Ekonomia — Wroclaw Economic Review 29/4 (2023)
Acta Universitatis Wratislaviensis
No 4195

https://doi.org/10.19195/2658-1310.29.4.13

Joanna Dębicka*
ORCID: 0000-0002-8905-2565
Wroclaw University of Economics and Business
joanna.debicka@ue.wroc.pl

Edyta Mazurek*
ORCID: 0000-0001-7410-1638
Wroclaw University of Economics and Business
edyta.mazurek@ue.wroc.pl

Jana Špirková**
ORCID: 0000-0001-5864-9353
Matej Bel University in Banská Bystrica
jana.spirkova@umb.sk

Changes in the structure of mortality due to COVID-19 in Czechia, Poland, and Slovakia

Date of submission: 02.11.2023; **date of acceptance:** 27.11.2023

JEL classification: C10, I18, J11

Keywords: index similarity of structure, life expectancy, age of death, COVID-19

Abstract

Objectives: The objective of our paper was to determine the statistical significance of the impact of the COVID-19 disease on the average age of death of an individual and the dependence of the average age of death on the causes of death in 2020.

Study design: Awareness of the effects and consequences of the pandemic prompted us to check whether COVID-19 had a statistically significant impact on death patterns in Czechia, Poland, and Slovakia.

* This work was supported by the Ministry of Science and Higher Education in Poland within the program "Regional Initiative of Excellence" 2019–2022 under grant 015/RID/2018/19.

** This work was supported by the Slovak Scientific Grant Agency VEGA under grant 1/0150/21.

Methods: The research is based on a detailed comparative analysis of the age structure of deaths from COVID-19 in countries that are regionally and culturally close. The Renkonen similarity index is calculated, followed by the non-parametric test for similarity of structures.

Results: The average life expectancy in the analyzed countries decreased by about 1–2 years, and the forecasts of the increase in the number of deaths in 2020 turned out to be underestimated by 11% in the case of Slovakia and by 15% in the case of Poland and Czechia. COVID-19 was the fourth leading cause of death for women and the third leading cause of death for men in Poland and Czechia. In Slovakia, it was the third leading cause of death among women and the fourth among men.

Conclusions: The pandemic caused not only direct deaths from the virus, but also indirect deaths due to the disruption of healthcare systems, socioeconomic shocks, and mental health consequences.

1. Introduction

The COVID-19 pandemic not only has left a permanent mark on our way of life and work, but more importantly, it has disturbed the process of demographic change. It led to hundreds of thousands of deaths and has caused disruptions in usual care across the world (Glance et al., 2022)· There have been more excess deaths in several age groups and gender cohorts during the pandemic (Jacobson and Jokela, 2020; Torres et al., 2023). The COVID-19 pandemic is one of the causes why the improvement in life expectancy has slowed down. This, in turn, requires knowledge gleaned from an analysis of demographic change, particularly those related to life expectancy. It is essential in many areas of socioeconomic life. The European Commission's Demography Report (European Commission, 2020), describing the crucial factors of demographic changes and their impact on Europe, has already started a process to help find concrete actions and solutions to support the people, regions, and communities most affected by the crisis. Very inspiring is the article describing how the pre-pandemic situation affected the UK's response to COVID-19 (Hiam et al., 2023).

From the point of view of private institutions, such as insurance companies, any change in life expectancy or in mortality rates due to particular diseases can significantly affect the calculation of life and health insurance premiums (Dash and Grimshaw, 1993; Haberman, 1983a, 1983b; Haberman and Pitacco, 1999; Pitacco, 1994; Pitacco, 2014). Additionally, life expectancy has a significant impact on economic growth (Azomahou et al., 2009; Cervellati and Sunde, 2011). In particular, the COVID-19 pandemic triggered significant mortality increases in 2020, a magnitude that has not been witnessed since World War II. Females from 15 countries and males from 10 countries ended up with a lower life expectancy at birth in 2020 than in 2015 (Aburto et al., 2021).

The structure of causes of death can also be used to evaluate the effectiveness of public health interventions and medical treatment.

Finally, the structure of causes of death can help to prioritize research efforts. By identifying areas of high mortality rates or unexplained increases in deaths, researchers can focus their efforts on understanding the underlying causes and developing new treatments or prevention strategies.

Awareness of the effects and consequences of the COVID-19 pandemic prompted us to check whether COVID-19 had influenced death structures in particular groups in Poland, Czechia, and Slovakia. Another interesting question is whether this impact was statistically significant. Finally, it will be examined whether there have been significant changes in the causes of death in these countries in 2020. The structure of deaths will be compared with the years 2015–2019 and between countries.

However, it is important to highlight the main publications that state that each country has implemented its own system for recording deaths from COVID-19, and that the systems have evolved over the months, thus it could be that the differences in mortality observed over time and space can be attributed only to standard deviations (Garcia et al., 2021).

We also recall a very interesting article by Bhaskaran et al. (2021), in which the authors emphasize that mortality from COVID-19 shows a strong relationship with age and pre-existing health problems, as does mortality from other causes. Most of the factors associated with COVID-19 death were similarly associated with death not related to COVID-19, but the magnitude of the association varied. Older age was more strongly associated with COVID-19 death than death not related to COVID-19, as was male sex or obesity.

