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# Patterns and drivers of excess mortality during the COVID-19 pandemic in 13 Western European countries

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## Abstract

**Background** Important differences in excess mortality between European countries during the COVID-19 pandemic have been reported. Understanding the drivers of these differences is essential to pandemic preparedness.

**Methods** We examined patterns in age- and sex-standardized cumulative excess mortality in 13 Western European countries during the first 30 months of the COVID-19 pandemic and the correlation of country-level characteristics of interest with excess mortality.

**Results** In a timeline analysis, we identified notable differences in seeding events, particularly in early 2020 and when the Alpha variant emerged, likely contributing to notable differences in excess mortality between countries (lowest in Denmark during that period). These differences were more limited from July 2021 onwards. Lower excess mortality was associated with implementing stringent non-pharmaceutical interventions (NPIs) when hospital admissions were still low in 2020 (correlation coefficient rho = 0.65, $p = 0.03$) and rapid rollout of vaccines in the elderly in early 2021 (rho = −0.76, $p = 0.002$). Countries which implemented NPIs while hospital admissions were low tended to experience lower gross domestic product (GDP) losses in 2020 (rho = −0.55, $p = 0.08$). Structural factors, such as high trust in the national government (rho = −0.77, $p = 0.002$) and low ratio of population at risk of poverty (rho = 0.55, $p = 0.05$), were also associated with lower excess mortality.

**Conclusions** These results suggest the benefit of early implementation of NPIs and swift rollout of vaccines to the most vulnerable. Further analyses are required at a more granular level to better understand how these factors impacted excess mortality and help guide pandemic preparedness plans.

**Keywords** COVID-19, COVID-19 / prevention & control, COVID-19 vaccines, Western Europe

## Background

By the end of 2021, the COVID-19 pandemic had led to an estimated 14.9 (95% confidence interval [CI]: 13.3–16.6) million excess deaths worldwide, including around 750,000 deaths in Western Europe [1]. The loss in economic output was estimated at US $12,500 billion by 2024 [2]. The impact of the COVID-19 pandemic on health can be assessed through various indicators including excess mortality [3–5]. Despite important similarities across Western Europe regarding gross domestic product, population structure, healthcare systems, climate, cultural

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values, or political systems, previous estimates have shown important differences in excess mortality between countries of the region [6–8]. Contrasts remained notable after age standardization, suggesting that differences in age distribution did not explain most of the differences observed between countries [9]. One limitation of most studies was the reliance on a short pre-pandemic reference period (2015–2019) to compute the expected mortality rates during pandemic years. Moreover, 2015 was characterized by a notable increase in mortality in several Western European countries due to a combination of a severe flu season and a heat wave in the summer [10–13]. A longer reference period would thus be preferable to account for long-term mortality trends in this region.

The analysis of excess mortality differences across countries may also provide valuable information to guide pandemic preparedness. Previous analyses have reported that higher prevalence of several comorbidities, lower healthcare quality indicators, or lower vaccine coverage were associated with higher COVID-19-related burden [9, 14]. Yet, these studies were either conducted outside of Western Europe [14] or included countries with highly diverse healthcare systems or policies [9], providing limited specific information for a relatively homogeneous region as Western Europe.

We thus aimed to estimate excess mortality rates specifically in 13 Western European countries (Belgium, Denmark, France, Germany, Ireland, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the UK) and the correlation of excess mortality with important policy contextual factors (non-pharmaceutical interventions — NPIs, vaccine rollout) and structural country-level population and health- or policy-related indicators. We accounted for both seasonality and long-term mortality trends using a 10-year reference period (2010–2019). We analyzed a longer period than prior estimates (27 January 2020–3 July 2022) [6–8] to include the period of predominance of the Omicron variant. We divided the period in three phases (January–June 2020: first wave; July 2020–June 2021: fall wave followed by the spread of the Alpha variant while stepwise vaccination was implemented; July 2021–June 2022: Delta and Omicron waves).

## Methods

### Excess mortality calculation

Excess mortality is defined as an increase in deaths from all causes beyond the number of deaths that would be expected based on past mortality trends. The use of excess mortality to compare countries with respect to health burden during the COVID-19 pandemic has several strengths and implications: (1) it is independent of COVID-19 testing and hospitalization rates; (2) the data are publicly and rapidly available; (3) it avoids issues related to misclassification of COVID-19-associated deaths; (4) it captures the medium-term effects of SARS-CoV-2 infection on mortality (e.g., increased risk of myocardial infarction, stroke, or thromboembolic events) [15]; (5) it captures the indirect mortality that may be associated with excess demand for healthcare, including the saturation of intensive care units, postponement of surgical procedures and preoperative delays, interruption of treatment and interventions in primary care, emergency, critical, and operative care, and disruptions of immunization activities and disease screening programs [16]; (6) it captures the beneficial effect of NPIs on all-cause mortality, including fewer traffic- and accident-related deaths, or the decrease in deaths attributable to other respiratory infections (e.g., influenza and respiratory syncytial virus) as a result of decreases in transmission [17–19]; and (7) it is a well-established measure of the impact of pandemic and seasonal influenza [20].

Considering that age is a major determinant of the risk of severe COVID-19, we accounted for differences in age structure across Western European countries by calculating age- and sex-standardized excess mortality rates. The methodology is the one used by the Institute and Faculties of Actuaries (London, UK), except for the calculation of expected mortality between 2020 and 2022, for which they used the 2019 mortality rate for 2020 to 2022, while we opted for using the projected mortality rate based on the 2010–2019 trend for 2020 to 2022 [21].

We used weekly age- and sex-stratified mortality rates provided by the Human Mortality Database [22] except for Ireland where data were not available; we therefore used monthly age- and sex-stratified mortality rates provided by the Central Statistics Office [23]. Age strata were defined as 0–14, 15–64, 65–74, 75–84, and 85 years and above.

In the Human Mortality Database, data are given separately for Northern Ireland, Scotland, and England, and Wales. We aggregated the data to obtain weekly age- and sex-standardized mortality rates for the UK. To do so, we weighted regional data by each region's population, dividing the number of crude deaths by the mortality rate.

We then calculated age- and sex-standardized weekly mortality rates for each week (w) (month for Ireland), year (y), and country (c), given by the following:

$$ASMR(w,y,c) = \frac{1}{2}\left(\sum_a \left(MR_a^{Male}(w,y,c) \times \frac{ESP_a}{ESP_{total}}\right) + \sum_a \left(MR_a^{Female}(w,y,c) \times \frac{ESP_a}{ESP_{total}}\right)\right)$$

where $MR_a^{Male}(w,y,c)$ (respectively $MR_a^{Female}(w,y,c)$) is the mortality rate for males (respectively females) in age strata (a), in week (w), of year (y), and for country (c), and $ESP_a$ (respectively $ESP_{total}$) is the 2013 edition of the European Standard Population for age strata (a) (respectively total age strata). For Sweden, the Institute and Faculties of Actuaries reported that around 3% of death are assigned to a year but not to a specific week. Age- and sex-standardized weekly mortality rates were thus increased by 2.3% in years 2011 to 2019, 2.8% in 2020, 3.3% in 2021, and 4.0% in 2022 to adjust for deaths not associated with a particular week [21].

The annual age- and sex-standardized mortality rate $ASMR(y,c)$ is then obtained for each year (y) from 2010 (2011 for Italy as no data were available for 2010) to 2022 and each country (c), as the mean of age- and sex-standardized weekly (monthly for Ireland) mortality rates:

$$ASMR(y,c) = \frac{1}{Nweeks_y} \times \sum_w ASMR(w,y,c)$$

where $Nweeks_y$ is the number of weeks (month for Ireland) in year (y), following the ISO 8601–2004 guidelines.

