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Identifying age- and sex-specific COVID-19 mortality trends over time in six countries

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ABSTRACT

Objectives: The COVID-19 pandemic is characterized by successive waves that each developed differently over time and through space. We aim to provide an in-depth analysis of the evolution of COVID-19 mortality during 2020 and 2021 in a selection of countries.

Methods: We focus on five European countries and the United States. Using standardized and age-specific mortality rates, we address variations in COVID-19 mortality within and between countries, and demographic characteristics and seasonality patterns.

Results: Our results highlight periods of acceleration and deceleration in the pace of COVID-19 mortality, with substantial differences across countries. Periods of stabilization were identified during summer (especially in 2020) among the European countries analyzed but not in the United States. The latter stands out as the study population with the highest COVID-19 mortality at young ages. In general, COVID-19 mortality is highest at old ages, particularly during winter. Compared with women, men have higher COVID-19 mortality rates at most ages and in most seasons.

Conclusion: There is seasonality in COVID-19 mortality for both sexes at all ages, characterized by higher rates during winter. In 2021, the highest COVID-19 mortality rates continued to be observed at ages 75+, despite vaccinations having targeted those ages specifically.

Introduction

The COVID-19 pandemic is characterized by a sequence of waves that exhibit different features over time and through space. For example, in some European countries and in the Northeastern United States, COVID-19 mortality rates substantially declined between the first and the second wave [1]. Likewise, Italian provinces with the most severe initial COVID-19 outbreaks faced milder second waves [2,3]. However, the experience of successive COVID-19 waves in other countries remains relatively unexplored, as previous studies tend to focus on the cumulative number of deaths by a given date or use other approaches that make it difficult to clearly distinguish variations in the age and sex-specific structure of COVID-19 mortality across pandemic waves [4–7].

International comparisons of the demographic characteristics of people who died during these different waves provide valuable insights into the efficiency of health measures implemented by governments, from basic prevention—such as regular hand washing, facemask use, and lockdowns—to testing and immunization. To document the possible impact of those measures, it is crucial to carefully analyze the pace at which the lethal impact of COVID-19 progressed over time while simultaneously disaggregating COVID-19 mortality by age and sex. However, such comparisons must be conducted cautiously, given the heterogeneity of the available data across countries. More precisely, data collected through specific observation and registration systems could potentially lead to differences in data coverage and representativeness, thus introducing bias when carrying out undocumented international comparisons [8].

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Here, we aim to provide an in-depth descriptive analysis of the evolution of COVID-19 mortality in a selection of countries throughout the pandemic seasons and waves during the years 2020 and 2021, including changes in the age and sex structure of the deceased.

Since COVID-19 waves were driven by different variants of the virus and public health interventions, we hypothesize that the intensity of epidemic waves in each country may show distinct patterns according to calendar, overall lethality, and sex- and age-specific mortality. For example, we expect cross-country variations in the lethal impact of the first COVID-19 waves in 2020, which may partly reflect the strictness of public health protocols in the use of non-pharmaceutical interventions. Furthermore, considering that COVID-19 vaccination was introduced during the first months of 2021, we expect the 2020 waves to be more lethal than those of 2021, especially among the oldest age groups, who were the first to be targeted by vaccination campaigns and received booster shots in priority.

Data

We used national-level data on COVID-19 death counts by age and sex from "The Demography of COVID-19 Deaths" database [9], with a specific focus on six countries: Belgium, England and Wales, France, Scotland, Sweden, and the United States (see Supplements: Table S1 and Figure S1). We chose these countries because their official data sources use comparable definitions in the attribution of a death to COVID-19 [10], providing *comprehensive COVID-19 death counts*, that is, "statistics from the vital registration system, where COVID–19 is mentioned on the death certificate, or surveillance systems or health agencies that report both laboratory-confirmed and suspected COVID-19 deaths" [8]. Most data sources used in this study provide COVID-19 death counts based on data from the civil registration system, that is, death certificates where COVID-19 is mentioned. The only exception is Belgium, for which data come from the epidemiological surveillance system where both confirmed and suspected COVID-19 deaths are reported. Thus, even though we use comparable data from sources offering comprehensive death counts, our results refer to deaths associated with (and not due to) COVID-19, as not all data sources allow a clear distinction of the role of COVID-19 in the death, that is, whether underlying or contributory cause of death.

We focus on the period beginning with the pandemic in March 2020 and ending with the 2021-2022 winter season (i.e., until the end of February 2022)—except for France, who, at the moment of writing this article, has no available COVID-19 data after December 24, 2021.

For calculating COVID-19 mortality rates, we also used population counts by age and sex. Population estimates and projections for 2019, 2020, and 2021 were retrieved from the official national statistics websites pertaining to our study populations (see Supplements: Box S1).