The analysis of mortality by cause of death (Toubiana et al., 2023) provides quantitative answers to the overestimation of the impact of the COVID-19 epidemic in France. Their analysis shows that the emergency implementation of the *COVID-19 classification* led to many biases.

A significant number of deaths, usually classified as having a different main cause, i.e., neoplasms or diseases of the circulatory system, were somehow transferred under the COVID-19 label.

2. Methods

Data on the number of deaths reported by the Central Statistical Office of Poland (GUS, 2022), the Statistical Office of the Slovak Republic (2022), the Ministry of Health of Czechia (Ministry of Health of the Czech Republic, 2022), and the Ministry of Health of the Slovak Republic (Ministry of Health of the Slovak Republic, 2022) in 2015, 2019, and 2020 were used to estimate the mean and median age for all causes, including COVID-19, divided by gender. These data were also used to determine the structure of deaths by cause in 2015, 2019, and 2020. The Renkonen similarity index (1938) was used to compare the disease structures in the studied countries, and the statistical test of structure similarity introduced by Sokołowski

(1993) was used to detect statistically significant differences between the structures. The analysis was conducted with a significance level of 0.05.

The research is based on a detailed comparative analysis of the age structure of COVID-19 deaths in countries that are regionally and culturally close. The data are taken from the official websites of each country.

The Renkonen similarity index is calculated, followed by the non-parametric test for similarity of structures.

To compare the age structures of the COVID-19 deaths in the subpopulations, an index of percentage similarity of the structures was chosen. This measure was proposed by Renkonen (Renkonen, 1938) and is sometimes called the Renkonen similarity index. To calculate this similarity measure, each population must be standardized as percentages so that the relative abundances in each population add up to 100%. Often, instead of percentages, decimal values are assigned and then the sum of all indicators of the structure is equal to 1. The similarity index of structures is then calculated as follows:

$$\omega_p = \sum_{i=1}^{k} \min\left\{\omega_i^1, \omega_i^2\right\} \tag{1}$$

where
k — number of classes into which the population was divided,
i — number of the i-th class ($i = 1, 2, \ldots k$),
ω_i^1 — structure indicator of the i-th class in population 1 (i-th element of a simple structure for population 1),
ω_i^2 — structure indicator of the i-th class in population 2 (i-th element of a simple structure for population 2).

Despite its simplicity, the percentage similarity measure is one of the better quantitative similarity coefficients available (Wolda, 1981). The Renkonen similarity index is not affected by proportional differences in abundance between populations but is sensitive to additive changes. This index ranges from 0 — no similarity, to 1 — complete similarity.

$$\omega_p = \begin{cases} 0 & \text{completely different structures} \\ (0,0.6] & \text{no similarity of structures} \\ (0.6,0.7] & \text{slight similarity} \\ (0.7,0.8] & \text{considerable similarity} \\ (0.8,0.9] & \text{high similarity} \\ (0.9,1] & \text{very high similarity} \\ 1 & \text{identical structures} \end{cases} \tag{2}$$

The calculated value of the similarity index of structures multiplied by 100% indicates how many percentages the simple structures are similar to each other. This indicator also has a very important property from the point of view of the criterion for assessing the similarity of structures. There is a statistical test of the similarity of structures based on the Renkonen similarity index given by formula (1), introduced by Sokołowski (1993). The non-parametric test for similarity of structures consists of two test hypotheses:

H_0 : The structures are dissimilar,

H_1 : The structures are similar.

For a given level of significance, we have a right-tailed rejection region.

The critical values of the similarity structure test depend on the significance level (α) and the number of classes (k) in the compared structures. Table 1 includes the critical values $z_{\alpha,k,}$ for sample significance levels and a number of classes. Since the article analyses 17 groups of causes of death and 18 age groups into which people who died from COVID-19 were divided, the critical values in Table 1 are provided for this number of classes. The critical values for $k = 2$ are only supplementary for comparative purposes.

Table 1. Examples of critical values $z_{\alpha,k,}$ for selected significance levels

Significance level	Critical value		
	$k = 2$	$k = 17$	$k = 18$
0.01	0.9908	0.6976	0.6929
0.05	0.9687	0.6465	0.6424
0.10	0.9362	0.6188	0.6153

Source: own elaboration based on Sokołowski (1993).

When the value of the test statistic ω_p (see equation 1) does not belong to the critical set ($z_{\alpha,k,}$ ∞), there is no basis for rejecting the null hypothesis H_0 that the structures are dissimilar. However, if the value of the test statistic ω_p belongs to the critical set, ($z_{\alpha,k,}$ ∞) we reject the null hypothesis H_0 that the structures are dissimilar in favor of the alternative hypothesis H_1 that the structures are similar.

An important and useful property of the similarity test for structures is that the compared structures do not have to have the same number of components. If some components are missing in the examined structures, it is assumed that these missing components are equal to 0. In other words, if there is a lack of the i-th relative frequency in the examined variables, it is assumed that this relative frequency is 0.

3. Results

To start, let us look at the average age of death in 2020 in the monitored countries.

Figure 1 presents the average age of death by sex in Czechia, Poland, and Slovakia in 2020. It can be seen that the average age of death is highest in Czechia and lowest in Slovakia. In addition, women die at an older age than men in all three countries.

