Seasonality in mortality and its impact on life expectancy levels and trends across Europe

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ABSTRACT

Background Seasonal fluctuations in mortality affect annual life expectancy at birth (e_0). Nevertheless, evidence on the impact of seasonal mortality on longevity is very limited and mainly restricted to assessing season-specific mortality levels due to shocks (e.g., heatwaves and influenza epidemics). We investigated the influence of seasonality in mortality on life expectancy levels and temporal trends across 20 European countries during 2000–2019.

Data and methods We used harmonised weekly population-level mortality data from the Human Mortality Database. Seasonal contributions to life expectancy at birth and age 65, by sex, were estimated using the excess mortality approach and decomposition analysis. Time-series analysis was used to evaluate the impact on long-term mortality trends.

Results Seasonal mortality had a substantial but stable impact on e_0 between 2000 and 2019. On average, we found an annual reduction in life expectancy due to seasonal excess mortality of 1.14 years for males and 0.80 years for females. Deaths in the elderly population (65+) were the main driver of this impact: around 70% and 90% of these reductions in life expectancy were attributable to older ages. Excess mortality in winter had the strongest impact on annual life expectancy, especially in Portugal and Bulgaria (around 0.8-year loss on e_0).

Conclusions The study revealed significant cross-country variations in contributions of seasonal mortality. The most pronounced effects were observed in winter months and at older ages. These findings underscore the need for timely and targeted public health interventions to mitigate excess seasonal mortality.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Seasonal mortality is characterised by higher mortality during winter months and is known to affect annual life expectancy; however, the magnitude of the exact contribution of seasonality in mortality on life expectancy levels and trends remains unknown.

WHAT THIS STUDY ADDS

⇒ We quantified the effect of seasonality, both overall and by season, on life expectancy levels and temporal trends in the 21st century for 20 European countries, by sex, using long-term harmonised mortality data by country and advanced formal population-level analyses.

⇒ The overall impact of seasonal mortality on life expectancy was substantial for some countries, especially among older adults, and predominantly driven by excess mortality during winter, particularly in Southern and Eastern Europe.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ The findings highlight the need to incorporate seasonal mortality patterns into public health strategies, while monitoring seasonal mortality risks, to improve longevity, particularly in light of climate change and population ageing.

INTRODUCTION

Mortality dynamics in human populations are characterised by seasonal dependence,[1] usually defined by higher mortality during winter or summer months. These mortality fluctuations also affect life expectancy levels and trends.[1] However, the existing evidence about the extent of these effects is scarce. Despite the recognised importance of seasonal variations, most of the prior mortality studies have been primarily based on annual estimates. This approach, however, overlooks important seasonal fluctuations.

Recently, the COVID-19 pandemic has fostered the dissemination of detailed weekly mortality data, which are essential when addressing and monitoring epidemics and climate change threats.[2] This is particularly relevant in the context of population ageing and multiple long-term conditions,[3] with an increasing number of individuals with a higher risk of mortality during extreme temperature events, particularly in winter and summer months.[4 5] Furthermore, climate change may gradually influence seasonal mortality patterns, as human populations adapt to shifting temperatures; yet, it might be directly responsible for temperature-related excess deaths.[6]

Prior research that considers seasonal mortality has mostly focused on season-specific mortality levels.[7–9] These studies highlighted specific periods showing distinct peaks in mortality (e.g., heatwave of 2003[10] and winter influenza epidemics in 2004–2005,[11] 2009–10,[12] 2014–15[13] and 2016–17).[14] They also reported differences between countries in vulnerability to these events. However, the evidence about the exact contributions of seasonal excess mortality to aggregated mortality measures, such as annual life expectancy at birth (e_0), remains very scarce.

Even less is known about the impact of seasonality on temporal changes in life expectancy. Few evidence suggests that the overall impact of seasonality on mortality levels decreased during the 20th century,[15] partially due to economic, scientific, technological and medical progress, such as life-saving antibiotics and the introduction of advanced heating systems.[16 17] However, this process has been uneven across countries. For example, Japan showed a decrease in seasonal mortality impact already in the 1970s.[16] At the same time, the United Kingdom still experienced high excess winter mortality until the last decades of the 20th century.[16 17] A recent study has shown that 40% of the total increase in life expectancy at birth during the last 150 years can be explained by a decrease in seasonal mortality at age 60 and over.[5] Nevertheless, still little is known about the exact impact of seasonal mortality on changes in life expectancy during the most recent decades.