Finally, to compare the structure of COVID-19 mortality with that of all-cause mortality in a prepandemic year, we also used 2019 death counts by age and sex for each study country, retrieved from the Human Mortality Database (HMD, [11]).

Methods

To highlight overall differences and similarities between countries and across waves, we first show how total COVID-19 mortality rates have evolved over time. For international comparisons, we estimate weekly standardized COVID-19 death rates (SDR) for each country by applying the classic direct standardization method [12]. To remove the influence of different age structures across populations, we use Eurostat's European Standard Population [13].

Weekly and seasonal COVID-19 mortality rates by age are calculated as the number of COVID-19 deaths occurring (or registered) during a specific week or season, divided by the corresponding estimated population (see Supplements: Table S2 and Figure S2). For the analyses by season, we used the meteorological definitions: winter (December 1 - February 28), spring (March 1 - May 31), summer (June 1 - August 31), and autumn (September 1 - November 30).

Finally, sex differences are explored using the ratio of male-to-female COVID-19 mortality rates, that is, the age-specific COVID-19 mortality rates for men divided by those for women. We also used the sex and age distribution of COVID-19 deaths within each season in each country.

Results

Timing and intensity of COVID-19 waves

Figure 1 shows the evolution of the COVID-19 SDR by country. Within each country can be identified at least three waves that unequally affect the population.

The first COVID-19 wave began abruptly in March 2020 and peaked in April 2020, reaching 164 deaths per 1 million in Belgium; 149 in England and Wales; 127 in Scotland; 90 in France; 70 in Sweden; and 62 in the United States. Then, the SDR declined in all countries, albeit slightly faster in Belgium and France. In the five European countries included in Figure 1, few COVID-19 deaths occurred during the summer and beginning of autumn 2020. In contrast, in the United States, there was a new period of increase beginning in June 2020, which reflects the geographic spread of the pandemic from east to west [14,15].

During the second wave, mortality increased rapidly in Belgium, with an SDR rising from about eight at the end of September to 120 at the beginning of November 2020. However, England and Wales had the highest COVID-19 mortality rates during the second wave, as the SDR reached 162 in the third week of January 2021. France had the lowest SDR at the peak of the second wave (60.1 in the second week of November 2020), followed by renewed periods of increased mortality between which the SDR did not substantially decline.

During the spring and summer of 2021, a new stabilization phase began, first in England and Wales and in Scotland (March) and then in Belgium, France, and Sweden (June). Unlike the stability observed during the summer of 2020, the SDR increased slightly in England and Wales, Scotland, and France during the summer of 2021.

Compared with the same seasons 1 year earlier, markedly lower COVID-19 mortality rates were observed in autumn 2021 and in winter 2021-2022. This difference is striking in all study countries except the United States, where COVID-19 mortality was higher than in the other countries during the indicated period. Although the weekly SDR did not exceed 100 in the United States at any moment during the study period, it is the only country where it did not decline close to zero, as occurred in the European countries during the summer months. By the end of the study period, the United States had the highest cumulative COVID-19 mortality rate since the beginning of the pandemic, followed by England and Wales (see Supplements: Figure S3).

Variations in COVID-19 mortality by age group

Figure 2 illustrates the differential impact of COVID-19 on mortality by age, as younger age groups were less affected than older ones in all countries and waves. Below age 45, marked wave patterns in the death rates are observed only in England and Wales and in the United States. From age 45, each wave has a distinct