To account for long-term mortality trends, we fitted a log-linear model (as recommended [24] and used elsewhere [9, 21]) to annual standardized mortality rates between 2010 (2011 for Italy as data were not available for 2010) and 2019 and projected it to estimate the expected annual rates in 2020, 2021, and 2022:

$$ASMR^{expected}(y,c) = \exp(a_c + b_c \times y)$$

where for each country (c) as follows:

$$a_c, b_c \in argmin\left\{\sum_y \left(\log(ASMR(y,c)) - (a_c + b_c \times y)\right)^2\right\}$$

In a sensitivity analysis, we produced estimates using a linear model instead of a log-linear model to estimate the expected annual mortality rates (Additional file 1: Figure S7), showing only minimal differences with the estimates produced with the log-linear model. To account for seasonal variation, we calculated a weekly (monthly for Ireland) seasonality factor representing the mean proportion of the annual standardized mortality rate occurring in each week (or month for Ireland) between 2010 (2011 for Italy) and 2019:

$$SF(w,c) = \frac{\sum_y ASMR(w,y,c)}{\sum_y ASMR(y,c)}$$

As only a few years are defined with 53 weeks, we took the value of week 52 for each country to account for the seasonality factor of week 53.

We calculated the expected weekly mortality rates by multiplying the expected annual mortality rates in 2020, 2021, and 2022 by weekly (monthly for Ireland) seasonality factor:

$$ASMR^{expected}(w,y,c) = ASMR^{expected}(w,y,c) \times SF(w,c)$$

We finally subtracted the weekly expected rates from the weekly observed rates to calculate the weekly age- and sex-standardized excess mortality rates for each country:

$$ExcessM(w,y,c) = ASMR(w,y,c) - ASMR^{expected}(w,y,c)$$

As excess mortality is sensitive to sudden increases in deaths unrelated to the COVID-19 pandemic, we only considered excess mortality up to June 2022 to avoid the impact of the summer 2022 heat wave on European countries, which resulted in an estimated 61,672 (95% *CI*: 37,643–86,807) heat-related deaths between 30 May and 4 September 2022 [25]. The data and code used to produce the results are available on GitHub [26]. See the "Availability of data and materials" from the declaration section for more details.

### Excess mortality trajectories analysis

First, we described the evolution of the cumulative age- and sex-standardized excess mortality rates across Western European countries throughout the period of interest. We considered three distinct time periods: the first phase (27 January–28 June 2020), which included the first pandemic wave; the second phase (29 June 2020–27 June 2021), characterized by the second and third pandemic waves (autumn 2020 and Alpha waves) and the introduction of COVID-19 vaccines in early 2021; and the third phase (28 June 2021–3 July 2022), corresponding to the Delta and Omicron waves that occurred amid increasing infection- and vaccine-derived immunity at the population level. We examined the main contrasts in excess mortality, particularly the countries at the high and low ends of cumulative excess mortality for each period, in light of factors such as seeding events, NPIs, or vaccine rollout. We investigated the timeliness of NPI implementation by measuring the correlation of the ongoing hospital burden at the time strict NPIs (stay-at-home orders or recommendations) were implemented with subsequent excess mortality. We measured the pace of vaccine rollout and the final coverage by calculating the area under the curve (AUC) of the coverage in those aged 80 years and above (the population which contributed the most to excess mortality) for the first dose and the first booster. We examined the correlation of the AUC with excess mortality in the subsequent months including a 1-month lag. We used the Google Mobility Index to retail and recreation sites (restaurants, cafés, shopping centers, theme parks, museums, libraries, and movie theaters) which compares mobility to a baseline period from January 3 to February 6, 2020, as a proxy for changes in contact patterns induced by NPIs [27].

#### Ecological analysis of excess mortality potential factors

We examined the correlation of excess mortality with several structural factors at the country level, including sociodemographic characteristics and health status of the population, economic metrics, and healthcare system. For intergenerational contacts, we used contact matrices that were inferred from the latest available assessment in 2005–2006 [28, 29] A survey conducted in Belgium in 2010–2011 suggested contact patterns were stable over time [30]. All correlations were estimated using Spearman's rank coefficient (rho).

## Results

### Excess mortality trajectories across Western European countries during the COVID-19 pandemic

We used age- and sex-stratified weekly mortality data provided by the Human Mortality Database for each country between 2010 and 2019 to calculate age- and sex-standardized weekly mortality rates. Excess mortality was defined as the difference between weekly observed mortality and expected mortality estimated between 2020 and 2022 through a log-linear model fitted on the values between 2010 and 2019.

Figure 1 represents the log-linear trends estimating the expected age- and sex-standardized mortality rates between 2020 and 2022 relying on a 5-year or a 10-year reference period. We observe notable differences between the two projections for several countries related to a peak of mortality in 2015 (mainly Italy, Ireland, the Netherlands, Spain, Sweden, Switzerland, and the UK). Thus, we considered that a 10-year reference period would better reflect the long-term trends and be more robust to yearly fluctuations.

Figure 2 shows the annual age- and sex-standardized and non-standardized observed and expected mortality rates. The observed mortality rates increased between 2010 and 2019 in most countries, reflecting an aging population. Conversely, the age- and sex-standardized rates decreased, in line with the gains in life expectancy observed over the period [31]. All annual standardized mortality rates were comprised between 8.1 (Switzerland in 2021) and 11.0 (Germany in 2022).

Figure 3 shows the age-stratified cumulative excess mortality rates calculated using a similar method for each age stratum. Excess mortality was highest in people aged 85 years and above for most countries.

Cumulative excess mortality across the 13 Western European countries from 27 January 2020 to 3 July 2022 ranged from 0.5 to 1.0 excess deaths per 1000 population (Norway, Denmark, Ireland, Sweden) to around 2.7 excess deaths per 1000 population (Italy). All other countries experienced intermediate levels of excess mortality ranging between 1.0 and 2.0 (in ascending order Germany, Switzerland, France, Spain, Portugal, the Netherlands, the UK, and Belgium).

#### *The first phase (January–June 2020)*

From the beginning of the pandemic to June 2020, age- and sex-standardized cumulative excess mortality was below zero for three countries (Denmark, Germany, Norway), highest in the UK (0.89 per 1000), and ranged between 0.08 and 0.78 per 1000 for other countries (in ascending order Switzerland, Portugal, Ireland, France, the Netherlands, Sweden, Belgium, Italy, and Spain) (Fig. 4A).

The initial seeding of SARS-CoV-2 was heterogeneous across Western Europe. Italy [32, 33], Spain [34], and France [35, 36] all experienced important early seeding events. The UK also had multiple importations from Spain, France, and Italy in the second half of February, leading to a rapid increase in infections during the first half of March [37]. In contrast, few seeding events were identified in Denmark and Norway. Germany had several introductions or small outbreaks starting in late January, but with early identification and control, transmission remained comparatively limited [38, 39].

Following a massive outbreak in Lombardy [39], Italy was the first country in Europe to implement a stay-at-home order on 9 March. Other Western European countries followed suit between 13 March (Denmark) and 24 March (the UK), except for Sweden, which opted for stay-at-home recommendations from 16 March. As COVID-19 cases were increasing rapidly [40], the countries implementing NPIs early (i.e., when hospital admissions per capita were still low) were those with lower cumulative excess mortality during the first wave (Spearman's correlation coefficient rho $=0.65$, $p=0.03$) (Fig. 5A). Considering past evidence that Organisation for Economic Co-operation and Development (OECD) countries which opted for elimination rather than mitigation strategies had better economical outcomes, we examined if the timing of NPI implementation was correlated with changes in gross domestic product (GDP) [41]: late implementation of NPIs was marginally associated with higher GDP losses in 2020 (Fig. 5B) (rho $=-0.55$, $p=0.08$). Restrictions achieved important decreases in population mobility as measured by the Google Mobility Index: mean changes in mobility to