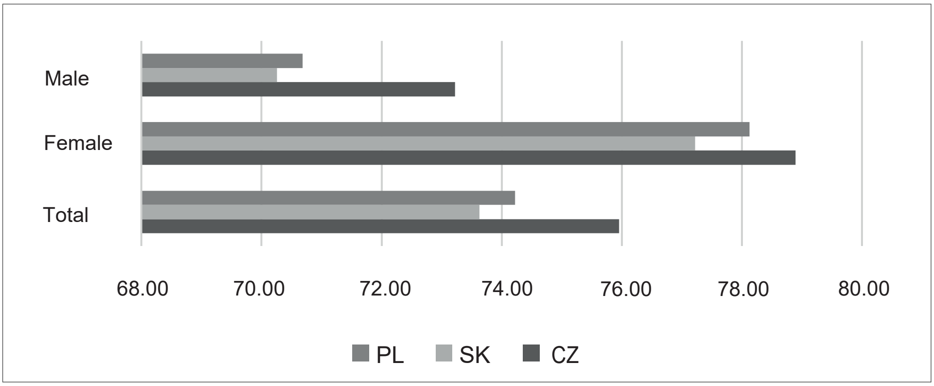

Figure 1. The average age of death in 2020 (in years)

Source: own elaboration based on Eurostat database.

To investigate what effect causes of death, including COVID-19, had on the average age of death, the mean age of death by cause of death was analyzed. In the analysis, causes of death are classified according to the International Statistical Classification of Diseases (Haberman and Pitacco, 1999), see Table 2.

The average age of death in 2020 for Czechia, Slovakia, and Poland is interpreted graphically as the sum of all bars in the graph in Figure 2, where on the horizontal axis, there are 5-year age groups (corresponding to the age of people at the time of death), on the vertical axis we have the symbols of causes of death from Table 2. The analysis of the charts allows us to identify the five causes of death that contributed most to the average age of death. These causes by country are presented next to each graph in Figure 2. It turns out that COVID-19 is in third place as a cause of death in the entire Czech population and fourth place among both the Slovak and Polish ones. In Poland, among women, the order of causes of death is the same. However, among men, COVID-19 is in third place as the cause of death that significantly impacts the average age of death. In Czechia, COVID-19 is the third most crucial cause of death among men and women. While in Slovakia, COVID-19 is the third most crucial cause of death among women and the fourth among men. In terms of age groups, the higher the age, the more significant the contribution to the average age of death.

Table 2. The causes of death's classification

Symbol	Cause of death
A–B	Certain infectious and parasitic diseases
C–D (0–48)	Neoplasms
D (50–89)	Diseases of the blood and blood-forming organs and certain disorders involving the immune mechanism
F	Mental and behavioral disorders
G–H	Diseases of the nervous system and the sense organs
I	Diseases of the circulatory system
J	Diseases of the respiratory system
K	Diseases of the digestive system
L	Diseases of the skin and subcutaneous tissue
M	Diseases of the musculoskeletal system and connective tissue
N	Diseases of the genitourinary system
O	Pregnancy, childbirth and the puerperium
P	Certain conditions originating in the perinatal period
Q	Congenital malformations, deformations and chromosomal abnormalities
R	Symptoms, signs and abnormal clinical and laboratory findings not elsewhere classified
U	COVID-19
V–Y	External causes of morbidity and mortality

Source: own elaboration based on *The International Statistical Classification of Diseases and Related Health Problems. 10th Revision* (Ministry of Health of the Slovak Republic, 2022).

