrs.), Distrito Federal (+3.75 yrs.), Goiás (+3.74 yrs.), Paraná (+3.58 yrs.), Rio de Janeiro (+3.55 yrs.), Amapá (+3.53 yrs.), Mato Grosso do Sul (+3.21 yrs.), São Paulo (+3.19 yrs.), and Tocantins (+3.06 yrs.). In fourteen states the recovery was smaller than the one observed for Brazil: Piauí (+1.19 yrs.), Paraíba (+1.31 yrs.), Bahia (+1.36 yrs.), Alagoas (+1.57 yrs.), Sergipe (+1.80 yrs.), Rio Grande do Norte and Maranhão (+1.82 yrs.), Pernambuco (+1.90 yrs.), Ceará (+2.17 yrs.), Rio Grande do Sul (+2.20 yrs.), Pará (+2.25 yrs.), Minas Gerais (+2.47 yrs.), Santa Catarina (+2.52 yrs.), and Espírito Santo (+2.57 yrs.) (Figure 1).

However, despite the bounce back observed in 2022, the both sexes LE at birth was still below the pre-pandemic levels in most of the Brazilian states, except in Acre (+0.81 yrs.), Rio de Janeiro (+0.48 yrs.) and Amapá (+0.24 yrs.). The difference between the 2022 both sexes LE at birth compared to the 2019 levels was lower than the country's estimative (−0.72 yrs.) in ten states: Distrito Federal (−0.07 yrs.), Sergipe (−0.22 yrs.), Amazonas (−0.29 yrs.), Rio Grande do Norte (−0.31 yrs.), Pará (−0.45 yrs.), Roraima (−0.50 yrs.), Goiás (−0.61 yrs.), Pernambuco and Espírito Santo (−0.64 yrs.), and São Paulo (−0.72 yrs.). Whereas it was higher in 14 states: Minas Gerais and Alagoas (−0.79 yrs.), Rio Grande do Sul (−0.91 yrs.), Ceará (−1.01 yrs.), Santa Catarina (−1.07 yrs.), Bahia (−1.08 yrs.), Tocantins (−1.09 yrs.), Maranhão (−1.16 yrs.), Mato Grosso (−1.19 yrs.), Paraná (−1.34 yrs.), Paraíba (−1.51 yrs.), Mato Grosso do Sul (−1.54 yrs.), Piauí (−1.55 yrs.), Rondônia (−1.63 yrs.) (Figure 1).