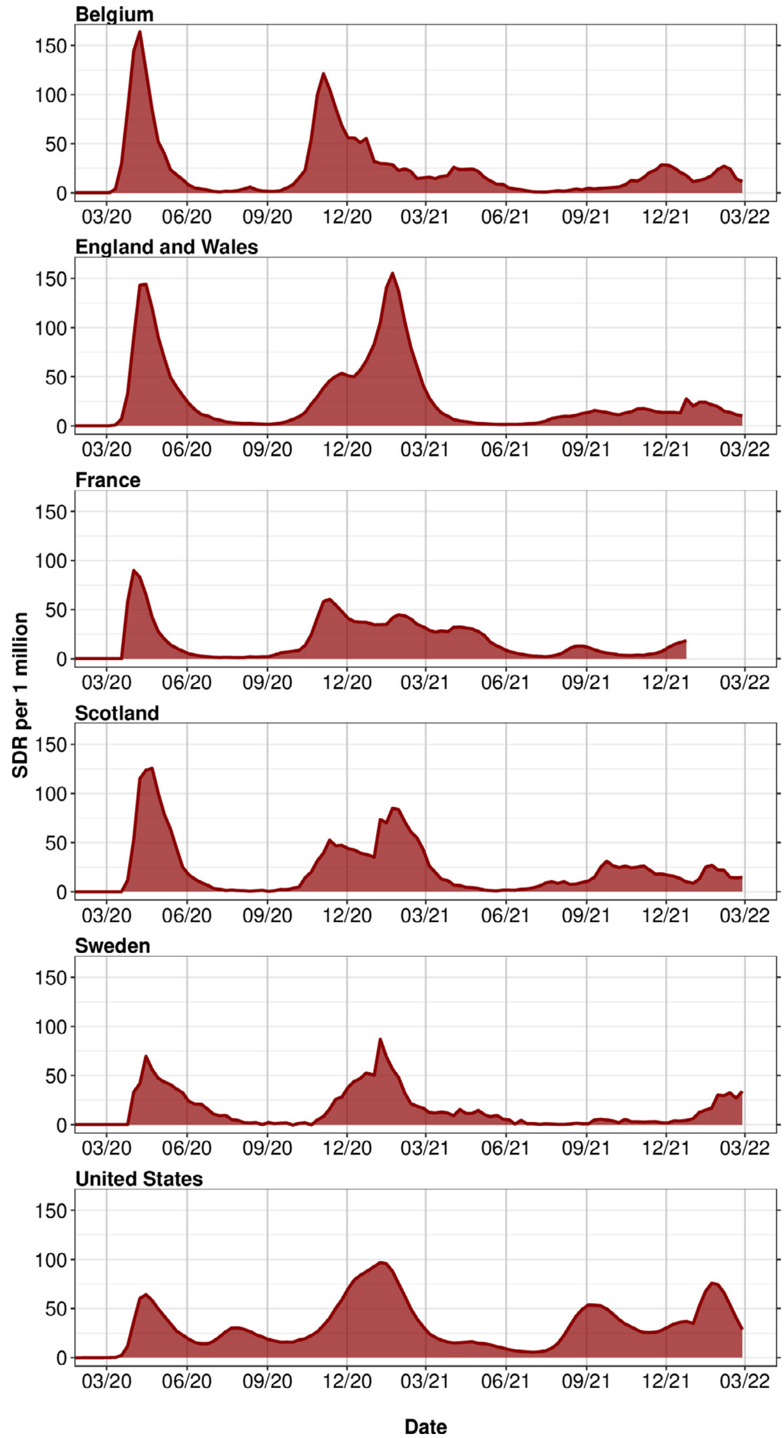

Figure 1. Weekly standardized death rate (SDR, per 1 million) associated with COVID-19 by country.
Note: Labels for the dates on the x-axis correspond to the first day of the indicated months. The gray vertical lines indicate the start of each season. SDR, standardized COVID-19 death rates.

impact in all countries. At the peak of the first wave, England and Wales had the highest mortality rates under age 75, while Belgium had the highest mortality at ages 75+. Comparing the age patterns with all-age COVID-19 mortality (Figure 1), the mortality peaks at ages 75+ clearly drive each country's trends in COVID-19 mortality and the intensity of each wave.

A rapid mortality decline following the second peak is observed at all ages in England and Wales and in Scotland, and above age 75 in the United States, whereas a slight mortality increase from March to May 2021 is observed in France and Belgium at all ages, and below age 75 in the United States. After spring 2021, the mortality rates at ages 75+ significantly diminished in comparison to previous levels in all countries.

Unlike the summer of 2020, more cross-country variation in COVID-19 mortality rates is observed during the summer of 2021, with most countries (except Belgium and Sweden) having an in-

