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Replication

The role of sex and age in seasonal mortality – the case of Poland

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Abstract

BACKGROUND
Seasonality of mortality is a well-research topic. However, there are few cross-national studies on total populations that would allow a clear comparison of the results. This article replicates Rau and Doblhammer (2003) and adjusts their methods to Polish data nearly two decades later.

OBJECTIVE
The article addresses the following questions about the seasonality of deaths in Poland: How do men and women differ in terms of seasonal fluctuations in mortality? How does the seasonality of deaths change with age as well as between cohorts for the same age groups? Do the results follow the ones from the original study?

METHODS
A 5 percent sample drawn from Polish population ages 50+ who lived in the year 1988 was followed by 30 years. A logistic regression model was used to estimate the odds ratios of dying in different age, sex, and month/season.

RESULTS
Winter excess mortality for Poles ages 50+ was 9.6 percent of all deaths in the years 1988–2017. Clear seasonal fluctuations in mortality were recorded for both men and women and different age cohorts. The seasonality increased with age, affected elderly men more than elderly women, and decade of birth had an impact on mortality risk.

CONTRIBUTION
This study documents the seasonality of deaths in Poland by sex and age over the past three decades. It replicates the paper on the Danish population ages 50+ and reflects on differences and similarities between the results.

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1. Introduction

The seasonality of mortality seems to have its own seasons of high and low research interest, when either heat waves or cold spells are recorded and recently also due to the COVID-19 pandemic (Chirumbolo, Pandolfi, and Valdenassi 2022; Gregory et al. 2022). Most scholars focus on the effects of temperature on mortality (e.g., The Eurowinter Group 1997; Lerchl 1998; Keatinge et al. 2000) or analyse the seasonality linked to the most common causes of death (e.g., Feinstein 2002; Nakaji et al. 2004). The concept of the seasonality of human mortality over the causal chain and the historical perspective is comprehensively introduced by Rau (2007). It has been widely used as the background theory and reference for numerous papers in the topic (e.g., Richards et al. 2020; Richards 2022).

This paper replicates Rau and Doblhammer (2003), who analyse whenever there are seasonal fluctuations in mortality in Denmark and then measure gender and age differences. Although their work was recognised and cited in multiple studies in the last two decades (e.g., Stafoggia et al. 2009; De Freitas and Grigorieva 2015), it has not been replicated in another country setting. Therefore, this paper is focused on demographic aspects of the population, namely sex and age and their impact on seasonality of mortality in Poland.

Poland has been a research subject in a few subpopulation studies focused on regional seasonality of mortality, with focus on the whole country in only a few cases. Cold spells and extreme heat had a positive impact on the mean relative risk of deaths of people aged > 65 years in three selected Polish cities in Kuchcik and Degórski (2009). The dependence of mortality on weather was the focus of Kuchcik (2001), as there was an increase of deaths in the capital of Poland, Warsaw, during extreme hot and extreme cold days. Budnik and Liczbińska (2015) analyse the causes of deaths in a historical selected province of Poland. Their results revealed seasonality of deaths in the population aged > 50 years to be statistically significant with peaks in fall and winter and a minimum in the summer. No study thus far has focused on the demographic aspects (sex and age) in the entire country.

The aim of this study is to verify if in a large central European population (such as in Poland) there are differences in mortality fluctuations between sex and age similar to those found in Denmark in the late twentieth century. This study therefore follows the methodology presented in Rau and Doblhammer (2003) involving both cross-sectional (comparing in the same time frame different cohorts at different ages and different cohorts at the same age) and longitudinal (comparing the same cohorts at different ages) cohort analysis. The results obtained from the Polish data are presented next to the quoted Danish ones. It should be noted here that because we did not have data from Poland for the same time period, the comparison of Poland and Denmark does not meet the requirements of a cross-sectional cohort analysis. Yet we strongly believe that this does not lower the significance of the received results as the same age groups are targeted in the same manner. Studying the seasonality in different countries and/or time periods and comparing it with already published analyses provides a better understanding of the nature and causes of the seasonality of human mortality. This paper, additionally, contributes to that.

2. Data and methods

The data included all Poles who were aged ≥ 50 years as of 1 January 1988 and consisted of 9,268,814 individuals that were followed for 30 years until end of December 2017. A total of 7,419,865 individuals (80.1%) died during the studied period, leaving 1,835,317 survivors (19.9%). A total of 0.5% of the individuals had an incorrect entry of birth or deaths and were deleted from the population. For each individual, birth and death were recorded by month and year from the national registry of the Universal Electronic System for Registration of the Population (PESEL). The dataset used was received upon the authors' request from the Polish Ministry of Digital Affairs in 2018.