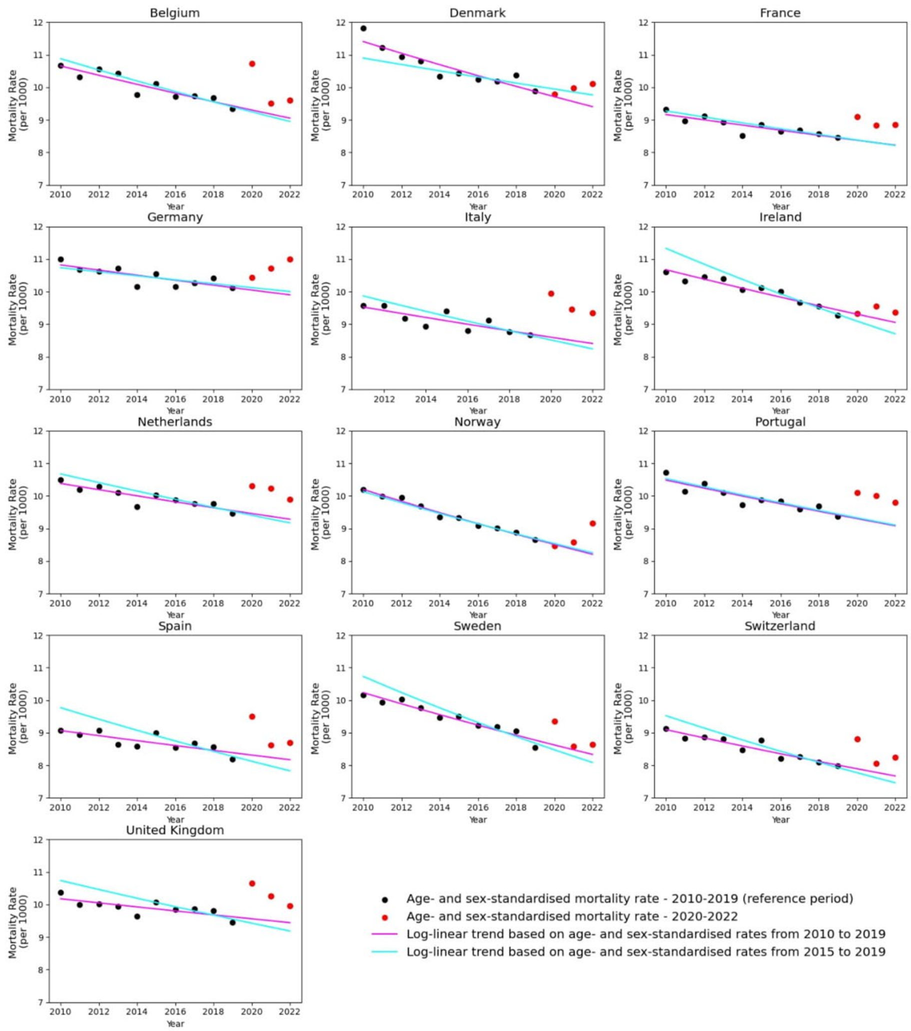


**Fig. 1** Annual age- and sex-standardized mortality rates between 2010 (2011 for Italy) and 2022. Log-linear models fitted to data from 2010 (2011 for Italy) to 2019 and 2015 to 2019. Each point includes data for the full year, thus including the weeks preceding the period of interest in early 2020 (before 27 January) and following the period of interest in late 2022 (after 3 July). Weekly mortality data are provided by the Human Mortality Database (except for Ireland for which monthly mortality data are provided by the Irish Central Statistics Office). Age strata are defined as 0–14, 15–64, 65–74, 75–84, and 85 years and above. The reference population for age and sex distribution is the 2013 edition of the European Standard Population

retail and recreation sites ranged between −53.3% (Spain) and −11.0% (Sweden). Contact surveys available for some Western European countries suggest this reduction in mobility translated into a decrease in contacts in nonhome settings [42, 43]. Negative excess mortality in some countries during this phase (Denmark, Norway, and Germany) has been attributed to the decrease in the circulation of other respiratory viruses [44], as well as in traffic-related accidents [18, 45] during stay-at-home orders.

After the stay-at-home orders were lifted in May 2020 in most Western European countries, SARS-CoV-2 transmission remained low, likely influenced by reduced contact between people, among other factors [46]. Cumulative excess mortality plateaued until the beginning of the summer in most countries.

### *The second phase (July 2020–June 2021)*

During the second phase, age- and sex-standardized cumulative excess mortality was negative in Norway and Ireland; low in Denmark and Sweden (0.07 and 0.25 per 1000, respectively); between 0.56 and 0.85 per 1000 in Spain, the UK, Germany, the Netherlands, France, Belgium, and Switzerland; and was highest in Portugal and Italy (1.24 and 1.32 per 1000, respectively) (Fig. 4B).

The second phase began with a gradual rise in infections in July–August (when school holidays occur in

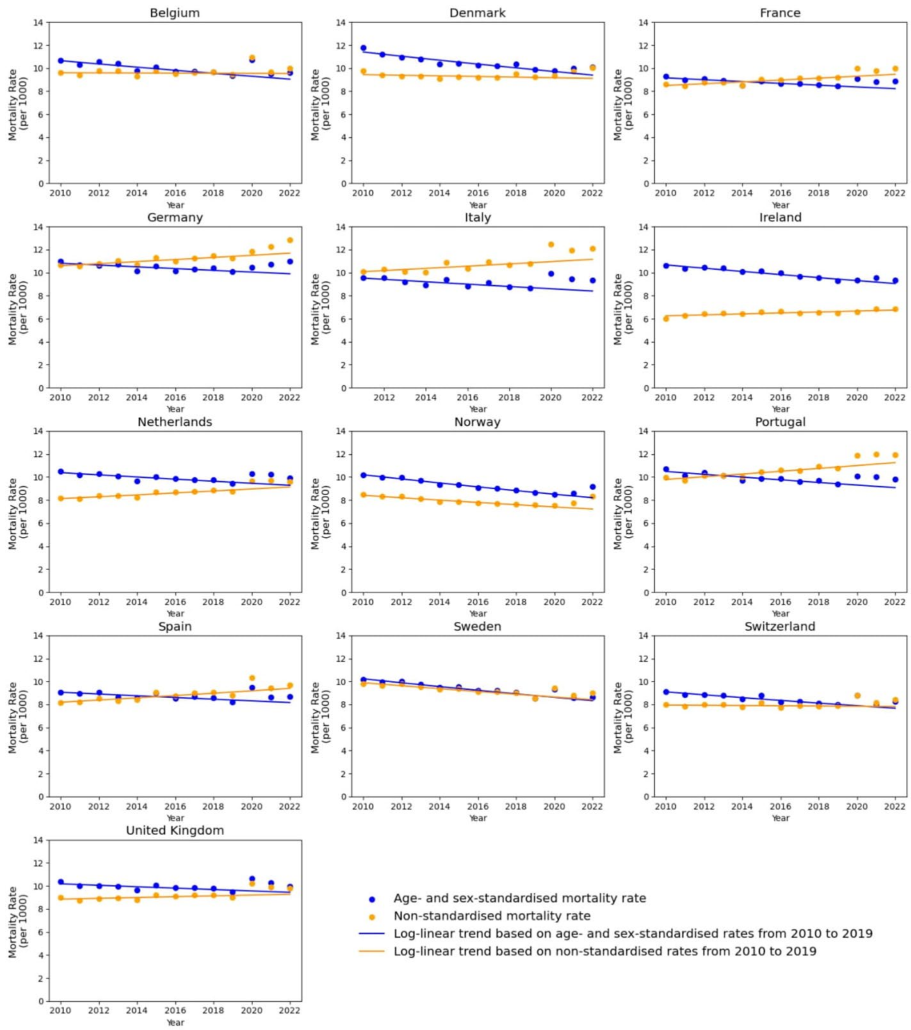


**Fig. 2** Annual age- and sex-standardized and non-standardized mortality rates between 2010 (2011 for Italy) and 2022. Log-linear models fitted to data from 2010 (2011 for Italy) to 2019. Each point includes data for the full year, thus including the weeks preceding the period of interest in early 2020 (before 27 January) and following the period of interest in late 2022 (after 3 July)

most countries), mostly in young adults before gradually spreading to older adults [47]. Genomic analyses identified that the spread of the 20E (EU1) and 20A.EU2 variants from Spain and France, respectively, to the rest of Western Europe was facilitated by travel and tourism [48, 49]. Of note, there was a heatwave episode in August 2020 with a high impact on excess mortality in Belgium and the Netherlands [50].