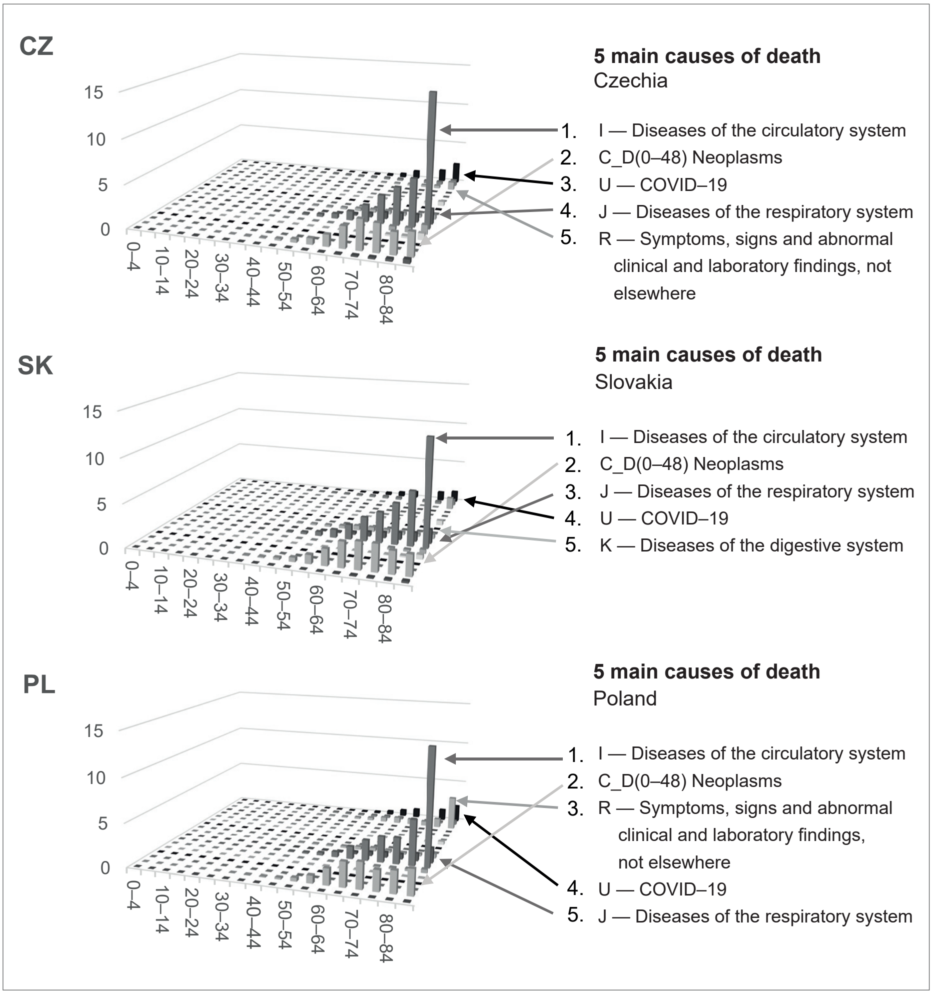

Figure 2. Contribution to the mean age of death of people in a certain age class who died of a certain cause, 2020

Source: own elaboration based on *The International Statistical Classification of Diseases and Related Health Problems. 10th Revision* (Ministry of Health of the Slovak Republic, 2022).

Figure 3 illustrates the median deaths (*Me*) and the typical range of variability for the average age (*Me–Q*, *Me+Q*) where *Q* is the quarter deviation, in the entire population and separately among those who died of COVID-19.

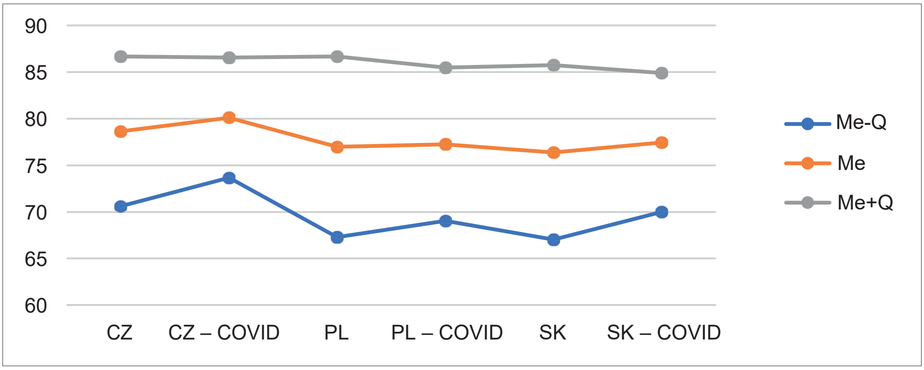

Figure 3. The median and typical ranges of the age of death in the whole population and among those who died of COVID-19 for Czechia, Slovakia, and Poland, 2020

Source: own elaboration.

Let us note that the median age of death for people who died due to COVID-19 is higher than the median age of death for people who died in 2020 by 0.4% in Poland, 1.4% in Slovakia, and 1.9% in Czechia, respectively. Larger differences are observed when comparing the typical age of death. Namely, it turns out that the typical age of people who died due to COVID-19 is within the range typical for people who died in general. This is mainly due to the fact that the quarterly deviation of the age of death among people who died of COVID-19 is 20% smaller in Poland and Slovakia, and 15% smaller in Czechia than that calculated for the entire population of people who died in 2020.

Looking at the median and typical ranges of the age of death due to COVID-19, it can be seen that in all countries, the median age of death for women is higher than for men by 3–4%. The diversity of death age for women is 10% lower than for men in Poland and 14% in Czechia and Slovakia, respectively (see Figure 4).

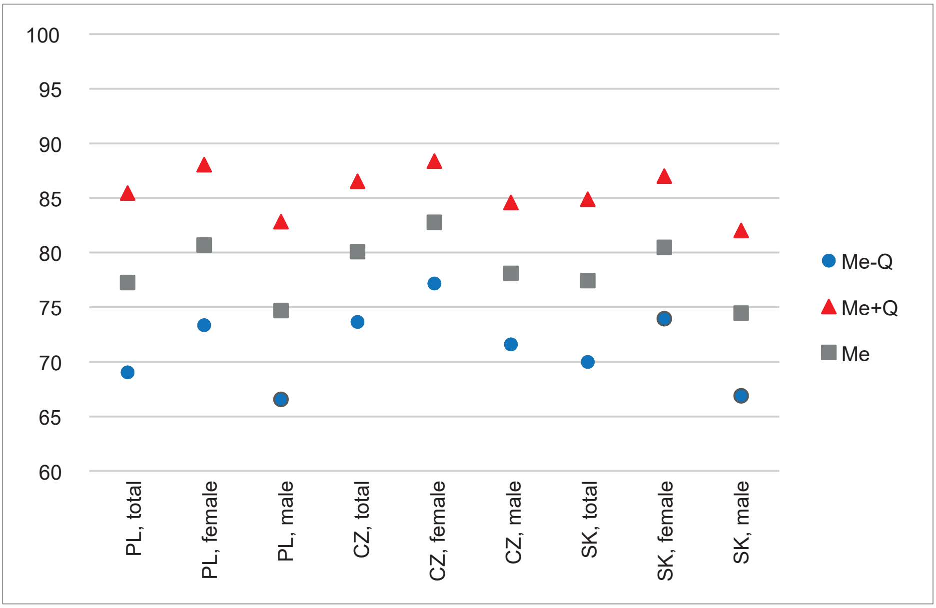

Figure 4. The median and typical ranges of the age of death due to COVID-19, 2020

Source: own elaboration.