As in the original study by Rau and Doblhammer (2003), the analysis started with an estimation of winter excess mortality for the entire population, which for the Northern Hemisphere can be expressed by the formula

$$EWD = D - \left(12 * \frac{D_{JUL}+D_{AUG}+D_{SEP}}{3}\right),$$

where *EWD* represents the number of excess winter deaths, *D* is the number of all deaths during the studied period, and D_{JUL}, D_{AUG}, and D_{SEP} represent the number of deaths during the summer months. Death numbers were calculated for all months standardised to 30 days with adjustment for leap years. The proportion of winter excess deaths is obtained by computing *EWD / D*.

To measure the relative risk of dying in a particular month, a logistic regression model was used where each individual was listed as many times as the number of lived months between January 1988 and December 2017. The maximum was 360 repetitions for an individual who survived the study period. As in the Danish case, a random sample was drawn to avoid an excessively large dataset (almost 1900 million entries). The sample consisted of the same ratios of age and sex as the total population in the cohorts. The 5% sample dataset included 95,695,914 person–months individuals. Table 1 presents and compares the studied populations from Poland and Denmark by cohort classification, sex, and survival status. Danish data are quoted from Rau and Doblhammer (2003) and marked with italics. Since the time period of the analysis is shifted by 20 years compared to the Danish study, comparing the same age groups in Poland and Denmark also required moving the birth cohorts by the same period, for example, Cohort I includes people aged 80 to 99 – that is, Poles born from January 1898 to December 1907 and Danes born from April 1878 to March 1888. The decision to adopt the same cohort numbering for the different birth cohorts in Poland and Denmark was supported by the readability of the comparisons presented below.

Table 1: Study population of Poles in January 1988 aged ≥ 50 years divided by sex and age cohort and *Danes* in April 1968

Cohort	Birth date Poland *Denmark*	Sex	Persons alive in Jan. 1988 *Apr. 1968*	Person–months lived	Surviving Dec. 2017 *Mar. 1998*
I	Jan. 1898–Dec. 1907 *Apr. 1878–Mar. 1888*	M	172,994 *1,551*	11,654,281.0 *100,158.0*	7,379 *25*
I	Jan. 1898–Dec. 1907 *Apr. 1878–Mar. 1888*	F	403,887 *2,072*	30,361,938.0 *144,257.0*	16,903 *44*
II	Jan. 1908–Dec. 1917 *Apr. 1888–Mar. 1898*	M	589,778 *4,715*	61,911,738.0 *509,106.5*	13,249 *18*
II	Jan. 1908–Dec. 1917 *Apr. 1888–Mar. 1898*	F	1,019,916 *5,792*	129,402,945.0 *760,124.5*	28,784 *93*
III	Jan. 1918–Dec. 1927 *Apr. 1898–Mar. 1908*	M	1,234,205 *8,117*	209,992,186.0 *1,341,481.5*	74,931 *80*
III	Jan. 1918–Dec. 1927 *Apr. 1898–Mar. 1908*	F	1,704,221 *8,464*	368,816,078.0 *1,646,669.5*	204,449 *95*
IV	Jan. 1928–Dec. 1937 *Apr. 1908–Mar. 1918*	M	1,947,815 *8,616*	458,077,265.0 *1,790,307.0*	491,527 *152*
IV	Jan. 1928–Dec. 1937 *Apr. 1908–Mar. 1918*	F	2,146,939 *6,966*	623,701,855.0 *1,578,623.5*	998,095 *177*
I–IV	Jan. 1898–Dec. 1937 *Apr. 1878–Mar. 1918*	M	3,944,792 *22,999*	741,635,470.0 *3,741,053.0*	587,086 *275*
I–IV	Jan. 1898–Dec. 1937 *Apr. 1878–Mar. 1918*	F	5,274,963 *23,294*	1,152,282,816.0 *4,129,674.5*	1,248,231 *409*
I–IV	Jan. 1898–Dec. 1937 *Apr. 1878–Mar. 1918*	both	9,219,755 *46,293*	1,893,918,286.0 *7,870,727.5.0*	1,835,317 *684*

Sources: Author's analysis of data from the Universal Electronic System for Registration of the Population (PESEL); data for Denmark from Rau and Doblhammer (2003).