This study systematically assesses the impact of seasonal excess mortality (both overall and by season) on annual levels and temporal changes in life expectancy in 20 European countries between 2000 and 2019. The findings contribute to the existing literature by providing new evidence on the exact impact of seasonal fluctuations on mortality, which is based on harmonised weekly mortality data, by country and sex. This new knowledge, considering spatial variations in the impact of seasonality, will serve as a solid base for further studies examining the future scenarios and consequences of climate change in a rapid population ageing context.

DATA AND METHODS

See online supplemental material: A for more detailed information regarding the data and methods.

We used data from the Human Mortality Database (HMD).[18] Annual population exposures were retrieved from the HMD core dataset, while the weekly death counts were obtained from the Short-Term Mortality Fluctuations[19] (STMF@HMD) data series. Specifically, we used weekly death counts and annual population exposures on the 1st of January by sex and 5-year age group (0, 1–4, 5–9, …, 95–99, 100+), from 2000 to 2019. All the analyses were carried out separately by sex for each of the 20 European countries: Austria, Belgium, Bulgaria, Croatia (from 2001), Estonia, Finland, France, Germany, Hungary, Lithuania, Latvia, the Netherlands, Norway, Poland, Portugal, Russia, Slovakia, Spain, Sweden and Switzerland. The European median was calculated as the median of 20 countries' life expectancy estimates.

To assess the impact of seasonal fluctuations on annual life expectancy at birth (e_0), we first computed the annual and seasonal e_0, by applying standard demographic life table techniques[20] to observed age-specific mortality rates. Second, we calculated the 'expected mortality' in the absence of excess seasonal mortality based on the lowest quartile of death counts in a year (13 weeks of the corresponding year with the lowest death counts).[21] Using the 13 weeks with the lowest mortality and not a fixed timeframe allowed us to assess the minimum achievable level of mortality in a year, measuring intra-annual variation consistently over time. We conceptualised this as the 'best' mortality scenario (*upper* e_0), theoretically achievable in each country each year (online supplemental figure S1 online supplemental Material B and online supplemental figure S1, online supplemental material C). Third, e_0 losses due to seasonal excess mortality were calculated as the difference between the *upper* and observed e_0.

To compute the season-specific contribution to the e_0 losses due to seasonal excess mortality, we applied a modification of the stepwise decomposition by age and cause of death,[22] using season-specific death counts instead of cause-specific counts. We decomposed the difference between observed and expected (*upper*) e_0 by season and age as follows:

$$e_{0,t}^{observed} - e_{0,t}^{upper} = \Delta e_{0,t} = \sum_{x=0}^{100+} \sum_{season} \Delta e_{x,t}^{season} \qquad (1)$$

where $\Delta e_{x,t}^{season}$ are the age-, year- and season-specific contributions of excess deaths and $season \in$ (Winter, Spring, Summer, Autumn).

Finally, to measure the impact of excess seasonal mortality on changes in life expectancy, we calculated e_0 without season-specific excess mortality using as mortality rates:

$$m_{x,t}^{-season} = \frac{D_{x,t}^{-season}}{k_t P_{x,t}} \qquad (2)$$

where $D_{x,t}^{-season}$ are the age- and year-specific death counts, after the elimination of excess deaths of specific seasons. The elimination of season-specific excess deaths was performed by replacing season-specific deaths with those based on the lowest quartile of death counts in the corresponding year. We compared the observed and estimated e_0 under two hypothetical scenarios of (a) no overall excess seasonal mortality and (b) no season-specific (spring, summer, autumn and winter) excess mortality.

Since seasonal mortality might affect differently the elderly population (65 years and above), we analysed separately the impact of seasonal mortality on remaining life expectancy at age 65 (e_{65}). These estimates were based on the same 13 weeks selected with the overall lowest death counts instead of age-specific lowest death counts, as selecting the latter instead did not significantly change the outcomes (online supplemental figure S1, online supplemental material D) and the former ensured consistency and comparability of the estimates.

The analysis was conducted in R version 4.2.3.