Figure 5 presents the empirical distributions of the age of death of people who died due to COVID-19 (in general and by gender) for the populations analyzed in the article.

It is therefore natural to ask whether the age structure of COVID-19 deaths in the analyzed countries differs significantly due to gender and among themselves.

Among those who died from COVID-19, people in their 30s are a marginal part of the collective, and no differences were observed between women and men in each country. In Poland, for both men and women, the number of deaths increases until the age of 70. Afterwards, it decreases and rises slightly again from the age of 80. A similar trend is observed among Czech men; however, the correlation between age and the number of deaths increases continuously for women. In Slovakia, the number of deaths increases continuously for women like in Czechia. However, in the case of men, the situation among those who died over 80 years old is different from that in Poland and Czechia. In fact, the number of deaths from COVID-19 among men between 30 and 70 years of age increases with age, but later we observe a decline. Furthermore, relatively more men than women died from COVID-19 up to the age of 80 in Poland and Czechia and up to the age of 75 in Slovakia, while the situation is the opposite for older people, see Figure 5.

According to the similarity index of structures presented in Table 3, the similarity of the age structures of COVID-19 deaths between women and men in each country is high (see Formula (2)).

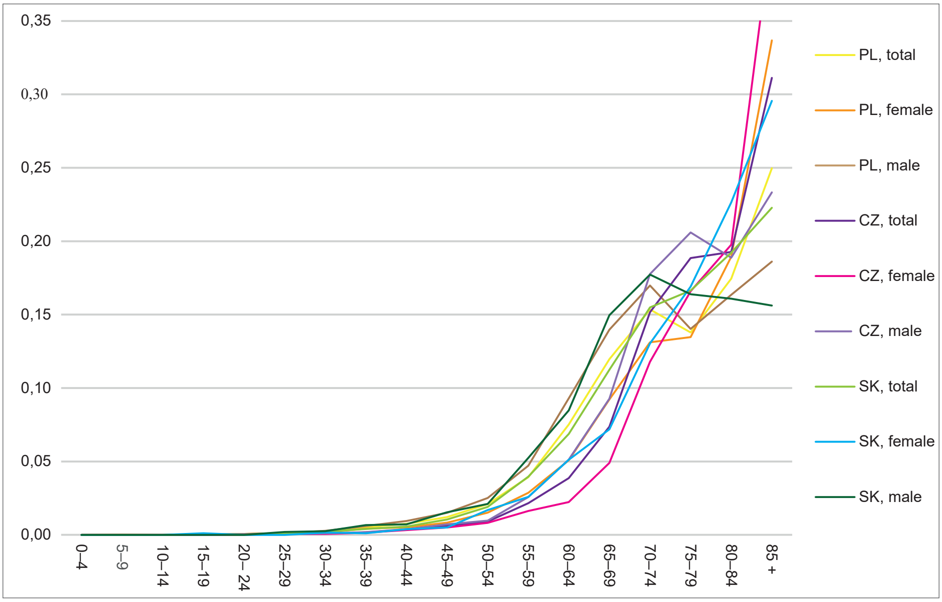

Figure 5. The age structures of COVID-19 deaths (overall and by sex) for Czechia, Slovakia and Poland, 2020.

Source: own elaboration.

Table 3. The value of the index of similarity ω_p of the age structures of COVID-19 deaths, 2020

	Populations	Structure similarity coefficient		Populations	Structure similarity coefficient
CZ	Female / Male	0.81	Female	CZ / SK	0.88
SK	Female / Male	0.79	Female	CZ / PL	0.89
PL	Female / Male	0.82	Female	SK / PL	**0.93**
Total	CZ / SK	0.89	Male	CZ / SK	0.85
Total	CZ / PL	0.87	Male	CZ / PL	0.85
Total	SK / PL	**0.95**	Male	SK / PL	**0.95**

Source: own elaboration.

Comparing the age structures of deaths due to COVID-19 in the analyzed countries, it turns out that the greatest similarity is observed between the structures of death age in Poland and Slovakia. In all cases, the similarity test of the structures rejected the hypothesis that the similarity of the structures is random. All calculated indicators ω_p gathered in Table 3 belong to the critical set $(z_{0.01,18}, \infty) = (0.6929, \infty)$ (see Table 1). Therefore, at the high significance level of 0.01, we can assume that the age structures of the deaths are very similar regardless of gender or citizenship.

To get the full picture, let's look in more detail at the empirical structure of causes of death. Over time, the change in the structure of deaths was based on observations from 2000 to 2020. This period was chosen based on a detailed analysis of deaths in Poland from 2000 to 2020. For Poland, more complex data were available. Additionally, due to proximity and similar healthcare policies, it was assumed that the structure of deaths before the COVID-19 pandemic in Czechia and Slovakia would be similar. With this data, it was possible to observe a change in trend in 2014 for most causes of death. Therefore, only the years 2015–2019 were chosen.