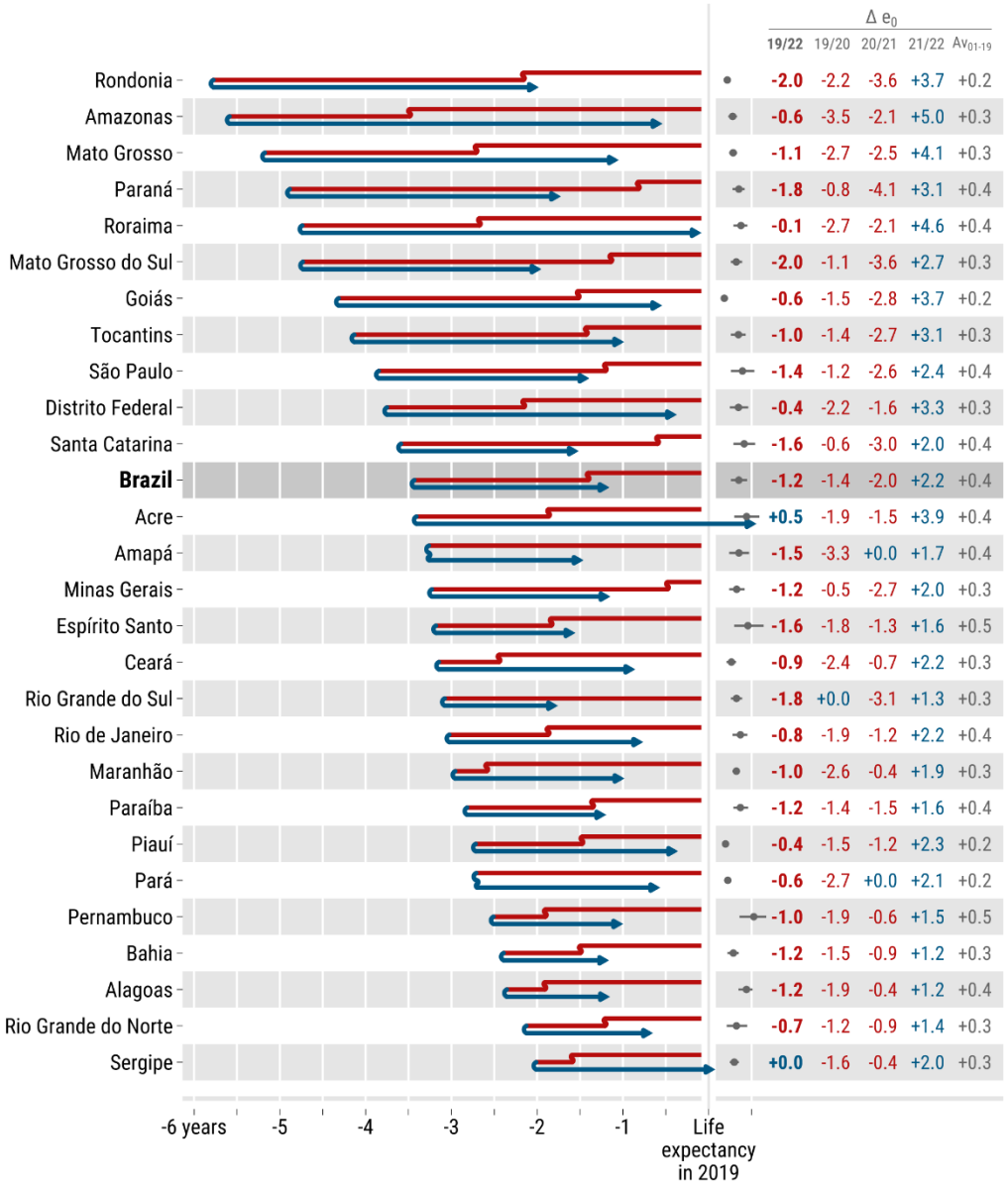

Figure 1 – Life expectancy at birth (e_0) changes in 2019-2020, 2020-2021 and 2022-2021 in Brazil and across all the Brazilian states. The states were ordered by increasing cumulative losses. The three-line segments indicate the annual changes in e_0 in 2020, 2021 and 2022 respectively. The red lines indicate losses, whereas the blue indicate gains in e_0. The grey dots and lines indicate the average annual LE changes along with 95% CIs. Δe_0 marks the change in period LE over the designated period.

Age contribution to changes in combined-sex LE at birth between 2019 and 2022

In Brazil we observed that during the first year of the pandemic, the excess mortality at older ages explained most of the estimated losses in combined-sex LE at birth (e_0), particularly among individuals aged 60 years or older, which contributed with almost one-year loss in e_0. However, in 2021 it was the excess deaths occurred at younger ages groups that explained most of the losses. The age group 30-59 yrs. old contributed with more the one-year of loss, or more than half of the estimated drop of LE at birth in Brazil by 2021 (i.e., of −2.04 yrs.). The bounce back observed in 2022 was driven mainly by the decline

in excess mortality of the population aged 45-74 years old, which contributed with a gain of almost two years of LE at birth (+0.94 yrs. from the age group 45-59 and +1.0 yr. from the age group 60-74 years old), or near 70% of the rebound observed in the country (i.e., +2.74 yrs.) (Figure 2).

The estimated deficit in LE at birth in 2022 from the pre-pandemic level in 2019 is mainly explained by excess mortality among individuals with 60 years old or more, despite the mortality shift towards younger ages in 2021. By 2022 the higher risk of death in age group 60^{+} explained almost 70% of the LE at birth deficit from the 2019 level (i.e., of −0.72 yrs.) (Figure 2).