RESULTS

Annual life expectancy and seasonal fluctuations of mortality

During the period 2000–2019, the median e_0 increased from 77.7 years (80.7 females and 74.2 males) to 81.4 years (83.5 females and 78.8 males). However, the increase has not been steady during the last two decades, also due to slowdowns or even stagnation in mortality in some western countries. Seasonal e_0 was characterised by drops during winter and higher values during milder climate seasons (figure 1). The largest decreases in seasonal e_0 were observed during the winter seasons of 2009–2010 and 2014–2015 when we observed a reduction of 1.0 and 1.2 years for both sexes combined. Country-specific values showed much bigger variation across territories and years (online supplemental figure S2, online supplemental material B for the country-specific results and online supplemental figure S2, online supplemental material C for the analysis of older ages).

Contribution of seasonal mortality to annual life expectancy

On average, seasonal mortality decreased each year life expectancy at birth by around 1.14 years for males and 0.88 years for females (figure 2). However, in terms of country-specific outcomes, the total contribution of excess seasonal mortality varied between 0.71 and 1.73 years for males and between 0.75 and 1.53 years for females (online supplemental figure S3, table S1a,b, online supplemental material B).

The aggregated findings for the median across the selected 20 European countries showed a decreasing trend in the total contributions of seasonality to life expectancy at birth (although not statistically significant). Nevertheless, the country-specific

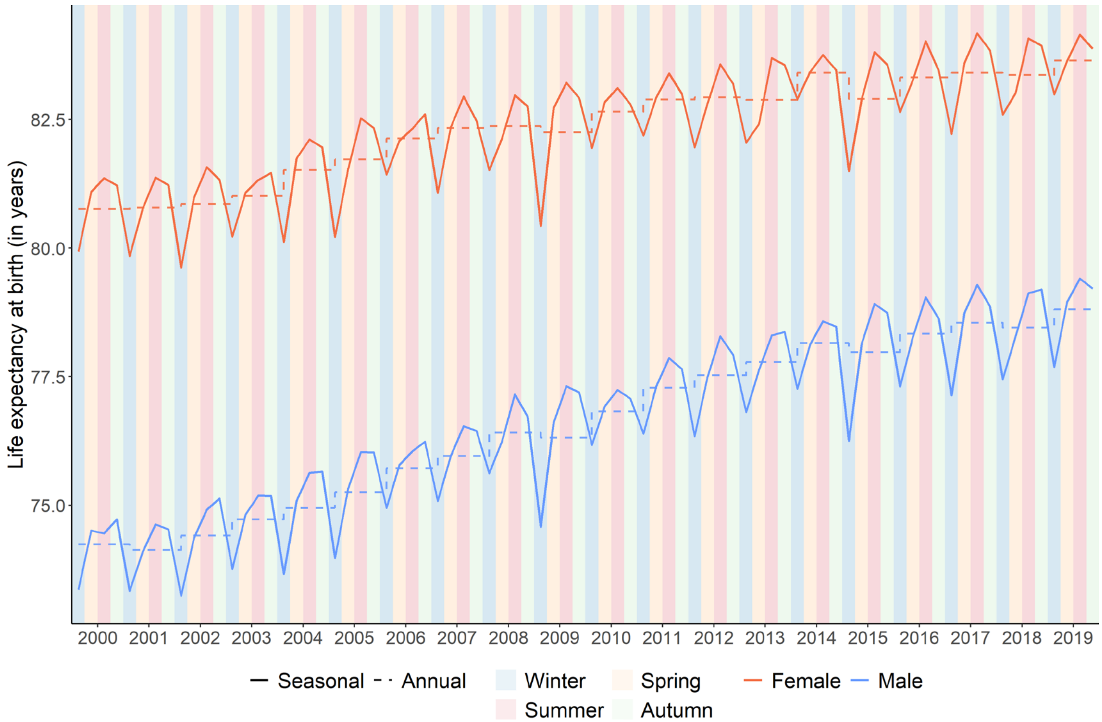

Figure 1 Annual (dotted line) and seasonal (solid line) life expectancy at birth by sex, median across the selected 20 European countries, 2000–2019.

analysis (online supplemental figure S3, online supplemental material B) revealed a heterogeneous pattern. For males, Bulgaria and Estonia suggested a statistically significant decrease in the contribution of seasonality over time. Similarly, it was also possible to observe the signs of reduction in the impact of seasonality for females in Bulgaria, Estonia, Latvia and Russia. On the contrary, Swedish females and Polish, Slovak and German males showed evidence of increases over the observed period.