Four cohorts were set up[3] to compare the effect of age and sex on the seasonality of mortality. The oldest cohort (Cohort I) was born between January 1898 and December 1907. At the beginning of the study period (1 January 1988), individuals in this cohort were between 80 years and 89 years and 11 months old. They were followed until a maximum age of 99 years and 11 months (from December 1997 to December 2007). Individuals in the second cohort (Cohort II) were born between January 1908 and December 1917 and were aged 70 years to 79 years and 11 months in 1988 at the start of

[3] The division into cohorts made here may be slightly distorted by birthdate misregistration – a phenomenon that occurred in the years of birth of the population under study, which, among other things, included the registration of children born in December as having been born in the following January (Cypryjański 2022).

the study period and were followed up to age 99 years and 11 months (from December 2007 to December 2017). Individuals in the third cohort (Cohort III) were born between January 1918 and December 1927 and were aged 60 years to 69 years and 11 months at start of the study period and reached ages 90 years to 99 years and 11 months in December 2017. Individuals in the fourth and the youngest cohort (Cohort IV) were born between January 1928 and December 1937 and were aged 50 years to 59 years and 11 months at start of the study period and reached ages 80 years to 89 years and 11 months in December 2017.

Figure 1: Cohort visualisation in Lexis Diagrams (years provided in brackets on the Period axis refer to the original study of Rau and Doblhammer 2003)

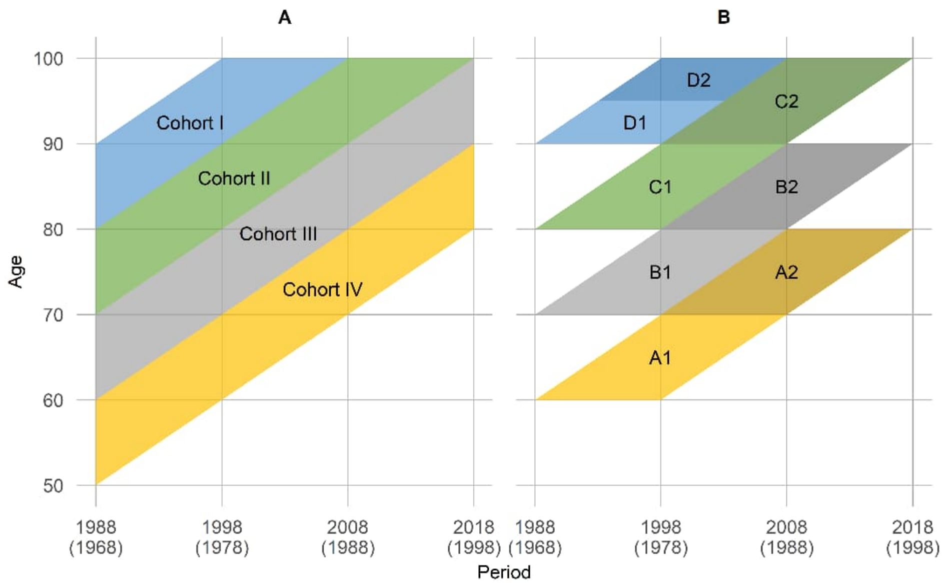


Figure 1 is a Lexis diagram (for historic overview, see Vandeschrick 2001) that visualises the four cohorts (panel A) and the modified cohort definition used in the age-specific analysis (panel B). Similar to the Danish paper, the age-specific analysis required several modifications to the preliminary study cohorts to allow each member of a specific cohort to theoretically reach each of the analysed ages. Each cohort was divided into two age-specific groups, and the year was divided into quarters.

The changing risks of dying in a different month (and similarly quarters) of the year was then analysed with a logistic regression model:

$$\log\left(\frac{P_{it}}{1-P_{it}}\right) = \alpha + \sum_{M=1}^{11} \beta_m x_{i,m} + \delta v_{i,t} + \gamma w_{i,t},$$

where the log of the probability P_{it} that death will occur for individual *i* at time *t*, given that death did not occur $1 - P_{it}$, is related to an intercept α, the following covariates: 11 dummy variables $x_{i,m}$ representing the current month with one month as a reference, a continuous variable $v_{i,t}$ representing the period effect for individual *i* at time *t* and a continuous variable $w_{i,t}$ representing the age of individual *i* at time *t* as well as the associated regression coefficients β_m, δ, γ, respectively. The exponentiated β_m coefficients represent odds ratios (OR) for different months (and similarly quarters). Separate models were analysed for women, men, and the different age groups.

As in the reference paper, Hewitt's test (Hewitt et al. 1971) was employed to investigate whether the relative risks of dying follow a seasonal pattern. This test consists of assigning ranks to individual months in such a way that rank 12 is given to the month with the highest value of the variable, 11 to the month with the next highest, and so on down to rank 1 for the month with the lowest value of the variable. The test statistic *T* is the maximum sum of ranks for any six consecutive months (e.g., November, December, January, February, March, and April) and its highest value is 57 (12+11+10+9+8+7). Thus, testing for seasonal fluctuation here amounts to dividing the year into two six-month periods, the first with a relatively high and the second with a relatively low value of the variable. The exact significance levels for the test were taken from Walter (1980).