Across the Brazilian states in 2020 it was observed that the excess mortality among individuals aged 60^{+} contributed with more than 70% of the LE at birth drop in seven states: Minas Gerais, Amazonas, Pará, Distrito Federal, Acre, Goiás, and Roraima. However, in Amazonas, Amapá, Pará and Roraima, this contribution represented more than two years of e_0 loss, whereas in Minas Gerais it represented less than six months of loss. In sixteen states the excess deaths of the population aged 60^{+} contributed with a loss between 60-70%: Tocantins, Maranhão, Rio Grande do Norte, Rio de Janeiro, Santa Catarina, Amapá, Sergipe, Bahia, São Paulo, Mato Grosso do Sul, Espírito Santo, Pernambuco, Piauí, Mato Grosso, Alagoas, Paraná. And it was between 50-60% in three states: Paraíba, Rondônia, and Ceará. In Rio Grande do Sul no drop was observed, despite the small negative contribution of the population aged 60^{+}.

By 2021 the contribution of excess mortality of the population younger than 60 years old was between 60-84% in ten states: Alagoas, Maranhão, Roraima, Pernambuco, Amazonas, Paraíba, Bahia, Rio Grande do Norte, Acre, and Mato Grosso. In eleven states it was between 50-60%: Goiás, Distrito Federal, Rio de Janeiro, Mato Grosso do Sul, São Paulo, Paraná, Sergipe, Tocantins, Ceará, Piauí, and Rio Grande do Sul. And in three states it was lower than 50%: Rondônia, Espírito Santo, and Minas Gerais. Whereas in Pará and Amapá the small drop in e_0 was totally due to the excess deaths in age group 60^{-}.

During the recovery phase in 2022, in eleven states the decline of excess mortality of the population aged 60^{-} explained most of the e_0 bounce back of: Paraíba, Rio Grande do Norte, Bahia, Paraná, Goiás, Rio Grande do Sul, Alagoas, São Paulo, Mato Grosso do Sul, Ceará, and Amapá. While in sixteen states it was the contribution of excess deaths of the population aged 60^{+} was higher than 50% in: Pará, Piauí, Espírito Santo, Distrito Federal, Tocantins, Amazonas, Maranhão, Sergipe, Pernambuco, Rondônia, Rio de Janeiro, Minas Gerais, Mato Grosso, Acre, Santa Catarina, and Roraima.

In all states that showed a deficit in combined-sex LE at birth by 2022 from 2019 level, the excess mortality in the age group 60^{+} explained most of the deficit, except in Distrito Federal, Tocantins and Mato Grosso, where the contribution of the age group 60^{-} was higher. Whereas in the three states with a e_0 surplus by 2022 (i.e., Acre, Amapá and Rio de Janeiro) the change was driven mainly by the decline of deaths in the age group 60^{-}.