A sudden rise in SARS-CoV-2 incidence in most Western European countries occurred in the autumn of 2020, likely due to changes in weather and contact patterns [42, 46]. Consequently, stay-at-home orders or contact restrictions were reimplemented in late October and early November. Despite these control measures, excess mortality increased in most countries in November and December (except Denmark, Norway, and Ireland), with the starkest increases observed in Belgium, Italy, and Switzerland. As in the first phase, countries which implemented NPIs earlier (i.e., when hospital admissions were still low) had lower excess mortality between October and December 2020 (rho = 0.65, $p$ = 0.04) (Fig. 5C). Though less intense, the restrictions led to notable decreases in mobility between July and December 2020: the mean change for mobility to retail and recreation sites ranged between −31.9% (the UK) and +1.8% (Denmark).

The more transmissible and virulent B.1.1.7 (Alpha) variant was first detected in the UK in late 2020 [51, 52]. This variant quickly spread to Portugal in December 2020 [53]. It became predominant across all Western European countries by mid-February 2021 [51]. While excess

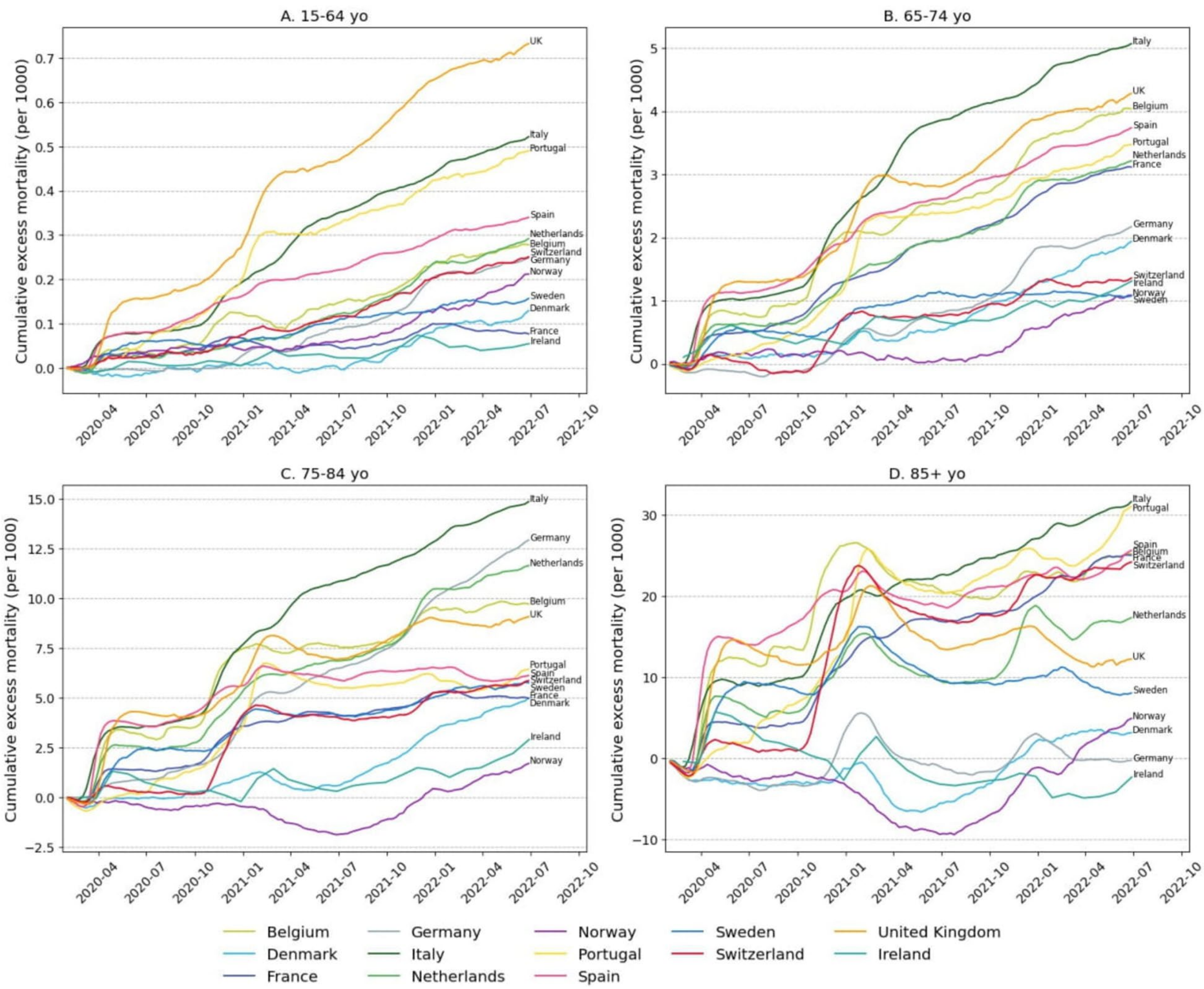


**Fig. 3** Age-stratified cumulative excess mortality rates across 13 Western European countries from 27 January 2020 to 3 July 2022. **A** 15–64 years old. **B** 65–74 years old. **C** 75–84 years old. D People aged 85 years and above. Data for 0–14 years old not shown

mortality increased for all countries except Norway in January–February 2021, the greatest increases occurred in the UK and Portugal despite re-implementing stay-at-home orders on 5 and 15 January 2021, respectively (likely in response to the emergence of the Alpha variant before or around the end-of-year celebrations) [54].

Between December 2020 and January 2021, Western European countries began the first COVID-19 vaccination campaigns, initially prioritizing older adults who were at highest risk of severe disease. Vaccine rollout among those aged 80 years and above (the population which contributed the most to excess mortality) increased rapidly in most countries in March and April 2021 to reach a coverage between 80 and 100% (Fig. 6A) [55]. To account for both the uptake speed and the vaccine coverage, we calculated the area under the curve (AUC) of the vaccine coverage and its association with excess mortality, including a 1-month lag. The AUC between February (when the rollout started picking up in most countries) and May 2021 was significantly negatively correlated with excess mortality between March and June 2021 (rho = $-0.76$, $p = 0.002$) (Fig. 6B). Most Western European countries maintained high-stringency NPIs during that period, including those with high mortality between March and June 2021 (France and Italy) or low mortality (Norway, the UK), suggesting the correlation between vaccine coverage and excess mortality was not mediated by differences in stringency of NPIs.

In a context of maintained stringent NPIs in most countries and increasing vaccine coverage in the most vulnerable people, the excess mortality remained stable in most countries between March and June 2021. The two exceptions were France and Italy, which might