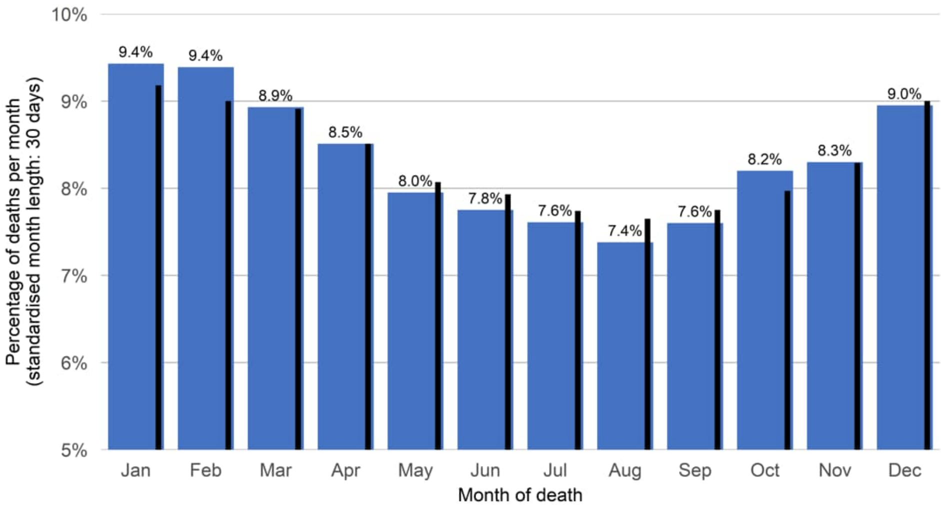
3. Results

3.1 Measuring seasonality

Figure 2 presents the monthly standardised death counts for the Polish population aged ≥ 50 years. Danish results are indicated with black markings. The figure shows the monthly distribution as a percent of all deaths of the population aged ≥ 50 years (total 7,317,370 individuals) that occurred in the 30-year study period. The different month lengths were controlled by standardising all records to a weight of 30 days. Similar to Denmark, the peak in death counts was recorded in January (total 689,855 deaths), while the minimum was recorded in August (total 540,228 deaths). The share of death counts between May and September and in December was higher in Denmark than in Poland. The winter excess mortality in years 1988–2017 accounted for 703,423 deaths for the Polish population aged ≥ 50 years, being roughly 23,447 deaths per year and 9.6% of all deaths.

The corresponding value for the Danish population aged ≥ 50 years from years 1968–1998 was 6.69% of all deaths.

Figure 2: Distribution of monthly mortality with standardised length of month

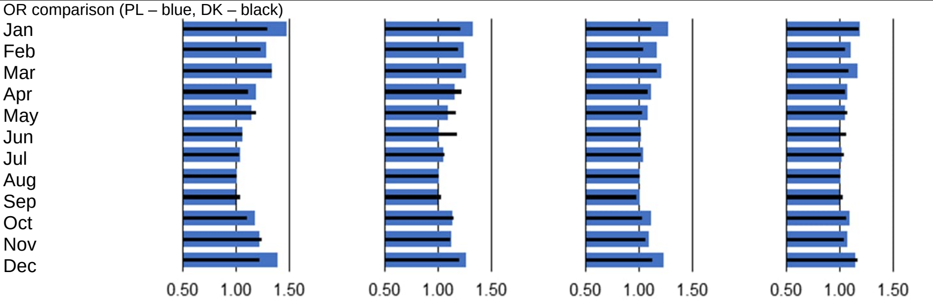


Source: Author's analysis of data from the Universal Electronic System for Registration of the Population (PESEL); data for Denmark from Rau and Doblhammer (2003).

The ORs of dying in a particular month were calculated via logistic regression, and the results are presented in Table 2 for all four study cohorts. Setting up August (lowest death count in total) as the reference month, the risks for dying in January (and not August) for the oldest cohort (Cohort I) was nearly 50% higher. For Cohorts II and III, the risk of dying at the beginning of the year was approximately 30% higher than in August, while the youngest cohort had < 20% increased risk. Hewitt's test confirmed the seasonality of mortality in the studied population. The statistics T for the four cohorts was 57, 56, 56, and 56, respectively, and thus the p-values for the test reached an acceptable level of significance of $p \leq 0.0253$ for all four cohorts (Table 2). Additionally, Table 2 also presents the results from Rau and Doblhammer (2003).