Based on data from 2015–2019, for each group of causes of death, the theoretical variability ranges were determined. It turned out that the data from 2020, in some groups of causes of death, exceeded the theoretical range of variability determined based on the years 2015–2019. Therefore, it can be inferred that in these groups, the number of deaths was indeed higher than in the previous five years:

— G–H: Diseases of the nervous system and the sense organs (CZ, PL);

— R: Symptoms, signs and abnormal clinical and laboratory findings, not elsewhere (CZ);

— M: Diseases of the muscloskeletal system and connective tissue (PL),

or lower as in case of:

— Q: Congenital malformations, deformations and chromosomal abnormalities (CZ), see Table 4.

Table 4. Changes in the number of deaths in countries: total and from causes identified as outliers in relation to those in 2015–2019

Cause of death	Average rate of change 2015–2019 (%)	Increase in 2020 vs. 2019 (%)	Difference (percentage points)
CZ, total	0.08	15.18	15.10
G–H	4.00	13.00	8.00
R	4.00	138.00	134.00
Q	0.00	−14.00	−14.00
PL, total	0.70	16.16	15.46
G–H	4.00	20.00	16.00
M	1.00	12.00	11.00
SK, total	−0.22	11.30	11.52

Source: own elaboration.

It should be noted that the COVID-19 pandemic and prolonged lockdowns were the reason for changing the lifestyle of entire populations, which could significantly affect mortality from emotionally related diseases, which is very clearly visible in Czechia and Poland.

In the years 2015–2019, the number of deaths increased on average by less than 1% per year in Czechia and Poland, and decreased slightly in Slovakia. In 2020, the number of deaths increased by 16% in Poland, 15% in Czechia, and 11% in Slovakia compared to 2019. Therefore, the difference shows that for Czechia as well as for Poland, the predicted numbers of deaths, based on the data from 2015–2019, were underestimated by about 15%, and by 11% in the case of Slovakia.

The data presented in Table 4 suggest that the number of deaths from particular causes (causes identified as standing out with a high frequency of deaths compared to the previous five years) are higher and lower in only one case. Thus, the question of whether the entire structure of causes of death has been disturbed arises, see Figure 6.

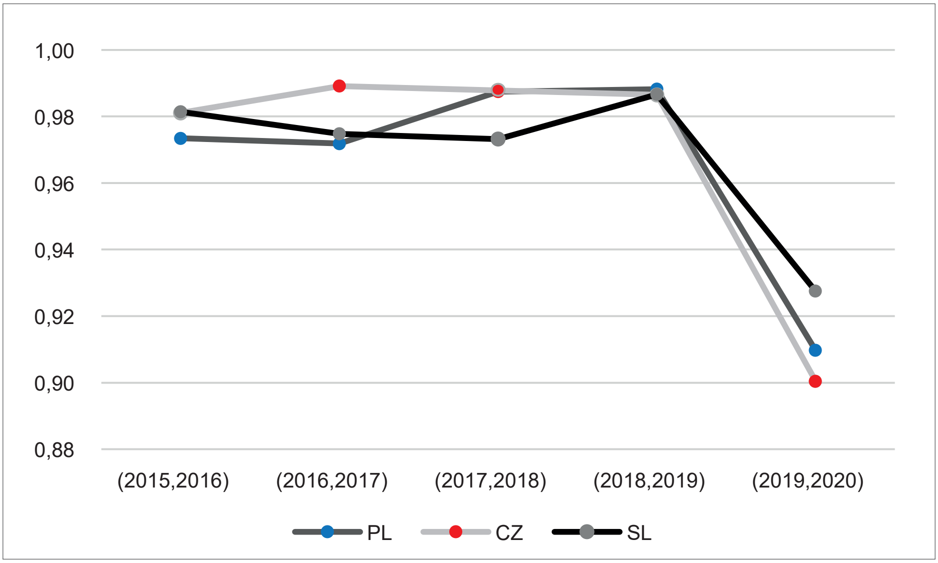

Figure 6. Similarity index of cause of death structures (year-on-year), 2015–2020

Source: own elaboration.

In each country, the coefficient of similarity of structures year-on-year decreased significantly from 2020 to 2019. However, this is not enough to reject the hypothesis that the structures are similar. The values of the test statistic for the structures of the cause of death (2020 vs. 2019) are as follows: CZ — 0.90, PL — 0.91, SK — 0.93. The verification of such a hypothesis could have been conducted due to the possibility of utilizing the discussed statistical test for the similarity of two structures with different components. However, the differences between the structures and causes of death in each analyzed country are statistically significant. The test for similarity of structures is to be checked (all similarity indexes belong to the critical set $(z_{0.01,17}, \infty) = (0.6976, \infty)$; compare with Table 1).

Let us take a detailed look at the structures of causes of death, which are presented for the years 2015, 2019, and 2020 (see Table 5).