When considering the results for e_{65} (online supplemental tables S1a,b, figures S3a,b online supplemental material C), we found that excess seasonal mortality led to notable effects. On average, removing season-specific excess mortality would

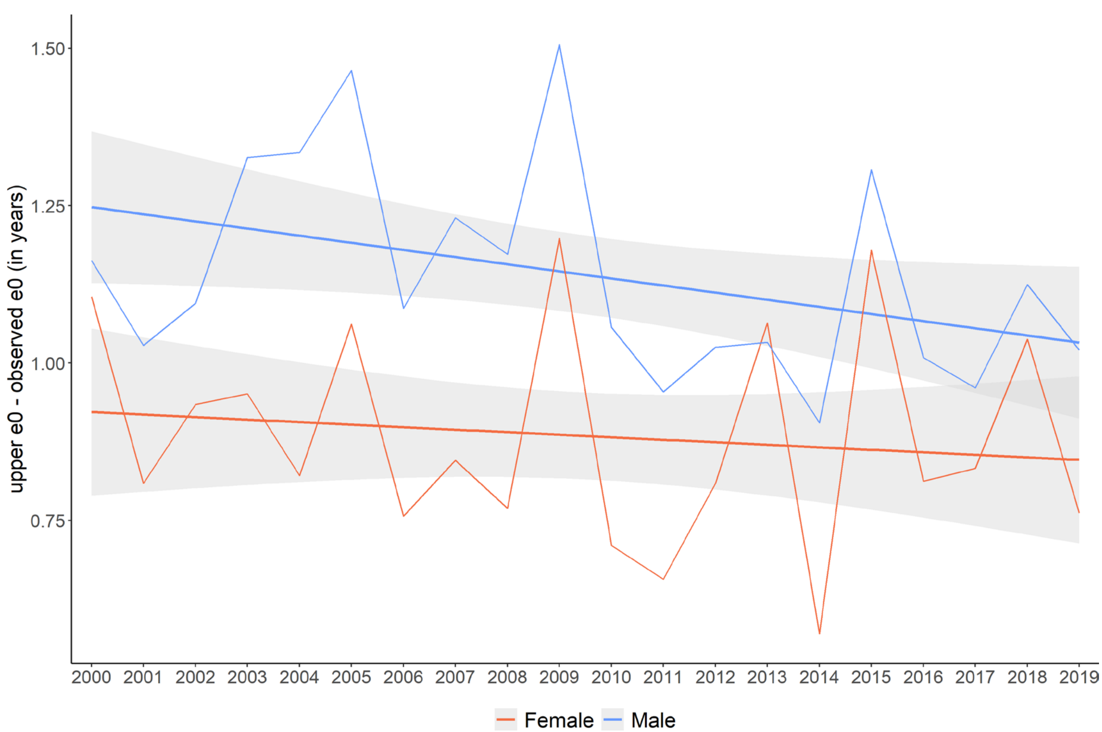

Figure 2 Difference between the upper and observed life expectancy at birth by sex (in grey, the 95% CI), median across the selected 20 European countries, 2000–2019.