Table 2: Odds ratios and levels of significance for month of death from logistic regression (reference: August)

Month of death	Cohort I born 1898–1907		Cohort II born 1908–1917		Cohort III born 1918–1927		Cohort IV born 1928–1937	
January	1.47	0.0000	1.32	0.0000	1.27	0.0000	1.19	0.0000
February	1.28	0.0000	1.24	0.0000	1.16	0.0000	1.10	0.0000
March	1.34	0.0000	1.25	0.0000	1.21	0.0000	1.17	0.0000
April	1.18	0.0000	1.16	0.0000	1.11	0.0000	1.07	0.0000
May	1.14	0.0000	1.09	0.0000	1.08	0.0000	1.04	0.0024
June	1.05	0.1001	1.01	0.7145	1.01	0.4866	0.99	0.5937
July	1.04	0.2216	1.05	0.0066	1.04	0.0062	1.02	0.2578
August	1.00	0.0000	1.00	0.0000	1.00	0.0000	1.00	0.0000
September	0.99	0.7761	1.00	0.8157	1.01	0.6251	0.99	0.5460
October	1.17	0.0000	1.14	0.0000	1.11	0.0000	1.09	0.0000
November	1.22	0.0000	1.12	0.0000	1.09	0.0000	1.06	0.0000
December	1.38	0.0000	1.26	0.0000	1.22	0.0000	1.14	0.0000
Height of amplitude	48%		32%		27%		20%	
OR comparison (PL – blue, DK – black)								



	Cohort I	Cohort II	Cohort III	Cohort IV
rank-sum (Hewitt's Test)	57	56	56	56
p-value for Hewitt's Test	0.0123	0.0253	0.0253	0.0253

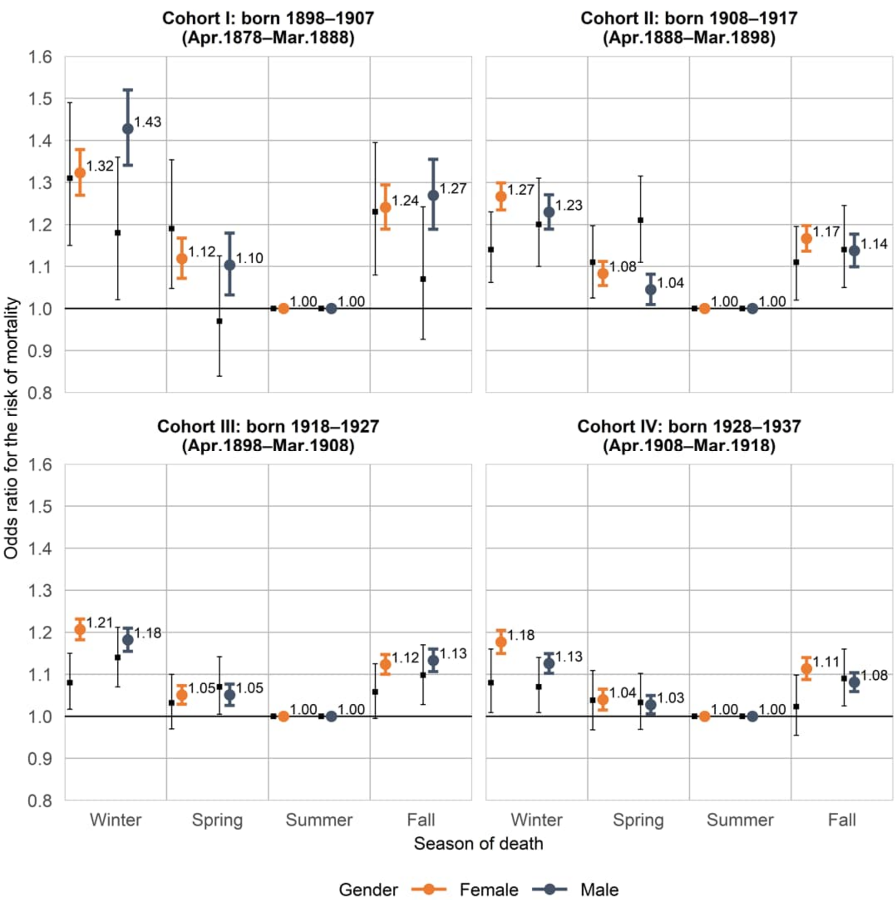
Source: Author's analysis of data from the Universal Electronic System for Registration of the Population (PESEL); data for Denmark from Rau and Doblhammer (2003).

3.2 Gender-specific seasonality analysis

The second set of estimations aimed to understand the gender differences within the four age cohorts. Therefore, women and men were analysed separately. The months were grouped into the seasons (winter: January, February, March; spring: April, May, June; summer: July, August, September; fall: October, November, December) to clarify trends with the reference group in the summer season. The results are presented in Figure 3.

There were strong seasonal fluctuations in mortality risk for Poles in Cohort I (aged 80/89 up to 99 years). A relative risk of dying in winter compared with summer was much higher for men (43%) and was also high for women (32%). The trend reversed in the spring, and men had a relative lower mortality risk than women. The highest peak in the winter was also observed in Cohort II (aged 70/79 up to 99 years) but relative risk of dying was higher for women (27%) than for men (23%). In fact, women in Cohort II had higher ORs than men in each season. Cohorts III (aged 60/69 up to 90/99 years) and IV (aged 50/59 up to 80/89 years) had very similar results, with lower values in Cohort IV.