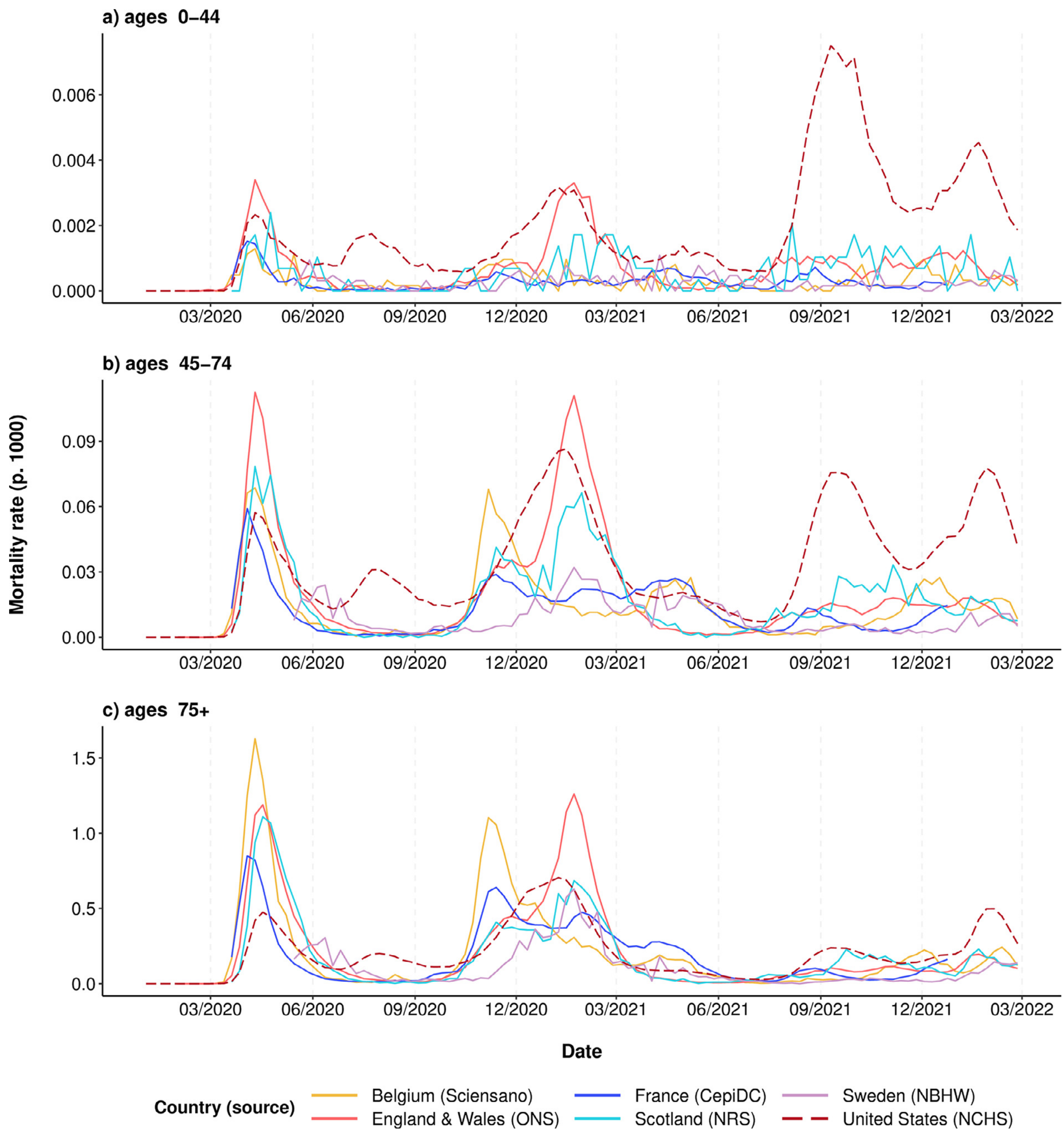

Figure 2. COVID-19 mortality rates (weekly deaths) by age group for both sexes combined.
Note: Scales for each age group are different. Due to different age groups in the original data sources, data for Sweden correspond to ages 0 to 49 and 50 to 74 (instead of 0 to 44 and 45 to 74, respectively). See also the cumulative mortality rates by age (Supplements: Figure S4).

crease toward the end of the season. This increase—which is more pronounced under age 75—was modest in England and Wales, Scotland, and France but sharp in the United States.

Figure 3 summarizes variations between seasons in the age structure of COVID-19 mortality. In general, mortality is highest during winter (especially the winter of 2020-2021) and at old ages. In all countries except the United States, the spring of 2020 (which represents the first wave) also has among the highest mortality rates at most ages compared with the other periods.

With a few exceptions, the COVID-19 mortality rates in 2020 increased or decreased proportionally at most ages across seasons, as shown by the solid lines shifting up and down. In 2021 there was a crossover, as COVID-19 mortality rates among the oldest age groups did not increase as much as in 2020 (except for France during the summer of 2021). However, at younger ages, COVID-19 mortality rates in 2021 were close to (or even higher than) those observed in 2020 in most countries and seasons.

In all countries except Sweden, COVID-19 mortality rates at all ages during summer 2020 were among the lowest observed, but they were higher in summer 2021, especially at the youngest ages. In Sweden, mortality rates in summer 2020 were relatively high, as they were even higher at most ages than those observed in the 2021-2022 winter season. Swedish mortality rates during the summer of 2020 were also higher in comparison with the other European study countries (see Supplements: Figure S5).