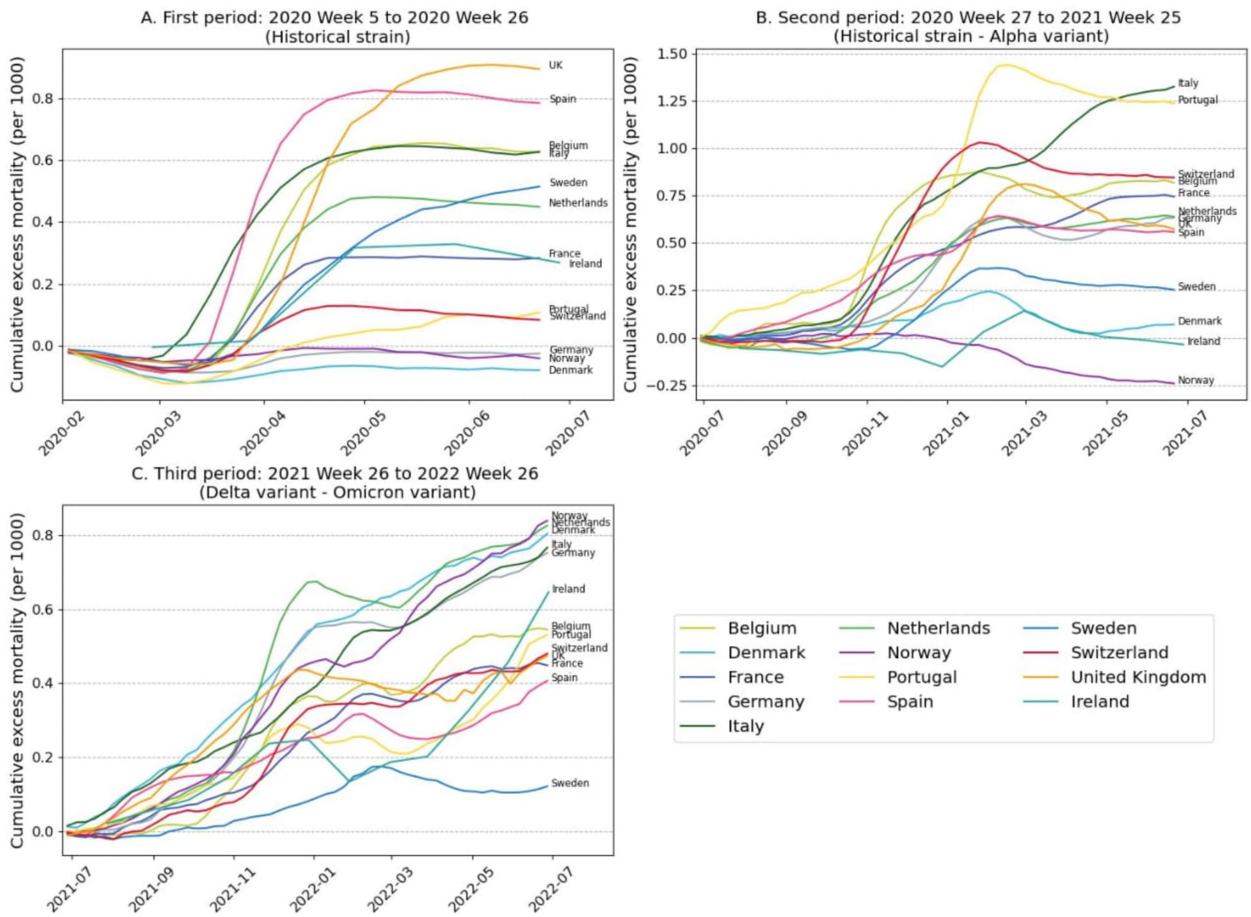


**Fig. 4** Age- and sex-standardized cumulative excess mortality rate in 13 Western European countries. **A** 27 January 2020 to 28 June 2020 (historical strain). **B** 29 June 2020 to 27 June 2021 (historical strain, followed by predominance of the Alpha variant). **C** 28 June 2021 to 3 July 2022 (predominance of the Delta variant followed by predominance of the Omicron variant and its descendent lineages)

be explained by consistently lower vaccine coverages in elderly populations as compared to other countries.

Throughout this period, all Western European countries increased somewhat homogeneously their contact-tracing (including through apps) and testing capacities. Denmark and the UK nonetheless stood out for their testing capacities: while all countries had a median of 2 to 4 daily tests per 1000 population between July 2020 and June 2021, these rates reached 13.9 tests per 1000 in Denmark and 6.0 tests per 1000 in the UK during the same period [56].

#### *The third phase (July 2021–June 2022)*

Compared with the second phase, we observed smaller differences between countries in cumulative excess mortality from July 2021 to June 2022. Excess mortality rates were lowest in Sweden (0.12 per 1000), highest in Norway (0.84 per 1000), and ranged between 0.41 and 0.83 per 1000 in Spain, France, the UK, Switzerland, Portugal, Belgium, Ireland, Germany, Italy, Denmark, and the Netherlands in ascending order (Fig. 4C). The third phase was characterized by waves of the Delta variant [57–59] followed by Omicron and its descendent lineages [60–63]. The cumulative excess mortality rate increased relatively steadily throughout the period in Norway, Denmark, and Italy. In Sweden, the rate had one single peak in February 2022 before decreasing. In other countries, it went through several periods of increase, including one in November–December 2021 that particularly affected the Netherlands, Germany, and Switzerland.

Throughout the third period, the stringency of NPIs decreased remarkably in most Western European countries due to increasing immunity in the population, as well as generalized fatigue towards public health measures. Drops in population mobility were more limited in the third phase than in the previous two: mean change for mobility to retail and recreation sites ranged between − 13.1% (Spain) and + 6.9% (Denmark).

Vaccination coverage was extended to all age groups through the summer of 2021, notably as a result of

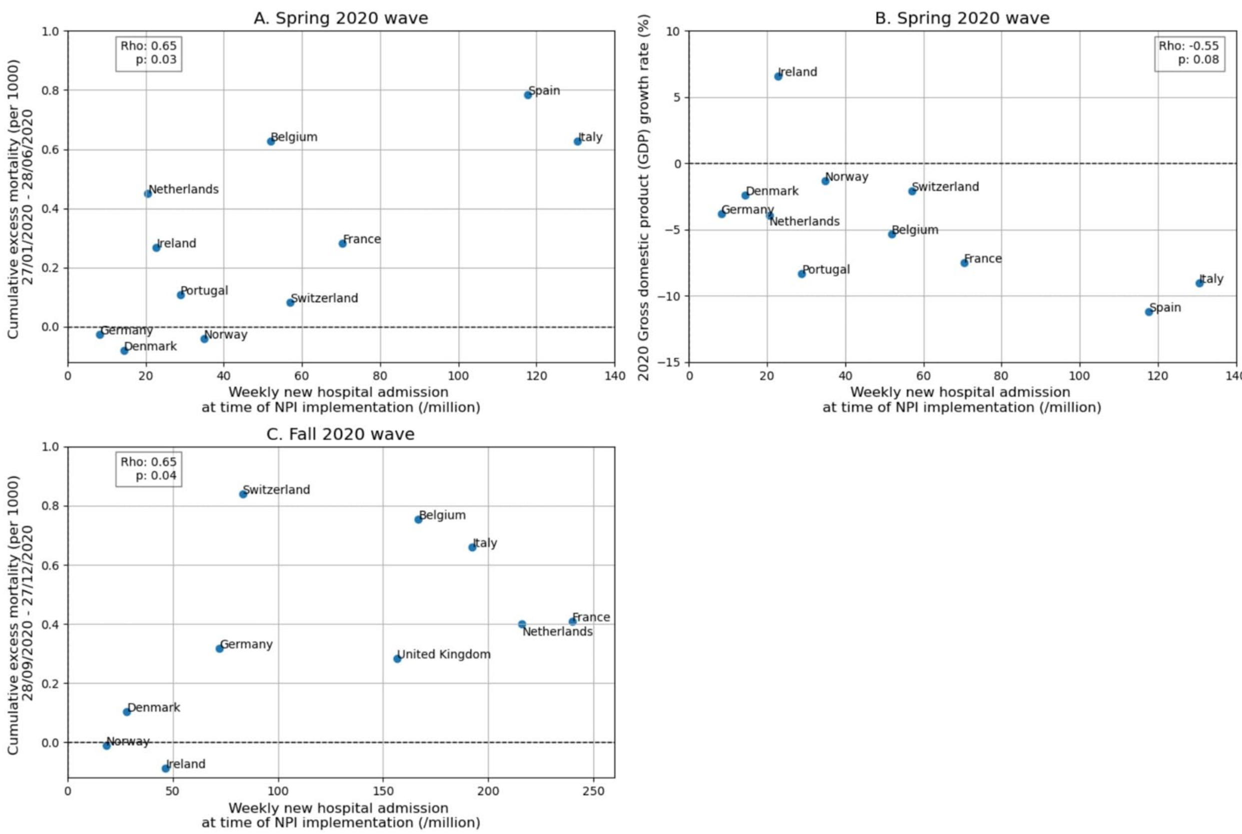


**Fig. 5** Correlation of weekly hospital admission rate on the day of implementation of non-pharmaceutical interventions with excess mortality and with the change in gross domestic product in 2020. Correlation coefficients are Spearman's rank coefficients. **A** Spring 2020, excess mortality from 27 January 2020 to 28 June 2020. **B** Spring 2020, change in GDP in 2020. **C** Fall 2020, excess mortality from 28 September 2020 to 3 January 2021. Italy opted for a stepwise implementation of restrictions in the fall of 2020. Among the possible dates, we retained the one closest to the peak of hospital admissions during that period minus 11 days (approximate time from infection to hospital admission): Italy opted for a nationwide stay-at-home recommendation as well as closure of nonessential shops and leisure venues on 26 October. Implementation of NPIs happened at the regional level during this period in Spain

communication campaigns, increased accessibility, and the need for vaccination certificates. After reductions in vaccine effectiveness against the Delta variant and waning of vaccine-derived protection over time became apparent [64, 65], a booster dose was recommended for the most vulnerable groups in the autumn of 2021. Most Western European countries rolled out booster doses in people aged 80 years and above somewhat simultaneously between September and November 2021 and achieved very high levels of vaccination coverage (the lowest rates were observed in France and Switzerland at around 80%) (Fig. 6D). The booster vaccine rollout started notably later in the Netherlands, Germany, and Switzerland, which might explain the larger increases in excess mortality observed in these countries during the Delta wave in November–December 2021. The AUC for the coverage of the booster dose in people aged 80 years and above between September and December 2021 was not associated with excess mortality between October 2021 and January 2022 (rho = −0.37, $p$ = 0.24) (Additional file 1: Figure S1).