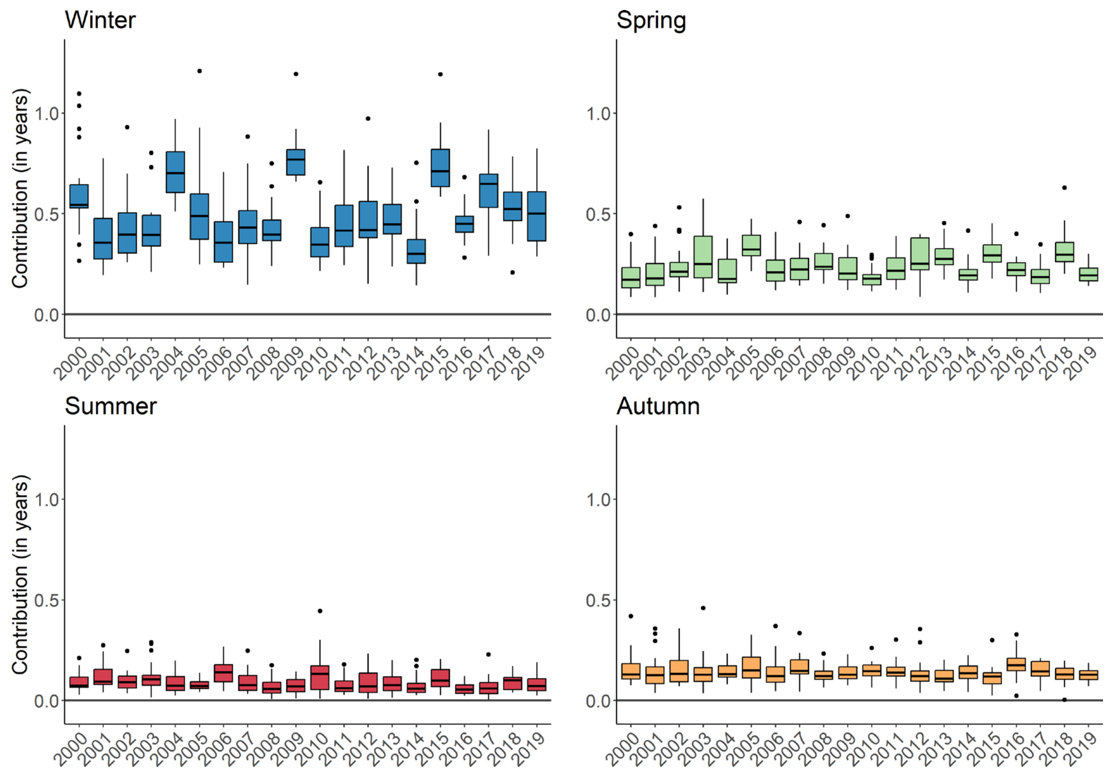

Figure 3 Contributions of season-specific excess mortality to the total differences between the upper and observed life expectancy at birth, total population, 2000–2019.

increase life expectancy at age 65 by 0.78 years for males and 0.74 years for females (around 70% and 90% of the total impact). Particularly, high burden was observed in Portugal (1.3 and 1.4 years), Estonia (1.2 and 1.2 years), Bulgaria (1.1 and 1.2 years) and Latvia (1.1 and 1.2 years).

See here [https://imarinetti.shinyapps.io/SeasonalityEurope/] for an interactive representation of our results.

Season-specific contributions to life expectancy losses

The analysis considering all four seasons separately revealed that winter excess mortality had not only the most significant contribution to the total life expectancy losses (about 0.55 years loss on average) but also showed the highest variations across countries and years (figure 3). The largest spatial heterogeneity was observed during the years 2000 and 2005. We also found the impact of specific winter epidemics (2004/2005, 2009/2010 and 2015/2016), leading to about a 0.7-year decrease in annual e_0. The countries with the highest impact of winter excess mortality were Portugal, Bulgaria and Spain, with an average annual contribution between 0.63 and 0.85 years (online supplemental tables S2a,b, figure S4a,b, online supplemental material B). On the other hand, northern countries, such as Sweden and Finland, and Russia were less affected by winter excess mortality (average annual contribution of 0.35 years). This significant impact of winter excess mortality was almost exclusively driven by older ages (online supplemental figure S4a–c, online supplemental material C).

Summers with pronounced heatwaves (e.g., the summer of 2003) had a smaller effect on e_0 compared with winters, with less heterogeneity across countries and years. For example, the 2003 heatwave reduced life expectancy in France and Spain by only 0.3 years for both sexes.

Seasonal mortality impact on life expectancy trends

Over the study period, the median life expectancy at birth (e_0) increased by 5.11 years for males and 3.31 years for females (predicted values, tables 1 and 2). Differences in the trends in life expectancy at birth with and without seasonal excess mortality between 2000 and 2019 varied by season and by sex (tables 1 and 2). A positive value means that e_0 improvement would have been larger in the scenario without seasonal mortality, whereas negative values suggest that removing excess seasonal mortality would have reduced these gains. In most cases, there was any possible significant reduction of the burden of excess seasonal mortality during 2000–2019 that would have led to faster improvement in longevity. For males, a few exceptions included Hungary, Poland and Slovakia, showing additional life expectancy gains of about 0.3 years under the scenario without seasonality. Similar size effects (0.4 years) were observed for Swedish, Hungarian and Slovak females. In general, the most important driver of the impact of seasonality on the total change in life expectancy at birth was the elimination of excess winter mortality, for both sexes. Similar patterns were also observed for life expectancy at age 65 (online supplemental table S2a,b, online supplemental material C).