Figure 3 shows that COVID-19 mortality rates were lower in the 2021-2022 winter season than in the previous one. However, while the difference is substantial in England and Wales, Scotland,

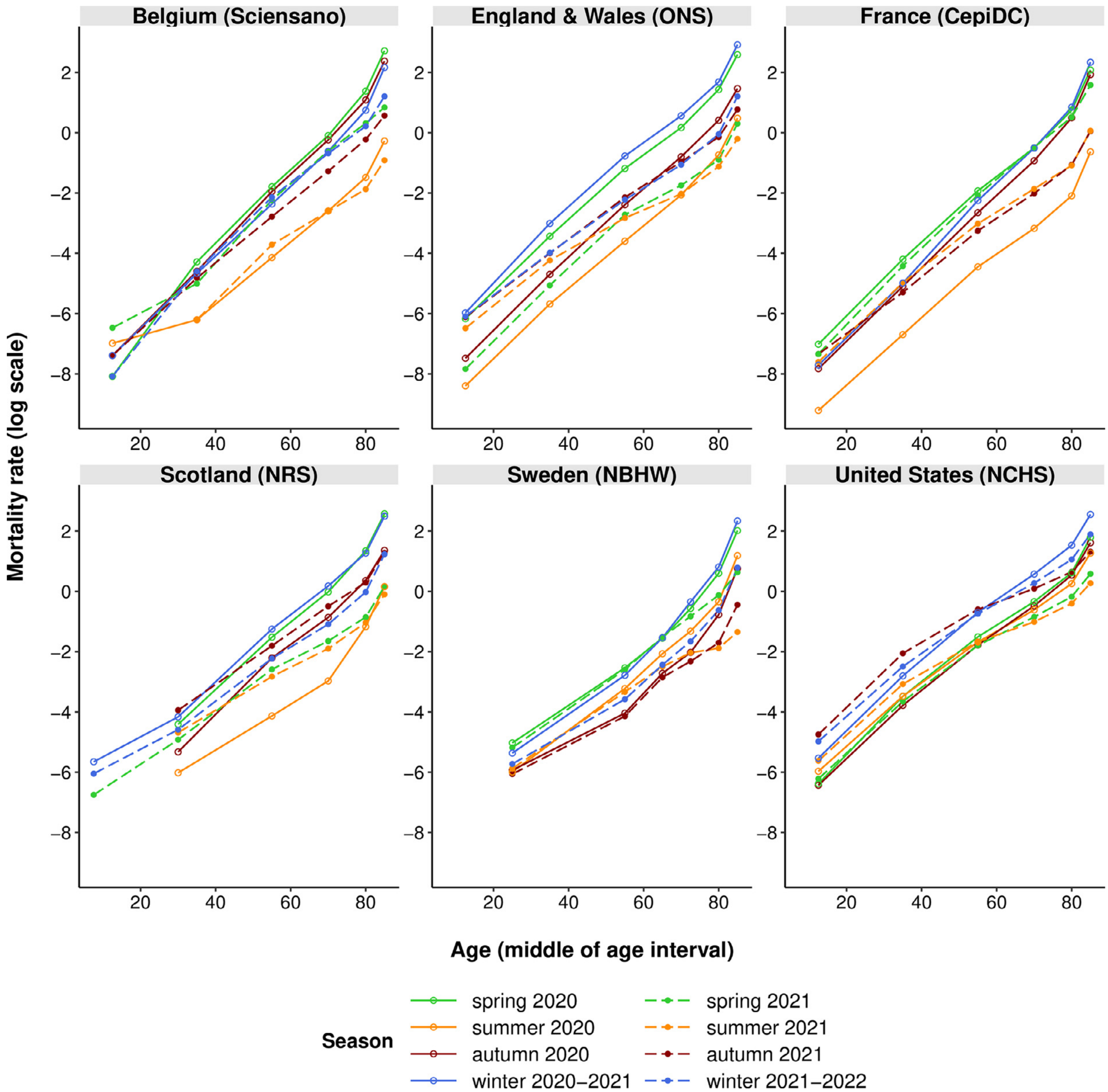

Figure 3. Age-specific COVID-19 mortality rates by sex and season.
Note: For Sweden, the point at the youngest age corresponds to the age group 0 to 49. Overall differences between seasons are further explored in the Supplements (Table S3). In Scotland (spring 2020 and summer and autumn of both years) and Belgium (summer 2021), no COVID-19 deaths were registered in the youngest age group (i.e., ages 0 to 14 in Scotland and ages 0 to 24 in Belgium). Therefore, we dropped those points from Figure 3, as the y-axis shows the mortality rate in log scale (and log(0) = - inf).

and Sweden, it is only modest and concerns mainly the oldest age groups in Belgium and in the United States. In the latter country, young age mortality was even slightly higher in the 2020-2021 winter season than in the previous one.

Variations in COVID-19 mortality by sex

Sex differences in COVID-19 mortality are explored in Figure 4. In general, COVID-19 mortality rates are higher among men than women. The largest differences are observed at ages 50 to 75. The only instances where women displayed higher COVID-19 mortality rates compared with men (shown in orange-red colors in Figure 4) concern the youngest age groups, but they involve very few deaths.