Figure 3: Odds ratios and 95 % confidence intervals for seasonal mortality by sex (reference: summer, Danish results in black with a square centre point)



Source: Author's analysis of data from the Universal Electronic System for Registration of the Population (PESEL); data for Denmark from Rau and Doblhammer (2003).

3.3 Gender- and age-specific seasonality analysis

Figure 4 allows a comparison of seasonality between different cohorts and age groups separately for women and men in Poland and Denmark. Such a comparison provides further nuance for the previous observations and reveals further interesting regularities.

A typical seasonality pattern suitable with the climatic condition in both countries (i.e., $OR_{Winter} > OR_{Spring} > OR_{Summer} < OR_{Fall} < OR_{Winter}$) was present in all studied cohorts and subcohorts for Polish women. For Polish men, the one exception was the oldest subcohort (D2 from Cohort I, aged 95 to 99 years), where OR_{Fall} was 4 percentage points higher than OR_{Winter}. The pattern seems to be disturbed in most Danish subcohorts and especially for women.

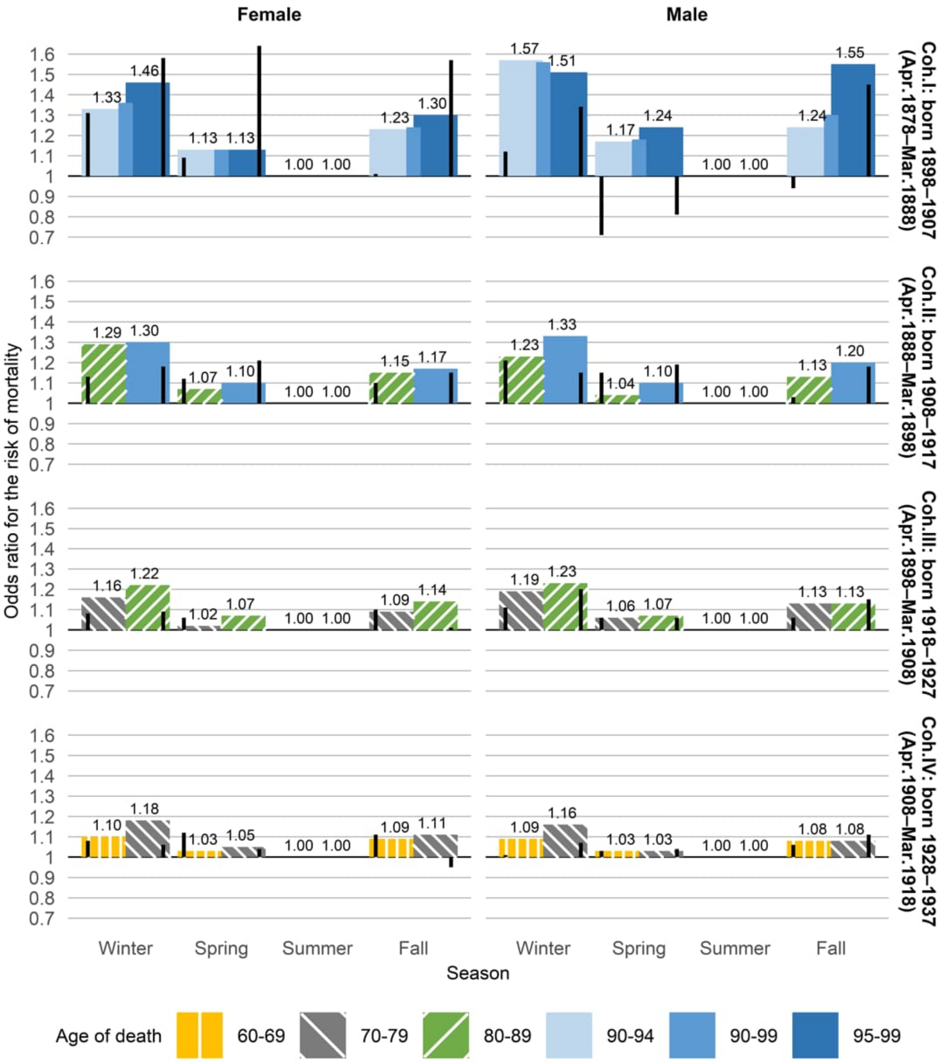
Figure 4 also allows examination of the amplitude ($OR_{MAX} – OR_{MIN}$) of the seasonal fluctuations. The amplitude, thus the seasonality, in Poland was higher than in Denmark for women aged 70 to 94 years, leaving the youngest and oldest studied women (subcohort A1 from Cohort IV, aged 60 to 69 years and subcohort D2 from Cohort I, aged 95 to 99 years) with higher seasonality in Denmark. As for men, only the oldest subcohort (D2 from Cohort I, aged 95 to 99 years) showed higher seasonality in Denmark than Poland.