DISCUSSION

Main findings

Our findings suggest persistent large impacts of excess seasonal mortality on annual life expectancy in Europe during the early 21st century. These impacts almost exclusively stem from ages above 65 years. Each year e_0 decreased on average by 1.14 years for males and 0.8 years for females due to excess seasonal mortality. The observed effect on e_0 levels amounted to approximately 400 000 deaths per year, pooling all countries together.

Table 1 Trends in life expectancy at birth with and without seasonal and season-specific excess mortality between 2000 and 2019, males

	Trends in e_0*			Without season-specific excess mortality (Δ in years)			
Country	With seasonality	Without seasonality	Δ Without seasonality	Δ Without winter	Δ Without spring	Δ Without summer	Δ Without autumn
Austria	4.69	4.62	−0.07	0.01	0.00	−0.02	−0.06
Belgium	4.84	4.95	0.11	0.03	0.08	−0.03	0.02
Bulgaria	3.54	3.22	−0.32	−0.11	−0.11	−0.01	−0.03
Croatia†	4.70	4.40	−0.30	0.00	−0.11	−0.09	−0.09
Estonia	10.02	9.67	−0.35	−0.08	0.01	−0.13	−0.14
Finland	5.04	4.95	−0.09	−0.01	−0.01	−0.12	0.05
France	4.62	4.72	0.10	0.07	0.04	−0.05	0.04
Germany	3.84	4.09	0.25	0.13	0.08	0.01	0.04
Hungary	5.86	6.19	0.33	0.28	0.02	−0.07	0.04
Latvia	7.01	6.70	−0.31	0.01	0.03	−0.08	−0.24
Lithuania	5.69	5.62	−0.07	0.09	0.04	−0.03	−0.15
Netherlands	5.08	5.11	0.03	0.03	−0.05	−0.03	0.05
Norway	5.28	5.21	−0.07	−0.03	−0.01	−0.04	0.01
Poland	4.65	4.98	0.33	0.19	0.07	0.02	0.04
Portugal	5.63	5.51	−0.12	0.02	−0.05	−0.06	0.01
Russia	10.71	10.71	0.00	0.07	0.06	−0.03	−0.09
Slovakia	5.35	5.63	0.27	0.20	0.06	0.00	0.00
Spain	5.08	5.15	0.07	0.07	0.02	−0.02	−0.01
Sweden	3.91	4.08	0.17	0.10	0.03	−0.02	0.05
Switzerland	4.73	4.72	−0.01	0.04	0.00	−0.04	−0.03
Median	5.24	4.92	−0.32	−0.16	−0.03	−0.11	0.00

*Predicted values: based on interpolated e_0 values, derived from a linear regression model.
†Data from 2001.

Our findings show that excess winter (and not summer) mortality still had the biggest impact on life expectancy levels (more than 0.5 years, less on e_0). The most significant winter mortality contributions were found in Portugal, Bulgaria and Spain.

Finally, the contributions of excess seasonal mortality to the total change in life expectancy at birth remained only marginal, warning about lacking improvement in reducing the public health burden of seasonality. It is also worrying that there was some indication of an increasing burden of seasonality among Swedish females and Polish, Slovak and German males, which should be examined more thoroughly in future studies.

Table 2 Trends in life expectancy at birth with and without seasonal and season-specific excess mortality between 2000 and 2019, females