Sweden is the country with the largest sex differences in COVID-19 mortality, as the rates for men in most age groups and in most seasons were at least 1.75 times higher compared with their female counterparts. In contrast, such large sex differences have been rare in the United States throughout the pandemic. Furthermore, the age gradient of sex differences in COVID-19 mortality has been smaller in the United States than in the other countries, where the rates at older ages have been much higher than at younger ages.

Finally, Figure 5 illustrates how the age and sex distribution of COVID-19 mortality changed across seasons in 2020 and 2021. We also compare these distributions with those of all-cause mortality in 2019. We chose 2019 because it is the most recent prepandemic year with available data for all study countries in the HMD. Furthermore, we do not distinguish between seasons in 2019 because the age and sex distribution of deaths from all causes did not vary much by season (see Supplements: Figures S6 and S7). Although there were indeed more deaths in winter, their age and sex distribution varied little compared with the other seasons in 2019.

In most seasons and countries, the age and sex structure of COVID-19 deaths in 2020 were older than that of all-cause mortal-

Figure 4. Sex differences in age-specific COVID-19 mortality rates (colored boxes) and total female COVID-19 death counts (numbers) by season.
Note: Relative differences illustrated with the colored boxes are calculated as the ratio of COVID-19 mortality rates for men to those for women. Similar mortality levels for men and women are represented in beige. Higher mortality among men compared with women is represented in blue, while higher mortality among women compared with men is represented in red (the darker the color, the greater the differences). Darker rows indicate higher male or female mortality during a specific season at various ages, while darker columns indicate higher male or female mortality for a specific age group across various seasons. Inside each colored box is indicated the total number of COVID-19 deaths among females observed in each country, season, and age group. Higher or lower COVID-19 mortality among men—as illustrated by the relative differences—is therefore calculated with respect to the shown number of female deaths.

ity in 2019. By contrast, the age and sex distribution in 2021 tells of a younger structure of COVID-19 deaths, driven mainly by a reduction in the proportional weight of female mortality at the oldest ages. In all countries, there is a marked decline in the proportions of female COVID-19 deaths at ages 85+ in the 2021 seasons compared with those of 2020. The younger structure of COVID-19 deaths in 2021 is, however, more visible among men, as there are higher proportions of male COVID-19 deaths in the 45 to 74 age range. This pattern is most visible in Sweden and Belgium during the summer of 2021 and in the United States during the summer and autumn of 2021. It should be kept in mind, however, that the data used for these analyses do not specify the role of COVID-19 in the death, which can contribute to an increase in the number of deaths (with or due to COVID-19) at young ages in periods with more contagious variants, such as Delta and Omicron in 2021.

Conclusion and discussion

This study shows that the timing and intensity of the waves of COVID-19 mortality experienced during 2020 and 2021 varied across study countries. Pronounced periods of stabilization were identified during the summer (especially in 2020) among the European countries included in our analyses but not in the United States. Possibly, this is related to stricter and more uniform public health measures within the European countries. For example, lockdowns were implemented almost simultaneously across the national territories of the European countries analyzed here, except for Sweden [16]. In contrast, the United States was more heterogeneous in terms of each wave's beginning and the types and timing of public health strategies implemented by local governments to contain the spread of the virus [14,15,17]. Between the European countries analyzed here, we found calendar differences, with France and Belgium experiencing an earlier start of the stabilization period in 2020 and Sweden doing so later. An analysis of the differential effect of public health policies could be refined in light of these findings, considering that Sweden distinguished itself from most other European countries during the first wave by not imposing mandatory lockdowns [18,19]. According to the Containment and Health Index [20], Sweden had the least strict policy responses to COVID-19 throughout the periods in 2020 and 2021, compared with the other European study countries. Seasonal variations in policy responses are most evident in France, where there is a relaxation of government measures during the summer months. Despite variations in policy responses to the COVID-19 crisis, our results show that there are certain similarities between the European countries in terms of the general trends in COVID-19 mortality, as noted previously.

In the European countries studied here, the first two COVID-19 waves were the most lethal, while the waves that followed during the year 2021 and the first months of 2022 were milder in comparison. Previous studies have observed a decrease in COVID-19 lethality over time as a result of a combination of factors, notably mass vaccination, improved medical management of the disease, immunity from natural infection, and new variants of the virus [21,22]. Nevertheless, we also observed a sharp increase in COVID-19 mortality in the United States toward the end of summer 2021, which lasted through the autumn and winter. This finding suggests higher mortality during the Delta and Omicron variants (predominant from July until November 2021 and from December 2021 until February 2022, respectively) in the United States than in the European countries studied here. This finding requires further investigation and should be interpreted with caution, however, as the data used here do not allow identifying the precise role of COVID-19 in the death. The Delta and Omicron strains, while highly contagious, were initially thought to be less fatal compared with previous variants. Nevertheless, in Massachusetts (a state with high vaccination coverage), Omicron caused a substantial number of excess deaths, even more than Delta [23].