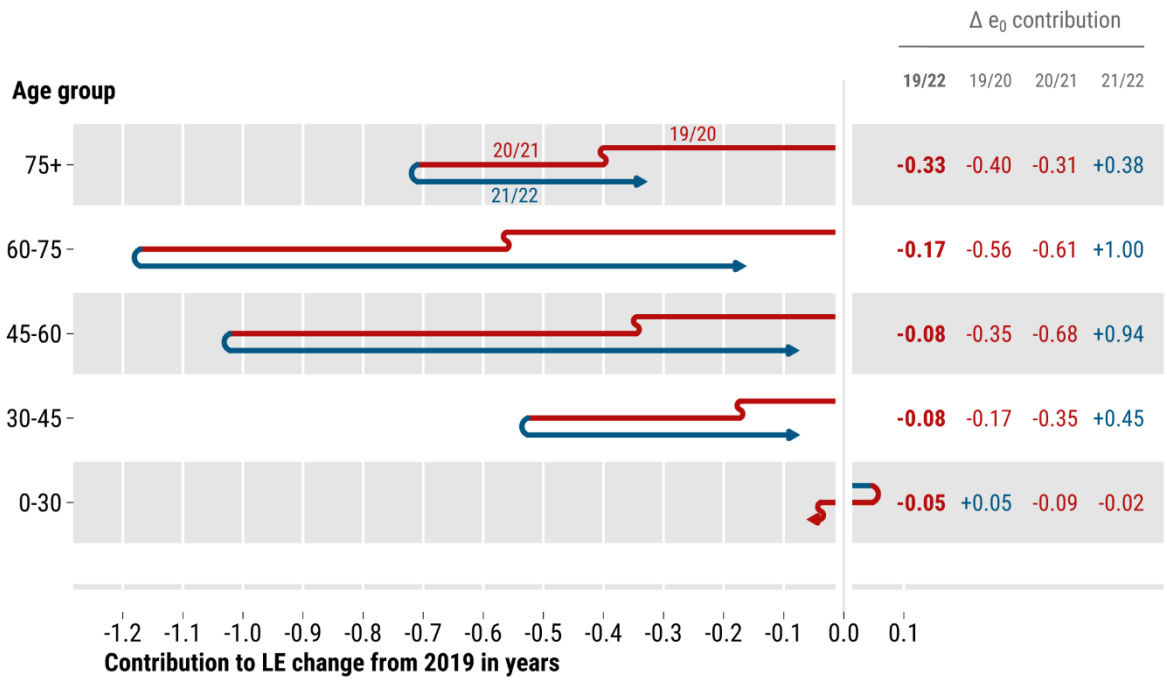

Figure 3 – Age contributions to changes in LE at birth from 2019 in years in Brazil. The continuous decomposition method proposed by Horiuchi and colleagues (Horiuchi et al., 2008) was used to decompose the changes in life expectancy over time and by age for Brazil and its states.

Changes in the structure of causes of death

The death toll in Brazil saw a sharp increase during the pandemic, rising from 1.34 million deaths in 2019 to 1.55 million in 2020 (+15.3%), and to 1.82 million in 2021 (+35.8% from 2019 level). By 2022 the death toll from all causes declined to 1.54 million deaths (a 15.4% decrease from 2021 level), but still above the pre-pandemic level. This trend was driven mainly, but not exclusively, by changes in COVID-19 deaths.

The COVID-19 related deaths (212,706) became the second leading cause of death in Brazil in 2020, only outnumbered by neoplasms (with 229,300 deaths). By 2021 the COVID-19 deaths turned to be by far leading cause of death in the country (424,461). However, in 2022, due to the sharp decline in COVID-19 mortality (65,764 deaths), it was no longer figuring as one of the leading causes of death, although it remained as the major cause of death among the infectious and parasitic diseases (ICD-10 Chap. I).

We observed that the non-COVID-19 death counts also changed after pandemic outbreak. The death counts of some causes increased for every year since 2020, such as: the cardiovascular diseases (CVD) excluding the acute CVD, suicides, drug-related deaths, alcohol-related deaths, and the rest of external causes of death, including homicides and traffic related accidents and injuries. While the death counts of some causes declined in 2020, but them followed by an increase in 2021 and 2022, which was the case of the deaths from: neoplasms, acute CVD (i.e., acute IHD and strokes), infectious and parasitic diseases excluding COVID-19 deaths, other disorders of brain and other cerebrovascular diseases, acute respiratory diseases, chronic ischemic heart disease (IHD). And in between these two cases, the diabetes death counts increased in 2020 and 2021, but them exhibited a small decline in 2022.

Across the Brazilian states a similar conclusion is obtained from the overall trend in mortality levels and the temporary changes in the causes of death structure. The cross-state comparison revealed regional

disparities, particularly in the magnitude of the pandemic in overall mortality, and thus of its share in the causes of death structure. However, the share of the COVID-19 deaths in overall mortality declined sharply in 2022, and it was below 6% in all states.