### Structural factors associated with excess mortality

In further exploratory analyses, we calculated Spearman's rank correlation coefficient of excess mortality with structural factors. Data for most factors were extracted from publicly available sources, such as the World Bank, the European Commission, or the OECD (Additional file 1: Table S1). We considered cumulative excess mortality over the entire period of interest for most variables and shorter periods for variables that were reassessed over time (trust in government, international arrivals) (Table 1).

Among differences between countries which might have affected the SARS-CoV-2 incidence, we found a significant correlation of age- and sex-standardized cumulative excess mortality rates with countrywide population density (rho = 0.65, $p$ = 0.02) but not with the proportion of the population living in an urban area (rho = 0.30, $p = 0.32$) (Additional file 1: Figure S2). Regarding households, neither the mean household size (rho = 0.40, $p = 0.18$) nor the mean number of contacts people aged 65 years and above have with those aged under 65 (rho = 0.20, $p = 0.50$) was correlated with excess mortality (Additional file 1: Figure S2). Trust in the national government measured in 2019 was negatively correlated with excess mortality during the first phase (January–June 2020) (rho = −0.77, $p = 0.002$), but the level of trust expressed in 2020 (on average 8.6 percentage points higher than in 2019) was not correlated with excess mortality during the second phase (July 2020–June 2021) (rho = −0.31, $p = 0.31$) (Additional file 1: Figure S3). The number of international tourist arrivals (as per the United Nations World Tourism Organization definition) was not significantly correlated with excess mortality in 2020 (rho = 0.34, $p = 0.25$) but was in 2021 (rho = 0.68, $p = 0.02$) (Additional file 1: Figure S3).

Regarding risk factors of severe COVID-19, we found no correlation with excess mortality for the underlying conditions that we were able to explore: prevalence of

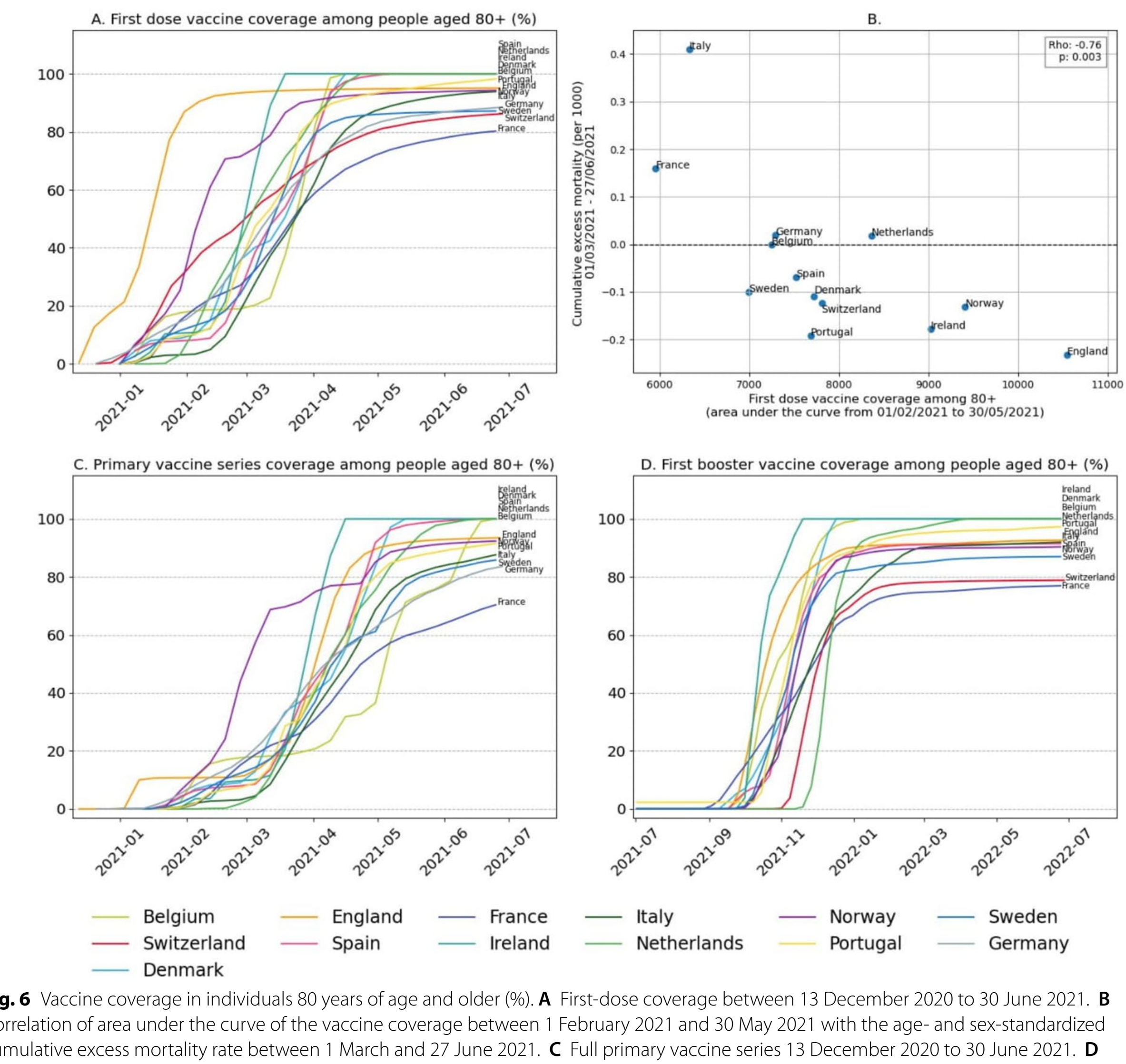


**Fig. 6** Vaccine coverage in individuals 80 years of age and older (%). **A** First-dose coverage between 13 December 2020 to 30 June 2021. **B** Correlation of area under the curve of the vaccine coverage between 1 February 2021 and 30 May 2021 with the age- and sex-standardized cumulative excess mortality rate between 1 March and 27 June 2021. **C** Full primary vaccine series 13 December 2020 to 30 June 2021. **D** First booster 1 July 2021 to 30 June 2021. Data sources are available in Additional file 1: Table S1. For some countries, the coverage provided by the European Centre for Disease Prevention and Control exceeded 100% (likely due to imprecise denominator data on the number of individuals 80 years of age and older). We capped this coverage at 100% when it was first reached. Data for booster vaccine coverage in Germany are available only among people aged 60 years and older. The coverage in this age group was 6.7% on 3 November 2021, 26.0% on 1 December 2021, and 61.8% on 1 January 2022