By the end of the study period, the highest cumulative COVID-19 mortality rates from the beginning of the pandemic were observed in the United States and then in England and Wales. However, we found that the age distribution of deaths in those two countries differs substantially, as the United States displayed the highest COVID-19 mortality rates at young ages. In addition to higher COVID-19 mortality, all-cause mortality was already higher in the United States than in Europe even before the pandemic. The

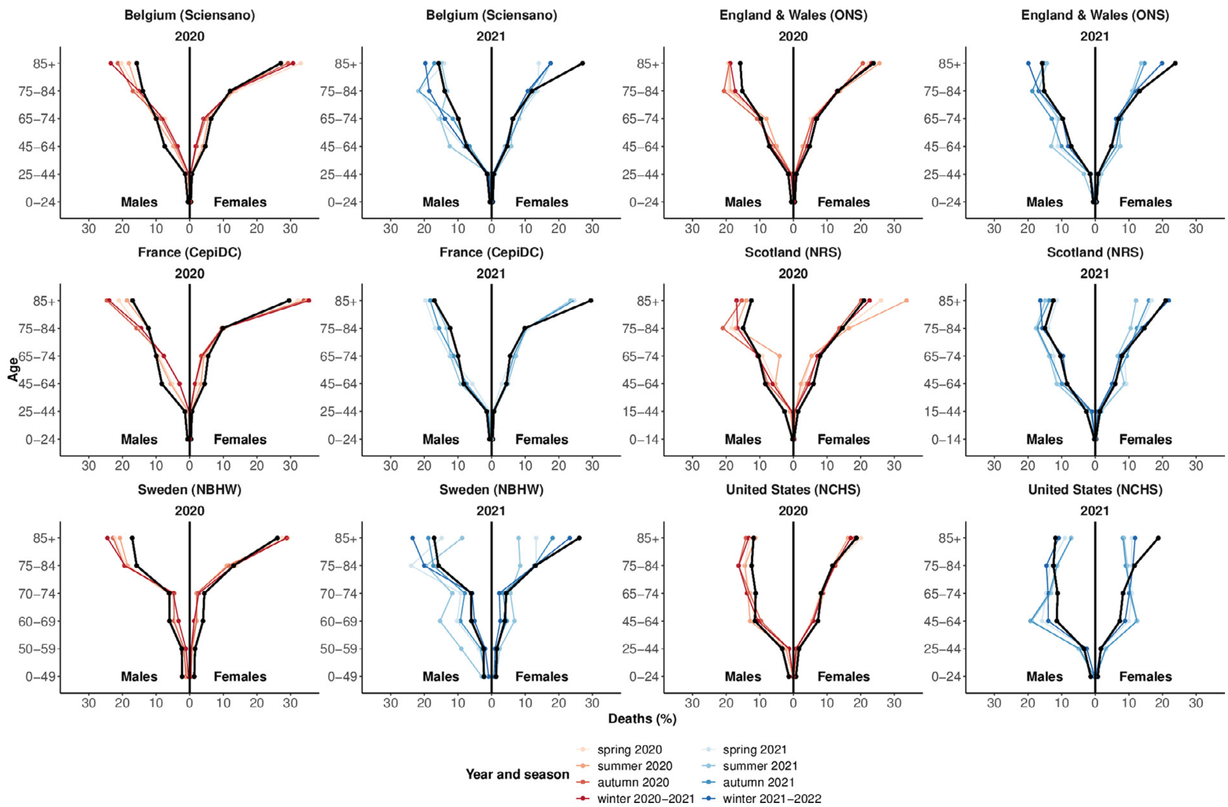

Figure 5. Age and sex distribution of COVID-19 deaths by season and of all-cause mortality in 2019.
Note: The colored lines (red and blue) show the distribution of COVID-19 deaths, whereas the black line shows the distribution of all-cause mortality in 2019. The age groups for Scotland and Sweden are different than those for the other countries due to different age groupings in the original data sources. For each season, the proportions by age and sex (i.e., the two characteristics simultaneously) add up to 100%.

pandemic may have “accentuated the preexisting mid-life mortality crisis” in the United States, as non-COVID mortality (mainly from external causes of death) also increased in 2020 and 2021 among working age adults, especially among men, possibly reflecting the lethal impact of drug overdose and homicides [24]. Previous studies have shown that COVID-19 hit the United States more severely than other countries; substantial losses in life expectancy in that country in 2020 are attributed to the pandemic [25–27].