The North region of the country was the most affected during the worst years of the pandemic. In all the seven states of the COVID-19 deaths were the leading cause of death. The highest peaks of COVID-19 deaths in overall mortality in Brazil were observed in the North region (34.7% in Rondônia and 32.2% in Amazonas by 2021). By 2022, the share of the COVID-19 deaths was below 6% in all the states.

In the Northeast region, only the in the states of Ceará and Pernambuco the COVID-19 deaths were the leading cause of death in 2020 and 2021. Whereas among the other seven states (Maranhão, Piauí, Rio Grande do Norte, Paraíba, Alagoas, Sergipe, and Bahia) the COVID-19 deaths were the leading cause only by 2021. In addition, the Northeast states exhibited the lowest peaks of the COVID-19 deaths share in all-cause mortality in 2021, which did not exceed 22%. In 2022, the share of COVID-19 deaths was reduced to 4% or less in all the nine states.

Among the four states of the Southeast region, the COVID-19 deaths turned to be leading cause of death by 2020 and 2021 in Rio de Janeiro and Espírito Santo. In São Paulo it was the second cause in 2020 and the leading by 2021. And in Minas Gerais it was the third in 2020 and the leading cause of death in 2021. In this region the peak of the COVID-19 deaths in the share of all-causes of death did not surpassed 26%. By 2022, the share of COVID-19 deaths were equal or lower than 5.2% in the four states.

The South region was the least affected during the first year of the pandemic. The COVID-19 deaths were only the third main cause of death by 2020 in Santa Catarina and Rio Grande do Sul, whereas in Paraná it was only the fourth. However, in 2021 it turned to be the main cause of death in all the three states. The highest peak of the COVID-19 deaths share in overall mortality was observed in Paraná (29.3%). In 2022, the COVID-19 deaths represented 5.0% or less of all-deaths in all states.

In the Midwest region, the COVID-19 deaths became the leading cause of death both in 2020 and 2021 in Mato Grosso, Goiás and Distrito Federal. While in Mato Grosso do Sul, it was only the third in 2020, but the leading cause of death by 2021. In addition, the Midwest states exhibited higher peaks of COVID-19 deaths share in all-cause mortality (32.2% in Mato Grosso in 2021), which approached the levels observed among the most affected states located in the North region. By 2022, the share of COVID-19 deaths in overall mortality did exceeded 5.5% in none of the four states.

Changes in age-standardized death risk ratios by causes of death

Analyzing the changes by causes of death, we observed a decrease in the risk ratios of neoplasms for all age groups in 2020, 2021 and 2022. Whereas the risk ratios of diabetes increased in 2020, in particular among the younger age groups, but than shifted back gradually in 2021 and 2022 to the pre-pandemic pattern. We also observed an increase in the risk ratio of the drug-related deaths, in particular, alcohol-related deaths and suicides, especially among the younger age groups, in 2020, 2021 and 2022. The effect of COVID-19 deaths could be seen in the residual causes of death category, which shows a high increase in 2020, followed by a large increase in 2021, especially among young age groups (i.e., 60^{-} yrs. old). And in 2022, it is possible to observe a sharp rebound in risk ratios (Figure 3).