**Table 1** Spearman's rank correlation coefficients of the associations between national demographic/health indicators and cumulative excess mortality across 13 Western European countries

| Indicator | Time period considered for age- and sex-standardized cumulative excess mortality rate | Correlation | *p*-value |
|---|---|---|---|
| **Socio-economic indicators** | | | |
| Population at risk of poverty | 27 January 2020–03 July 2022 | 0.55 | 0.05 |
| Population at risk of poverty and social exclusion | 27 January 2020–03 July 2022 | 0.52 | 0.07 |
| Gini index | 27 January 2020–03 July 2022 | 0.52 | 0.07 |
| Tertiary education attainment | 27 January 2020–03 July 2022 | − 0.30 | 0.31 |
| **Demographic indicators** | | | |
| Population density | 27 January 2020–03 July 2022 | 0.65 | 0.02 |
| Population living in urban area | 27 January 2020–03 July 2022 | 0.30 | 0.32 |
| Household size | 27 January 2020–03 July 2022 | 0.40 | 0.18 |
| Number of contacts 65 + | 27 January 2020–03 July 2022 | 0.34 | 0.26 |
| Number of contacts 65 + with younger individuals | 27 January 2020–03 July 2022 | 0.20 | 0.50 |
| Trust in government 2019 | 27 January 2020–28 June 2020 | − 0.77 | 0.002 |
| Trust in government 2020 | 29 June 2020–27 June 2021 | − 0.31 | 0.31 |
| International arrivals 2020 | 27 January 2020–03 January 2021 | 0.34 | 0.25 |
| International arrivals 2021 | 04 January 2021–02 January 2022 | 0.68 | 0.02 |
| **Health status** | | | |
| Multimorbidity (at least two conditions) | 27 January 2020–03 July 2022 | 0.40 | 0.29 |
| Daily smokers | 27 January 2020–03 July 2022 | 0.31 | 0.30 |
| Diabetes | 27 January 2020–03 July 2022 | − 0.18 | 0.56 |
| Obesity | 27 January 2020–03 July 2022 | − 0.01 | 0.97 |
| **Healthcare system** | | | |
| Treatable mortality | 27 January 2020–03 July 2022 | 0.25 | 0.40 |
| Preventable mortality | 27 January 2020–03 July 2022 | 0.32 | 0.28 |
| Long-term care facilities bed capacity | 27 January 2020–03 July 2022 | 0.17 | 0.60 |
| Intensive care unit (ICU) beds | 27 January 2020–03 July 2022 | 0.25 | 0.40 |
| Number of physicians per capita | 27 January 2020–03 July 2022 | − 0.46 | 0.12 |
| Number of nurses per capita | 27 January 2020–03 July 2022 | − 0.35 | 0.24 |
| Unmet medical need | 27 January 2020–03 July 2022 | 0.14 | 0.65 |
| Out-of-pocket health expenditures | 27 January 2020–03 July 2022 | 0.37 | 0.22 |
| **NPI implementation** | | | |
| Number of hospital admission at time of NPI implementation: Spring 2020 wave | 27 January 2020–28 June 2020 | 0.65 | 0.03 |
| Number of hospital admission at time of NPI implementation: Fall 2020 wave | 28 September 2020–27 December 2020 | 0.65 | 0.04 |
| **COVID-19 vaccine coverage** | | | |
| First-dose vaccination coverage 80 + — area under the curve from 01 February 2021 to 30 June 2021 | 01 March 2021–27 June 2021 | − 0.76 | 0.002 |
| First booster vaccination coverage 80 + — area under the curve from 01 October 2021 to 30 May 2022 | 01 November 2021–26 June 2022 | − 0.03 | 0.91 |

Legend: No adjustment for the performance of multiple statistical tests. For international arrivals (2020, 2021, and 2022), we considered cumulative excess mortality over the corresponding calendar year. For trust in government 2019, we considered cumulative excess mortality for the first period of interest (that is, the first half of 2020), while for trust in government 2020, we considered cumulative excess mortality for the second period of interest (from the second half of 2020 to the end of the first half of 2021)

diabetes, obesity, multimorbidity (two or more chronic conditions in individuals over age 50 years) [66], or daily smoking (Additional file 1: Figure S4). Regarding healthcare systems, we found no significant correlation between excess mortality and the number of physicians per capita (rho = − 0.46, $p = 0.12$), the number of nurses per capita (rho = − 0.35, $p = 0.24$), the number of long-term care facility (LTCF) beds per capita (rho = 0.17, $p = 0.60$), preventable mortality (rho = 0.32, $p = 0.28$), or treatable mortality (rho = 0.25, $p = 0.40$) (Additional file 1: Figure S4).

The population at risk of poverty, defined as households with an annual income below 60% of the national median (rho = 0.55, $p = 0.05$), and the Gini index for income inequality (rho = 0.52, $p = 0.07$) were both marginally correlated with excess mortality, whereas out-of-pocket health expenditure was not (rho = 0.37, $p = 0.22$) (Additional file 1: Figure S5).

## Discussion

We observed large differences in age- and sex-standardized cumulative excess mortality across 13 Western European countries during the COVID-19 pandemic. The first waves in 2020 were characterized by differences in the size and timing of seeding events. During this time, few countermeasures were available besides stringent NPIs. The implementation of these measures early on, when COVID-19 hospital burden was still low, was associated with a lower excess mortality. The emergence of the Alpha variant in late 2020 and early 2021 affected all Western European countries, with the UK and Portugal being particularly impacted due to its earlier detection in these countries. Rapid rollout of vaccines and high coverage in the elderly were associated with diminished excess mortality in the first half of 2021. The stringency of NPIs decreased progressively through 2021 and 2022. During the emergence of Delta followed by Omicron variants across Western Europe, we observed smaller differences in excess mortality between countries during that period, except in late 2021 due to the Delta variant in countries where the rollout of booster doses in the elderly occurred later. Alongside these contextual factors, we found several structural factors were correlated with lower excess mortality, such as high trust in the national government, low international tourist arrivals in 2021, low ratio of population at risk of poverty, and low population density. Our analysis offers key insights for interpreting the differences in excess mortality between Western European countries. These findings provide a foundation for building responses to future pandemics.

The differences in seeding events and the lower excess mortality observed in countries where NPIs were implemented while hospital burden remained low highlight the potential benefits of an early response, an association which has been documented previously [67], during both the spring and the autumn waves in 2020 [68, 69]. Northern European countries that observed the critical situation occurring in Northern Italy were able to implement measures when viral circulation was still low [70]. Implementation of NPIs when hospital burden is already high carries the risk of overwhelming the healthcare system as patients incubating the virus at the time of implementation may still require hospitalization. The mean delay between infection and hospitalization has been estimated at 11 days for COVID-19 [71]. Early implementation of NPIs, on the other hand, allows for the possibility of introducing lower-stringency NPIs, with their impact assessed through hospital surveillance, and strengthening them if needed. The stringency and the targeting of the NPIs may be also guided by the estimates of the effectiveness of individual and combined NPIs obtained during this pandemic [46]. This approach must be balanced with the impacts on societies (including on the economy, social cohesion, or public health) and the need for acceptance by the population, which may depend on the trust in government and institutions, as illustrated in this analysis. Of interest, countries that implemented NPIs while hospital burden was low tended to experience more limited GDP losses in 2020, suggesting prompt restrictions did not lead to worse economic outcomes. It is noteworthy that the intensity of NPIs required to bring the effective reproduction number below 1 seemed to differ between countries: while all countries achieved this in early 2020 for instance, Scandinavian countries did so with comparatively low-stringency measures and limited reductions in population mobility.

COVID-19 vaccines had a substantial impact on the pandemic by reducing the risk of severe disease and death [72], and our analysis supports the importance of timely vaccine implementation. The public health response benefited from the rapid development of safe and effective vaccines, the deployment of which alleviated the need for the most stringent NPIs. Efforts are under way to further shorten the delay between the start of a pandemic and the vaccination of the population [73]. Acceptance for stringent NPIs at the start of a pandemic will likely be improved if this is for a short time period, determined by the development and availability of an effective vaccine. However, for some emerging pathogens, vaccine development might be more difficult than it was for COVID-19, in which case the long-term acceptability of stringent NPIs strategies would likely be more challenging.

The correlation of the population at risk of poverty with excess mortality has also been identified in the United States in a state-level analysis [14]. Other studies have reported similar associations and suggested that higher exposure to the virus, higher prevalence of comorbidities, or poorer access to healthcare may be mediating factors [74, 75]. Together, these findings illustrate why mitigation of social health inequalities should be integrated into pandemic preparedness plans. We observed a strong association between high trust in the government and low excess mortality at the start of the pandemic. Other studies have found higher compliance with NPIs and vaccination coverage among those who trust the government, especially public health institutions [76–78]. Higher trust in the institutions likely facilitated compliance with control measures, particularly at the beginning of the pandemic, during a period of great uncertainty.