	Trends in e_0*			Without season-specific excess mortality (Δ in years)			
Country	With seasonality	Without seasonality	Δ Without seasonality	Δ Without winter	Δ Without spring	Δ Without summer	Δ Without autumn
Austria	3.11	3.19	0.08	0.06	0.05	−0.05	0.03
Belgium	3.00	3.16	0.16	0.05	0.12	−0.02	0.00
Bulgaria	3.65	3.12	−0.53	−0.19	−0.18	−0.02	−0.05
Croatia†	3.43	3.37	−0.06	0.04	−0.04	−0.02	−0.03
Estonia	6.66	6.07	−0.59	−0.30	−0.05	−0.04	−0.16
Finland	3.27	3.23	−0.04	0.00	−0.04	−0.08	0.08
France	2.88	2.93	0.05	0.05	0.04	−0.07	0.03
Germany	2.41	2.56	0.14	0.08	0.06	−0.01	0.01
Hungary	3.60	3.90	0.30	0.22	0.04	0.00	0.01
Latvia	5.01	4.52	−0.50	−0.22	−0.04	−0.06	−0.14
Lithuania	3.80	3.66	−0.15	−0.02	−0.07	0.07	−0.11
Netherlands	3.11	3.33	0.22	0.10	0.09	−0.02	0.06
Norway	3.31	3.41	0.10	0.00	0.05	0.01	0.03
Poland	3.76	3.87	0.11	0.08	0.04	−0.02	0.00
Portugal	4.53	4.34	−0.19	−0.05	−0.03	−0.05	−0.02
Russia	6.86	6.56	−0.30	−0.15	−0.03	0.01	−0.11
Slovakia	3.77	4.05	0.29	0.20	0.10	0.00	−0.01
Spain	3.30	3.32	0.03	0.06	0.02	−0.06	0.01
Sweden	2.61	2.97	0.36	0.15	0.10	0.00	0.08
Switzerland	2.87	2.88	0.01	0.02	0.02	−0.03	−0.01
Median	3.05	2.94	−0.11	−0.15	0.01	−0.05	0.00

*Predicted values: based on interpolated e_0 values, derived from a linear regression model.
†Data from 2001.

Explanation of findings

The observed impact of seasonality on life expectancy levels was almost entirely attributed to the older population, especially during mortality shocks, for example, influenza epidemics and heatwaves. Generally, our conclusions regarding the effect of seasonality on life expectancy levels align with the major existing literature that highlights the role of mortality shocks with a high concentration of excess seasonal mortality (particularly winter excess mortality).[12 23]

The higher mortality during winter time compared with the other seasons was likely driven by epidemiological processes (cardiovascular and respiratory diseases) that underlie cold-related mortality.[24] Influenza is a key direct contributor to winter mortality and additionally amplifies the risk of death due to downstream cardiovascular and respiratory events,[25] especially in the older population[1]. Indeed during the winters with the most severe influenza epidemics (2004/2005, 2009/2010 and 2014/2015), we observed peaking excess mortality.[11–13 26]

Spring and autumn months exhibited lower mortality and generally lower variability between European countries. This result might be explained by generally more reasonable and stable temperatures in those months.[27]

In line with other studies,[28] the effect of heatwaves in the older ages was smaller than the effect of cold observed in winter. Particularly, the heatwave of 2003 had a slight effect on e_{65} only in Portugal, France and Spain, showing about 0.3-year loss due to summer excess mortality. Nonetheless, the limited inclusion of Mediterranean countries in our analysis, which are historically the most affected by heatwaves,[29] could also underestimate the overall effect of summer excess mortality.

The cross-country differences in contributions of seasonal excess mortality might be attributed to variations in climate regimes, sociodemographic structures, such as age composition, poverty and well-being indicators (e.g., homelessness), healthcare resources and effectiveness of healthcare systems.[7 23 30] Moreover, despite increased energy conservation measures (e.g., house insulation) in Europe, differences in indoor housing conditions persist, particularly affecting Southern and eastern European countries.[31] Eastern Europe also faces greater impacts from respiratory infections due to less prepared healthcare systems.[32] Furthermore, resistance to certain pathogens varies, influenced by historical exposure patterns and vaccination rates, with western Europe generally having higher vaccination coverage and more robust disease surveillance systems[33]. This spatial variability can worsen short-term health shocks, as seen during severe influenza seasons and other infectious outbreaks, affecting more countries with lower healthcare capacity and fewer preventive measures.

The observed higher impact of seasonality on life expectancy for males is likely due to the higher vulnerability to seasonal health shocks, including influenza epidemics[34] and, especially at younger ages, during heatwaves.[28] Physiological, sociocultural[35] and age structure differences contributed to the elevated risk for men at younger ages. Indeed, additional analysis of our data showed that the importance of seasonal excess mortality was higher among males aged 15–64.

Despite observing mortality outbreaks, particularly during winter, contributions of seasonal excess mortality did not show any systematic reductions or increases. This important finding and indications of the growing burden of seasonality in a few countries require further investigation. It could be suggested that there were two or even more counterbalancing global factors explaining small progress in reducing seasonal effects. For example, although this progress was fueled by medical and healthcare advances and improvements in living conditions, other factors, such as increasing climate change threats and returning pandemics, remain important obstacles.