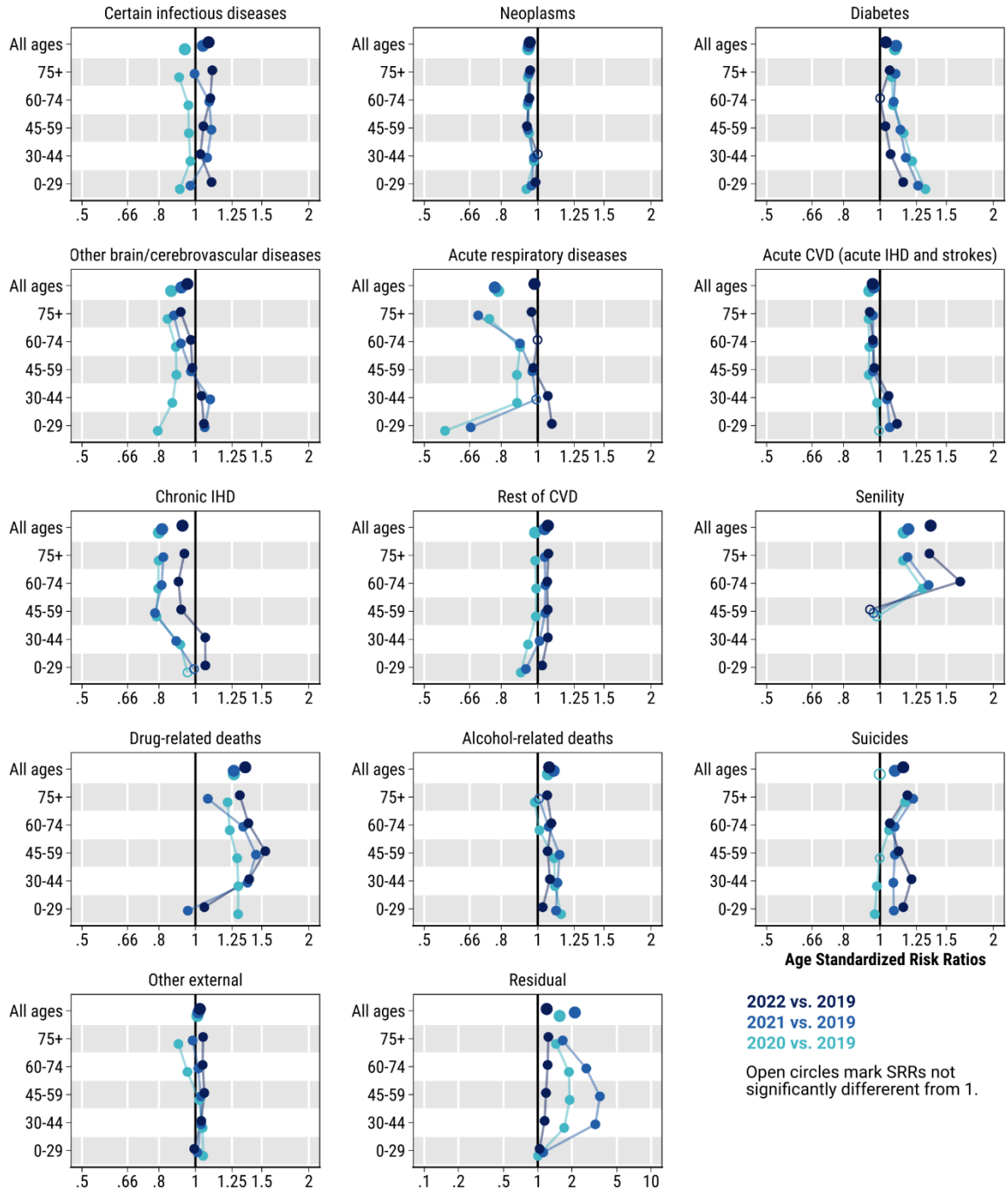

Figure 3 – Risk ratios changes by age group and causes of death in 2020/2019, 2021/2020 and 2022/2019. Direct standardization using Brazil 2019 population (CIs by Boyle & Parkin, 2006, in Eq 11.11. p 138). The COVID-19 deaths were coded in residual causes of death.

During the peak of the COVID-19 pandemic, Brazil saw a significant rise age-standardized crude death risk ratios. This trend was also observed for all age groups, except in the population aged 0-29 yrs. old. In 2020, the highest increases in risk ratios (higher than 1.15) were observed in the population aged 60-74, 45-59 and 30-44 yrs. old, respectively. However, regarding the non-COVID-19 mortality, a decline in risk ratios was observed across all age groups, except in the population aged 30-44 yrs. old.

Similarly, in 2021, the risk ratios increased across all age groups. Although the highest increases were observed in the population aged 45-59 (1.30) and 30-44 yrs. old (1.28). The risk ratios of COVID-19 mortality increased more than two times in the younger age groups: 30-44, 45-59 and 0-29 yrs. old, respectively. Whereas it increased less in the age groups 60-74 (1.90) and 75^{+} (1.38). In the non-COVID-19 mortality we observed small increases (but lower than 1.04) across all age groups.