Table 5. The structures of causes of death in 2015, 2019 and 2020

	CZ			PL			SK		
Cause of death	2015	2019	2020	2015	2019	2020	2015	2019	2020
I	0.479	0.444	0.409	0.468	0.405	0.376	0.457	0.439	0.429
C–D (0–48)	0.257	0.270	0.233	0.273	0.272	0.234	0.262	0.265	0.246
U (COVID-19)			0.086			0.089			0.065
J	0.070	0.077	0.067	0.063	0.068	0.062	0.069	0.063	0.069
V–Y	0.056	0.055	0.047	0.052	0.050	0.044	0.048	0.060	0.048
K	0.044	0.047	0.042	0.038	0.044	0.041	0.055	0.060	0.055
G–H	0.028	0.035	0.034	0.014	0.016	0.017	0.020	0.027	0.020
R	0.011	0.013	0.027	0.068	0.113	0.107	0.017	0.026	0.017
F	0.014	0.017	0.016	0.006	0.010	0.009	0.013	0.016	0.013
A–B	0.019	0.017	0.016	0.005	0.004	0.004	0.010	0.016	0.010
N	0.013	0.016	0.015	0.008	0.011	0.012	0.018	0.017	0.018
M	0.002	0.003	0.002	0.001	0.001	0.001	0.001	0.001	0.001
D (50–89)	0.002	0.002	0.002	0.001	0.001	0.001	0.001	0.001	0.001
L	0.002	0.002	0.002	0.001	0.001	0.001	0.003	0.004	0.003
P	0.001	0.001	0.001	0.002	0.002	0.001	0.002	0.003	0.002
Q	0.001	0.001	0.001	0.001	0.001	0.000	0.003	0.003	0.003
O	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Source: own elaboration.

In 2015–2019 the structures were stable and similar to each other. The introduction of the new cause of death in 2020 somewhat disrupted the death structure in three countries, as it became the third (CZ) and fourth (PL and SK) leading cause of death. However, from a statistical point of view, the difference in the structure of causes of death in 2019 cannot be considered statistically significantly different from that in 2020.

4. Discussion

This study provides a preliminary assessment of changes in the structure of mortality, taking into account COVID-19. First of all, it turned out that life expectancy in the analyzed countries fell by about 1–2 years in 2020, and the forecasts of the increase in the number of deaths in 2020 were underestimated by 11% in the case of Slovakia and by 15% in the case of Czechia and Poland. COVID-19 was the fourth most significant cause of death among women and the third among men in Poland and Czechia, and the third among women and the fourth among men in Slovakia.

Furthermore, it has been shown that COVID-19 may have an indirect impact on mortality from other causes, for example, by disrupting routine healthcare. The similarity coefficient of the cause-of-death structures (2020, 2019) decreased by (8–9)% compared to that in the subsequent years of the period 2015–2019. Nevertheless, the differentiation of the cause-of-death structures in 2020 cannot be considered statistically significantly different from that in 2015–2019. However, it is possible to distinguish causes of death due to which the number of deaths increased enough in 2020 compared to 2015–2019 to significantly disrupt the average rate of change in the number of deaths due to these causes. The results show that COVID-19 is undoubtedly a disease that generated demographic changes in the monitored countries. The pandemic has caused not only direct deaths due to the virus, but also indirect deaths due to the disruption of healthcare systems, social, and economic upheaval, and mental health consequences.

However, it is necessary to be very careful when using these data to assess the structure of mortality, including the coronavirus, not only between the countries but also within one country. The methods of diagnosing the disease vary; a different set of criteria is used, and it can change even within one country during a pandemic wave (Tsang et al., 2020). Some infected people have no symptoms. Therefore, it is very unlikely that they will be included in the coronavirus statistics. The World Health Organization (2020), in its guidelines for the certification and classification of COVID-19 as a cause of death, gives a broad definition that include confirmed and suspected cases.

Acknowledgments

Ethical approval

The authors declare that they have written a completely original work based on their own research and if they have used the work or words of other authors, it has been properly cited or cited to the best of their knowledge.

Funding

This work was supported by the Ministry of Science and Higher Education in Poland within the program “Regional Initiative of Excellence” 2019–2022 under grant 015/RID/2018/19; and by the Slovak Scientific Grant Agency VEGA under grant 1/0150/21.

References

Aburto, J.M., Schöley, J., Kashnitsky, I., Zhang, L., Rahal, Ch., Missov, T., Mills, M., Dowd J., Kashyap R. (2022). Quantifying impacts of the COVID-19 pandemic through life-expectancy losses: A population-level study of 29 countries. *International Journal of Epidemiology*, 51(1), 63–74. https://doi.org/10.1093/ije/dyab207.

Azomahou, T.T., Boucekkine, R., Diene, B. (2009). A closer look at the relationship between life expectancy and economic growth. *International Journal of Economic Theory*, 5(2), 201–244. https://doi.org/10.1111/j.1742-7363.2009.00105.x.

Bhaskaran, K., Bacon, S., Evans, S.J., Bates, C.J., Rentsch, C.T., MacKenna, B., Tomlinson, L., Walker, A.J., Schultze, A., Morton, C.E., Grint, D., Mehrkar, A., Eggo, R.M., Inglesby, P., Douglas, I.J., McDonald, H.I., Cockburn, J., Williamson, E.J., Evans, D., Curtis, H.J., Hulme, W.J., Parry, J., Hester, F., Harper, S., Spiegelhalter, D., Smeeth, L., Goldacre, B. (2021). Factors associated with deaths due to COVID-19 versus other causes: Population-based cohort analysis of UK primary care data and linked national death registrations within the Open SAFELY platform. *The Lancet Regional Health — Europe*, 6(2021), 100109. https://doi.org/10.1016/j.lanepe.2021.10010.

Cervellati, M., Sunde, U. (2011). Life expectancy and economic growth: The role of the demographic transition. *Journal of Economic Growth*, 16(2), 99–133. https://doi.org/10.1007/s10887-011-9065-2.