The amplitude increased together with the age of Polish women. Similarly, the amplitude increased with the age of Polish men. However, there was an exception in Cohort I where the amplitudes were much higher than in the other cohorts; the amplitude in men aged 95 to 99 years (subcohort D2) was 2 percentage points lower than in those aged 90 to 94 years (D1). The amplitude in the Danish study followed a different trend. For women from Cohorts III and IV, the amplitude remained low and relatively constant, and only in Cohort II (individuals aged 80 to 89 years from subcohort C1 and those aged 90 to 99 years from C2) and Cohort I (individuals aged 90 to 94 years from D1 and those aged 95 to 99 years from D2) were clear increases in amplitude observed that progressed with age. In contrast, amplitude increased with age among men regularly in all cohorts except Cohort II.

Comparing the amplitudes of the seasonal fluctuations of Polish women and men from the same subcohorts, there is clearly higher seasonality of men only in the oldest subcohorts D1 (aged 90 to 94 years) and D2 (aged 95 to 99 years). In the other subcohorts, seasonality in men and women was at a similar level. In Denmark, among the 60-year-olds, the amplitude was higher in women, levelling off among the 70-year-olds, before being higher in men among the 80-year-olds. In the oldest subcohort among those aged 95 to 99 years, the seasonality of women and men equalised again.

Figure 4 additionally shows the differences between individuals of the same age belonging to different birth cohorts, which we will refer to in the Discussion section.

Figure 4: Odds ratios for seasonal mortality by sex and age groups (reference: summer, Danish results in black)



Source: Author's analysis of data from the Universal Electronic System for Registration of the Population (PESEL); data for Denmark from Rau and Doblhammer (2003).

4. Discussion

At the time of publication, the work and approach by Rau and Doblhammer (2003) using exact exposures and occurrences of events (of death) was a novelty. Their results confirmed that Denmark was situated among Western countries with approximately 6.7% of annual deaths classified as winter excess deaths. Their approach was well grounded, especially in a study without cause of death. In almost two decades, the Rau and Doblhammer (2003) study was often cited but never replicated in a different population. Kruger and Nesse (2004) continue with the thought that men are more susceptible to mortality stemming from cold winter months than women and further extended the evolutionary understanding of gender differences in mortality rates. Stafoggia et al. (2009) acknowledge the studies of seasonal patterns of mortality, with rates higher in winter and lower in summer and added an analysis on how the mortality rate in winter may influence the temperature-mortality association in the following summer. Stafoggia et al. (2009) also observe that the effect of summer apparent temperature on mortality was stronger in years characterised by low mortality in the previous winter. De Freitas and Grigorieva (2015) clarify an additional peak around October that the most severe thermal strain occurs with the adjustment shift from hot-humid to cold and that mortality data clearly show the sensitivity to the acclimatisation process to cold during fall is greater than the seasonal shift to heat during spring (May).

As a replication study, this paper conducted seasonality analyses with the same main variables of age and sex as in Rau and Doblhammer (2003). Overall, the Polish population showed the same pattern of mortality seasonality across all cohorts, namely the risk of dying is lowest in summer, higher in spring, followed by fall and highest in winter. For both men and women, seasonal mortality fluctuations increase with age. The differences between men and women are relatively minor in Cohorts II–IV, while in the oldest Cohort I there is clearly higher seasonality in men. In addition, the study compared individuals in their 70s, 80s, and 90s from two consecutive birth cohorts. For Polish women in their 80s and 90s, the seasonality for those born a decade earlier was slightly higher. Polish men, on the other hand, showed minimal or no changes for those in their 70s and 80s but a strong increase in seasonality for 90-year-olds born a decade earlier. The differences among people of the same age but coming from a different birth cohort possibly indicate several external impact factors, such as different socioeconomic conditions or environmental changes over time.

There are many similarities in the Polish and Danish populations and some interesting differences as well. The EWD ratio for Denmark (6.69%, see Rau and Doblhammer (2003)) was 3 percentage points lower than the corresponding Polish ratio. However, it is notable that lower seasonal fluctuations in Denmark occurred in those aged < 94 years, while the amplitude of fluctuations in Denmark was higher than in Poland in the oldest subcohort. The pattern of seasonal fluctuations, which was the same in all age groups of Polish women and men, was also often distorted in Denmark. The last point worth noting is the sex differences in seasonality. These are evident in both Poland and Denmark, and in both countries they show some regularities indicating that the seasonality of deaths affected men more than women. However, again, the evidence supporting this finding is different. In Poland, seasonal fluctuations from the youngest cohorts onwards increase with age similarly in men and women; in Denmark, seasonality in women starts to increase at a later age than in men. On the other hand, seasonal fluctuations in the oldest cohorts are clearly lower for women than for men in Poland, while they are about the same in Denmark.