However, by 2022, there was a sharp decrease in the rate ratios by all-cause mortality, which was observed across all age groups, and in particular of those aged 45-59 (0.68) and 30-44 years old (0.73). Although not exclusively, these changes were driven mostly by changes in COVID-19 mortality. The risk ratios of COVID-19 mortality decreased to less than 0.3 in all age groups. Whereas in the non-COVID-19 causes of death, the decline in risk ratios was observed only in the 30-44 and 45-59 yrs. old (0.99 and 0.98, respectively) age groups, but it did not exceed 1.05 in none of the remaining age groups.

When compared to the 2019 levels, the risk ratios of all-cause mortality by 2022 was higher across all age groups, although not exceeding 1.08. And regarding the non-COVID-19 deaths it declined only in the 0-29 yrs. old, whereas in all the other age groups it has increased, but it did not exceed 1.05 in none of them. Across the Brazilian states we found heterogeneities, despite the similarity in the main trend observed between 2019 and 2022 for the country.

Discussion and next steps

We observed that the COVID-19 pandemic resulted in significant losses of LE at birth in Brazil, especially in 2021, the worst year of the pandemic, followed by a strong recovery by 2022, although not enough to reach pre-pandemic levels. Previous works reported LE losses in 2020 and predicted even higher losses by 2021 (Castro, Gurzenda, et al., 2021). At the subnational level, large disparities between states were observed during the worst years of the pandemic, as reported in the literature by previous works (Castro, Gurzenda, et al., 2021; Castro, Kim, et al., 2021), but the results presented in this paper also suggest that disparities persisted during the recovery period. However, the overall trend observed in Brazil and its states suggests a clear mortality shock caused by the COVID-19 pandemic.

Globally, cross-country studies also reported heterogeneities in LE changes during the worst years of the pandemic and during the recovery phase, especially among high-income countries (Aburto et al., 2021; Aburto, Schöley, Kashnitsky, & Kashyap, 2022; Aburto, Schöley, Kashnitsky, Zhang, et al., 2022; Scherbov et al., 2022; Schöley et al., 2022, 2023).

Among the Brazilian states in 2020, the most affected tend to be those located in the North and in the Northeast, the less developed regions of the country, followed by the states of the Midwest, Southeast and South regions, which are more developed. Previous works highlighted the role of social and regional vulnerabilities in explaining the unequal impact of the COVID-19 mortality in Brazil (Baptista et al., 2022; Baqui et al., 2020, 2021; Castro, Gurzenda, et al., 2021; Castro, Kim, et al., 2021; Martines et al., 2021; Rocha et al., 2021; Santos, Siqueira, Atienzar, Santos, et al., 2022; Szwarcwald et al., 2022).

By 2021, however, we observed an opposite pattern, with most of the states in the most developed regions among those with the highest LE at birth losses. In 2022, most of the highest rebounds in LE at birth were observed in the states that had the highest deficits in 2021 compared to pre-pandemic levels.

The age decomposition analysis showed that in 2020, most of the decline in LE at birth was due to deaths that occurred in the population aged 60 years or older. In 2021, on the other hand, we observed a shift towards the age groups younger than 60 years. The shift to younger ages, especially among those aged 60 years or younger, has been reported in the literature (Aburto, Schöley, Kashnitsky, Zhang, et al., 2022; Schöley et al., 2022). During the recovery from the pandemic through 2022, we found that in most states

(sixteen of twenty-seven), the largest contributions to LE at birth come from the population aged 60 years or older.

The analysis of the changes in age-standardized death risk ratios by causes of death revealed the direct impact of the COVID-19 mortality in the causes of death structure, but also how the risk ratios of other causes of death changed during the pandemic in Brazil. However, we still need to better understand the changes across each of the twenty-seven Brazilian states, which we plan to show in the final paper.

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