While LTCF residents were at greater risk of severe COVID-19 during the pandemic [79], by virtue of their age and comorbid conditions, we did not find any association between the number of LTCF beds per capita (an approximation of the population size in these facilities) and excess mortality. However, this finding may reflect the methodological limitations of our ecological correlation approach. Daly and colleagues underscored important organizational differences between LTCFs in five Western European countries [80]. Several studies found that the size of the LTCF and the associated rate of contact, the type of care (personal care only or nursing services), and the comorbidities of residents had an impact on the burden of COVID-19 in LTCFs [81–84]. A more detailed analysis of the organization of long-term care of the most vulnerable and the association with SARS-CoV-2-related burden would help understand key drivers of respiratory pathogen transmission in these settings [85].

Excess mortality has been used elsewhere to measure the impact of the COVID-19 pandemic [3, 4, 86]. Our study is one of the few to produce age- and sex-standardized estimates to increase comparability between countries with notable differences in age distribution (e.g., the proportion of people 80 years and older, who are at much higher risk of COVID-19 mortality, ranged from 3.4% in Ireland to 7.5% in Italy) [9]. We chose a longer reference period to estimate the expected mortality during pandemic years (10 years instead of the often-used 5 years) [3, 4, 9]. Indeed, the mortality peak observed in 2015 in several Western European countries would lead to overestimating the slope of the long-term decreasing trend. We also standardized on the European Standard Population 2013 age and sex structure, which is closer to the real age distribution in Western Europe than the often-used World Health Organization estimates (2000–2025) [87]. This makes the excess mortality estimates more interpretable. It also better preserves the contribution of the oldest age group to the standardized estimates (population aged 85 years and above represents 0.63% of the WHO standard population and 2.5% of the ESP) and thus keeps relevant contrasts more visible between Western European countries. Our methodology, and hence our results, were very close to those of the Continuous Mortality Investigation of the Institute and Faculty of Actuaries who also used age and sex standardization and a 10-year reference period [21]. The only difference is that they carried forward the predicted 2019 age- and sex-standardized mortality rate to estimate the expected mortality in 2020–2022, whereas we chose the projected value for 2020–2022 based on the model to compute expected mortality in these same years, aiming to account for the long-term decrease in mortality rates.

This work has several limitations. As discussed above, our estimates of excess mortality may be sensitive to the methodological choices we made regarding the reference period and estimation of the expected mortality. Our analyses were mainly based on ecological correlations at the national level and restricted to 13 Western European countries for which data on the indicators of interest were available and comparable. These data were compiled by international organizations or institutions which applied criteria to maximize the validity of the collected data. Associations of these country-level indicators with excess mortality should be considered with caution. Indeed, correlation is not causation, and analysis of potential confounding factors would be informative [88]. Further analyses will be needed to distinguish the relative contributions of different structural and contextual factors, as well as potential confounding and mediating effects. Unfortunately, with the small sample size of this study ($n = 13$ countries), such analyses were not possible and will require more granular data, probably at the subnational level. This level would also be more appropriate to assess the impact of climate conditions or population density on excess mortality [46] and the potential confounding role of factors such as quality of care, LTCF management, or the reduction in the number of contacts [42]. Furthermore, our analysis on the impact of the timing of NPI implementation cannot distinguish which NPI measures, among the range of NPIs that were implemented, had the greatest impact; additional research is needed. Likewise, contact-tracing capacities or infection prevention and control practices, such as mask wearing, could not be addressed. The analysis on the second wave in the fall of 2020 should also be considered with caution as several countries implemented NPIs gradually, and it was difficult to identify which NPIs impacted transmission. Understanding causal pathways between NPIs and excess mortality could benefit from finer analysis of specific NPIs. Strategies that were implemented outside Western Europe, such as the zero COVID-19 policy used in some countries in the Western Pacific, including China, or the use of digital contact-tracing tools in South Korea, are beyond the scope of this analysis. These strategies appear to have been able to reduce transmission to low levels up until the emergence of more transmissible variants, like Omicron; these remain important considerations for public health approaches during future pandemics. Finally, our analysis was limited to the medium-term impact of the pandemic (until mid-2022), and while we chose to restrict our analysis to the impact on excess mortality, the pandemic also needs to be evaluated for its impact on other aspects of health, both physical and mental, as well as its economic and educational impacts. Unfortunately, while sex- and age-stratified death counts were available on a weekly basis for the countries included in this analysis, allowing the estimation of excess mortality, similar data were not available for COVID-19 hospitalization or admission to intensive care units, preventing comparative analysis. Likewise, standardized data on long COVID prevalence across countries would have been important to consider, but were not available.

## Conclusions

This analysis explored the differences in excess mortality observed among 13 Western European countries during the first 2 and a half year of the COVID-19 pandemic. One major finding was the lower excess mortality in countries which implemented NPIs early during the first pandemic wave, while the hospital burden was still low. For future pandemics, countries should not delay the implementation of NPIs when modeling data indicate that health services will soon be overwhelmed. Countries which implemented NPIs early were also those which tended to experience lower GDP losses, suggesting that the earlier implementation of measures had a lower impact on the economy as compared to delaying their implementation. Countries with low ratio of the population at risk of poverty had lower age- and sex-standardized excess mortality, illustrating the importance of reducing social health inequalities and incorporating equity into pandemic preparedness plans. Further analyses, expanding to other indicators, and performed at a more granular level, will be required to better understand how each of these factors contributed to excess mortality which can improve preparedness for future pandemics.

### Abbreviations

| | |
|---|---|
| AUC | Area under the curve |
| CI | Confidence interval |
| ESP | European standard population |
| GDP | Gross domestic product |
| ICU | Intensive care unit |
| LTCF | Long-term care facility |
| MR | Mortality rate |
| NPIs | Non-pharmaceutical interventions |
| OECD | Organisation for Economic Co-operation and Development |
| SF | Seasonality factor |
| UK | United Kingdom |
| WHO | World Health Organization |

## Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s44263-024-00103-z.

Additional file 1: Supplementary figures: Figure S1. Correlation of the area under the curve of vaccine coverage among people aged 80 years and above with age- and sex-standardised cumulative excess mortality. Figure S2. Correlation of potential demographic determinants of SARS-CoV-2 incidence with age and sex-standardised cumulative excess mortality. Figure S3. Correlation of potential determinants of SARS-CoV-2 incidence with age- and sex-standardised cumulative excess mortality . Figure S4. Correlation of potential health status determinants of SARS-CoV-2 incidence with age- and sex-standardised cumulative excess mortality . Figure S5. Correlation of potential healthcare system determinants of SARS-CoV-2 incidence with age- and sex-standardised cumulative excess mortality . Figure S6. Correlation of socio-economic indicators with excess mortality. Figure S7. Annual age- and sex-standardised mortality rates between 2010 (2011 for Italy) and 2022. Linear and log-linear models fitted to data from 2010 (2011 for Italy) to 2019. Supplementary table: Table S1. Description of indicators inspected for association with excess mortality and data sources.

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On September 2023, a seminar of experts from 13 Western European countries (Belgium, Denmark, France, Germany, Ireland, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, and the UK) who actively engaged in the public health response to the COVID-19 pandemic took place at Institut Pasteur in Paris, France. During the seminar, excess mortality trajectories of the 13 countries during the COVID-19 pandemic were compared and discussed to identify factors that may be associated with differences in excess mortality across countries.

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### Authors' contributions

Simon Galmiche, Camille Coustaury, Kelly Charniga, Rebecca Grant, Simon Cauchemez and Arnaud Fontanet wrote the first draft of the manuscript. Simon Galmiche, Camille Coustaury and Arnaud Fontanet conducted the statistical analyses. All authors reviewed the manuscript for important intellectual content. All authors read and approved the final manuscript.

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**Data availability**

The results on excess mortality of the study are based on publicly available data from the Human Mortality Database downloaded on 15 February 2024 (https://www.mortality.org/) and the Central Statistics Office (https://www.cso.ie/en/index.html). All data used for the ecological analysis are described in table S1 of Additional file 1. They are made available alongside the code. See Coustaury Camille, Excess Mortality, Western Europe. GitHub, https://github.com/CamilleCoustaury/Excess-mortality_Western-Europe.git for the code necessary for replication of the results [26].

## Declarations

**Ethics approval and consent to participate**

Not applicable.

**Consent for publication**

Not applicable.

**Competing interests**

The authors declare no competing interests.

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