Dash, A., Grimshaw, D. (1993). Dread disease cover — an actuarial perspective. *Journal of Staple Inn. Actuarial Society*, 33,149–193. Retrieved September 5, 2022, from https://www.actuaries.org.uk/system/files/documents/pdf/0149-0193.pdf.

European Commission. (2020, June 17). *European Commission Adopted Report on the Impact of Demographic Change in Europe*. Retrieved August 17, 2022, from https:/www./ec.europa.eu/commission/presscorner/detail/en/ip_20_1056.

Garcia, J., Torres, C., Barbieri, M., Camarda, C.G., Cambois, E., Caporali, A., Meslé, F., Poniakina, S., Robine, J.M. (2021). Differences in COVID-19 mortality: Implications of imperfect and diverse data collection systems. *Population*, 76(1), 35–72. https://doi.org/10.3917/popu.2101.0035.

Glance, L.G., Dick, A.W., Shippey, E., McCormick, P.J., Dutton, R., Stone, P.W., Shang, J., Lustik, S.J., Lander, H.L., Gosev, I., Joynt Maddox, K.E. (2022). Association between the COVID-19 pandemic and insurance-based disparities in mortality after major surgery among US adults. *JAMA Network Open*, 5(7), e2222360. Retrieved September 2, 2022, from https://www.jamanetwork.com/journals/jamanetworkopen/fullarticle/2794297.

GUS. (2022). Główny Urząd Statystyczny. Retrieved September 15, 2022, from https://www.stat.gov.pl/en/.

Haberman, S. (1983a). Decrement tables and the measurement of morbidity: I. *Journal of the Institute of Actuaries*, 110(2), 361–381. https://doi:10.1017/S0020268100041391.

Haberman, S. (1983b). Decrement tables and the measurement of morbidity: II. *Journal of the Institute of Actuaries*, 111(1), 73–86. https://doi:10.1017/S002026810004155X.

Haberman, S., Pitacco, E. (1999). *Actuarial Models for Disability Insurance*. Boca Raton: Chapman & Hall.

Hiam, L., Dorling, D., McKee, M. (2020). When experts disagree: Interviews with public health experts on health outcomes in the UK 2010–2020. *Public Health*, 96–105. https://doi.org/10.1016/j.puhe.2022.10.019.

International Statistical Classification of Diseases and Related Health Problems. 10th Revision. (2019). Retrieved November 29, 2022, from https://www.icd.who.int/browse10/2019/en.

Jacobson, S.H., Jokela, J.A. (2020). Non-COVID-19 excess deaths by age and gender in the United States during the first three months of the COVID-19 pandemic. *Public Health*, 189, 101–103. https://doi.org/10.1016/j.puhe.2020.10.004.

Ministry of Health of the Czech Republic. (n.d.). Retrieved September 10, 2022, from https://www.mzcr.cz/.

Ministry of Health of the Slovak Republic. (n.d.). Retrieved September 10, 2022, from https://www.health.gov.sk/.

Pitacco, E. (2014). *Health Insurance. Basic Actuarial Models. EAA series.* New York: Springer.

Pitacco, E. (1994). LTC insurance. From the multistate model to practical implementations. In *Proceedings of the XXV ASTIN Colloquium, Cannes, France*, 437–452.

Renkonen, O. (1938). *Statisch-ökologische Untersuchungen über die terrestrische Käferwelt der finnischen Bruchmoore*. Societas zoologica-botanica Fennica Vanamo.

Sokołowski, A. (1993). Propozycja testu podobieństwa struktur. *Przegląd Statystyczny*, 40(3–4), 295–301.

Statistical Office of the Slovak Republic (2022). *Deaths by Causes of Death Age and Sex — SR-Reg-District*. Retrieved October 11, 2022, from http://www.datacube.statistics.sk/#!/view/sk/vbd_dem/om7036rr/v_om7036rr_00_00_00_en.

Torres, C., García, J., Meslé, F., Barbieri, M., Bonnet, F., Camarda, C.G., Cambois, E., Caparali, A., Couppié, É., Poniakina, S., Robine, J.M. (2023). Identifying age-and sex-specific COVID-19 mortality trends over time in six countries. *International Journal of Infectious Diseases*, 128, 32–40. https://doi.org/10.1016/j.ijid.2022.12.004.

Toubiana, L., Mucchielli, L., Bouaud, J., Chaillot, P. (2023). What the analysis of causes of death in France in 2020 reveals about the impact of the COVID-19 epidemic. *MedRxiv*, 1–14. https://doi.org/10.1101/2023.03.07.23286673.

Tsang, T.K., Wu, P., Lin, Y., Lau, E.H.Y., Leung, G.M., Cowling, B.J. (2020). Effect of changing case definitions for COVID-19 on the epidemic curve and transmission parameters in mainland China: A modelling study. *The Lancet Public Health*, 5(5), e289–e296. https://doi.org/10.1016/S2468-2667(20)30089-X.

WHO. (2020, April 20). *International Guidelines for Certification and Classification (Coding) of COVID-19 as Cause of Death.* World Health Organization. Retrieved September 30, 2022, from https://www.who.int/publications/m/item/international-guidelines-for-certification-and-classification-(coding)-of-COVID-19-as-cause-of-death.

Wolda, H. (1981). Similarity indices, sample size and diversity. *Oecologia*, 50(3), 296–302.