Although analysis of risk factors connected with the seasonality of deaths was not the focus of our study, when comparing the results from Poland and Denmark, it is impossible not to refer to the two main factors commonly associated with this phenomenon, namely climatic and socioeconomic conditions. Poland and Denmark are countries with similar climates (see Figure A-1), and the slightly colder winters and warmer summers in Poland should not, considering the results of Fowler et al. (2014) or Healy (2003), be of major importance. The case is different for macroeconomic factors. As Healy (2003) shows, countries with higher GDP per capita have less seasonal variation in mortality. A comparison of GDP per capita between Poland and Denmark (for the years in which the study populations lived and for which we were able to obtain data, Figure A-2) shows that GDP per capita in the respective years was on average 2.5 times higher in Denmark than in Poland. Even if we consider the two-decade difference (Danish data covered years 1968–1998, Polish data covered years 1988–2017) and the convergence phenomenon observed in recent decades (Batóg 2010), we can still assume that the living conditions of the compared cohorts were markedly better in Denmark than in Poland. This may explain the higher EWD ratio in Poland. However, other differences presented here require further research.

The authors are interested in the impact of the COVID-19 pandemic on the seasonality of mortality in Polish society and aim to conduct a follow-up study in the future. The authors recognise a major advantage of using the same methods, here by Rau and Doblhammer (2003), in studies in different countries and encourage other scholars to replicate the study for internationally comparable findings.

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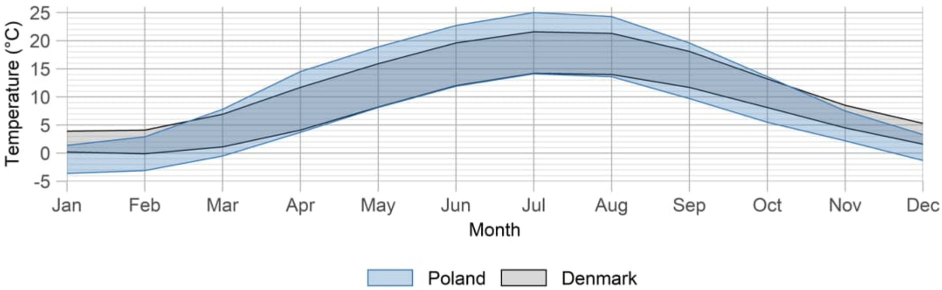
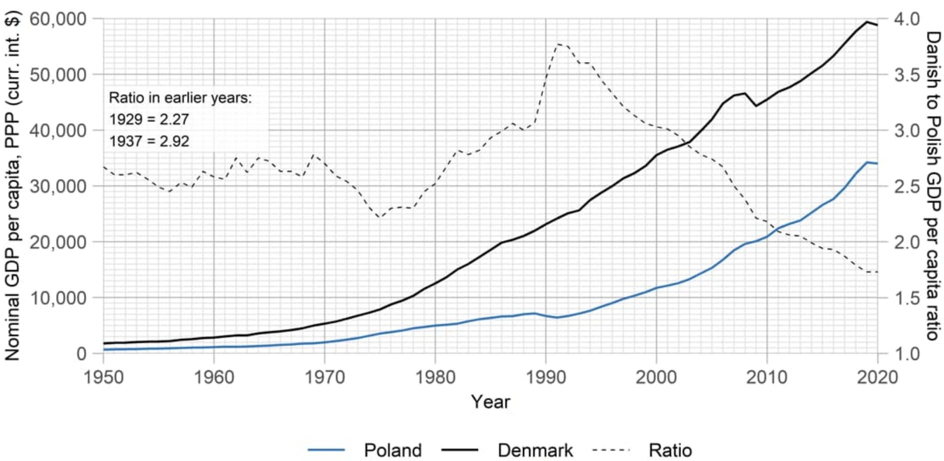
Appendix

Figure A-1: Daily maximum temperatures and night-time lows in Poland and Denmark. All temperatures correspond to the average monthly values of the last 20 years



Source: WorldData.info, retrieved on 15 Apr 2024.

Figure A-2: Nominal GDP per capita of Poland and Denmark (in current international dollars, converted using Purchasing Power Parities) and Danish to Polish GDP per capita ratio



Sources: The Conference Board Total Economy Database, April 2023. For ratio in earlier years: Broadberry and Klein (2012).