The effects of seasonality might rise in the future with increasing frequency and severity of temperature shocks, such as heatwaves.[36] The burden of seasonality was almost entirely been explained by excess mortality in the elderly population and the share of the population over 65 years in high-income countries is projected to reach one-thirds by 2070.[37] This change also suggests radical increases in absolute numbers and relative shares of those most vulnerable to seasonal risk factors. Hence, in the second half of the 21st century, heat-related mortality will most likely increase[38] and require population adaptation, but most importantly mitigation strategies, such as improvements in healthcare and early warning systems, vaccination against influenza or better acclimatisation and insulation of buildings.[39]

Strengths and limitations of the study

One of the major strengths of the study is the employment of weekly all-cause mortality retrieved from the STMF data series, an open-access and harmonised dataset that ensures comparability across countries and years.[1 11]

However, the estimation of the overall contribution of seasonality is a challenging task due to the counterbalancing effects of the different seasons and the choice of the baseline mortality level. To our knowledge, this is the first study that constructs a baseline level of within-year mortality to compute seasonal excess mortality. This approach has the important advantages of overcoming stochastic fluctuations of mortality rates and simultaneously measuring the trends and the differences between countries. Moreover, we used a year-specific mortality baseline and not an average of the analysed period, which was shown to bias the result.[40]

Most of the earlier studies relied on statistical modelling methods or regression analysis to detect changes in seasonal mortality patterns. We applied decomposition methods to quantify the exact contributions of seasonal excess mortality to the differences between upper (under no seasonality scenario) and observed life expectancies. This approach allowed us to quantify the effects of removing seasonality in terms of years of life and to avoid using strong modelling assumptions.

Our study has some limitations. First, the choice of the baseline for the computation of life expectancy in the absence of excess seasonal mortality (upper life expectancy) is arbitrary. However, the rationale behind this baseline choice followed previous research on excess mortality.[21] Sensitivity analyses using either longer or shorter time frames, and age-specific death counts instead of overall death counts to compute upper life expectancy estimates, revealed that our 13-week baseline minimises random fluctuations, capturing a more stable and consistent measure of upper life expectancy (online supplemental figures S1a, S2a,b, online supplemental material D). Moreover, the estimation of seasonal contributions to life expectancy change relies on the selected period. While we selected the start (2000) and end (2019) of our period, using a longer or shorter time frame might provide different results, particularly in instances of significant mortality fluctuations during the selected period.

CONCLUSIONS

To our knowledge, this is the first study to quantify the contributions of season-specific excess mortality to the annual life expectancy levels and temporal changes in selected European countries in the last 20 years.

The findings highlight the potential and importance of considering seasonal mortality patterns alongside traditional annual population health metrics, especially in the case of extreme short-term shocks, such as heatwaves or winter epidemics. Timely data are needed for reliable monitoring of public health losses and tailored public health interventions to address seasonal vulnerabilities. Public health policies should develop early warning systems and promote epidemic and unexpected weather conditions preparedness. Expanding social protection, such as heating subsidies and financial aid during extreme weather seasons. Supports vulnerable groups, especially the elderly, those with multiple long-term conditions, and populations in Southern and eastern Europe. Lacking progress in reducing the public health burden of seasonality reported in this study should be a matter of concern for health policies and should be addressed in further research.

This study not only contributes to advancing our understanding of mortality dynamics but also emphasises the significance of integrating seasonal considerations into future epidemiological and demographic research. Future mortality and life expectancy forecasts should consider a potentially growing impact of seasonality and short-term extreme temperature events. This study is focused on Europe and the results should not be extrapolated to other regions. We recommend analysing seasonal mortality in the Global South countries, which might be disproportionately affected by extreme temperature events.[30]

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Contributors IM, DAJ and FJ conceived and designed the study. IM conducted the statistical analysis and drafted the manuscript. DAJ and FJ provided critical input and revisions to the draft manuscript. DJ, MN and NI provided scientific advice for the interpretation and framing of the analysis. All authors revised the final draft and approved the final version of the manuscript. IM is responsible for the overall content as guarantor.

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Patient consent for publication Not applicable.

Ethics approval Not applicable.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data are available in a public, open access repository. All data used in this study are publicly available on the Human Mortality Database (https://www.mortality.org/).

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