We also found that in general, COVID-19 mortality is highest during winter (especially the winter of 2020-2021) and at old ages. The seasonality of COVID-19 mortality is hence similar to that of influenza, which is one of the causes of death associated with higher winter mortality - a pattern already observed before the pandemic. For instance, in the United States, ‘winter life expectancy’ is about 1 year lower than ‘summer life expectancy’ [28].

In 2020, the age and sex structures of COVID-19 deaths were older compared with that for all causes of death in 2019. Lower COVID-19 mortality rates and changes in the sex and age distribution of those deaths were observed in 2021, which could be linked to country-specific health policies. A marked reduction in COVID-19 mortality rates at the oldest ages was observed in England and Wales, Scotland, and the United States in the spring of 2021. This could possibly reflect (at least in part) the effects of vaccination in those populations (i.e., lower COVID-19 mortality rates with increasing vaccination coverage): by the beginning of April 2021, the share of people who had received at least one dose of COVID-19 vaccine was about 46% in the United Kingdom and 34% in the United States, but only 14% in France and Belgium and 13% in Sweden [29]. COVID-19 mortality at the oldest ages declined in France, Belgium, and Sweden during the summer of 2021, a period when these countries considerably increased their share of fully vaccinated people (70.5% in Belgium, 60% in France, and 56% in Sweden by the end of August 2021). Increased vaccination coverage during the summer of 2021 in these three countries is most likely related to reductions in mortality at ages 40 to 75 during the following autumn. In contrast, the reduction in COVID-19 mortality at ages 40 to 75 continued to be a challenge for the United States, which could possibly be related to the slower pace of vaccination during the second half of 2021. After being one of the forerunners in COVID-19 vaccination, the share of fully vaccinated people in the United States fell behind all other study countries; only 65% of the United States population was fully vaccinated by the end of February 2022. This proportion was higher at the oldest ages (92% and 86% at ages 65 to 74 and 75+, respectively) but considerably lower among the youngest (between 62% and 74% in the 18 to 49 age group) [30]. It should be noted, however, that other factors may also have contributed to changes in the structure and intensity of COVID-19 mortality during 2021 in the study countries, as vaccinations alone are insufficient to contain the pandemic [23,31,32]. Even when a large share of the population has been fully vaccinated, widespread COVID-19 testing among both vaccinated and unvaccinated individuals remains important as the efficacy of the vaccine wanes over time [33]. Furthermore, fully vaccinated individuals who later get infected with SARS-CoV-2 may carry high viral loads (even if they do not develop serious symptoms).

Finally, the pattern observed for sex differentials in COVID-19 mortality also shows consistency with that of all-cause mortality, with men experiencing higher risks of dying compared with women at any age [34,35]. Other studies have found that excess mortality—that is, higher mortality levels from all causes combined, compared with previous years—has been greater among men than women during the COVID-19 pandemic [36,37]. We found that sex differences were largest at ages 50 to 75. However, the magnitude of those differences varies by country. While comorbidities and, more specifically, respiratory diseases are major risk factors for COVID-19 death, sex differences in the prevalence of diseases might be at play. Another possible explanation could be differential exposure to the virus associated with sex differences in domestic, social, and economic activities. Further examinations are required for a better understanding of such variations across countries.

Strengths and limitations of this study

This paper compares the variability in cross-seasonal COVID-19 mortality by age and sex in six countries, covering the years 2020 and 2021. Our analyses add to current evidence on the lethality of COVID-19 by showing the changing age and sex structure of COVID-19 mortality between populations and over time within the same population.

Furthermore, unlike previous studies, our analyses are based exclusively on the type of data sources that currently offer complete information on COVID-19 deaths. These results provide solid material to be confronted with country-specific health policies implemented by governments. Nevertheless, the real burden of COVID-19 will be more accurately determined once vital statistics for 2020 and 2021 become available by assessing the precise role played by COVID-19 in death, whether the immediate, contributory, or underlying cause of death.

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Ethics approval

This study only uses aggregate data available online.

Author contributions

Conceptualization, methodology, writing original draft: CT, JG, and FM. Review and editing: MB, EC, and FB. Data collection and metadata curation: AC, EC, JG, CT, FM, MB, SP, CGC, and J-MR.

Data availability

Data and codes to reproduce the analyses presented here will be available in an open-access repository. The datasets were derived from sources in the public domain: French Institute for Demographic Studies (INED) (distributor). The Demography of COVID-19 Deaths https://dc-covid.site.ined.fr/en/.

Declaration of Competing Interest

The authors have no competing interests to declare.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ijid.2022.12.004.

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