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The contribution of population age-sex structure to the excess mortality estimates of 2020–2021 in Denmark, Finland, Iceland, Norway, and Sweden

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ABSTRACT

The Nordic countries offer an ideal case study of the COVID-19 pandemic due to their comparability, high data quality, and variable mitigations. We investigated the age- and sex-specific mortality patterns during 2020–2021 for the five Nordic countries and analysed the total age- and sex-adjusted excess deaths, ratios of actual to expected death rates, and age-standardized excess death estimates. We assessed excess deaths using several time periods and sensitivity tests, and 42 sex and age groups. Declining pre-pandemic age-specific death rates reflected improving health demographics. These affect the expected death estimates and should be accounted for in excess mortality models. Denmark had the highest death rates both before and during the pandemic, whereas in 2020 Sweden had the largest mortality increase. The age-standardized mortality of Denmark, Iceland and Norway was lowest in 2020. 2021 was one of the lowest mortality years for all Nordic countries. The total excess deaths in 2020–2021 were dominated by 70−89-year-olds, were not identified in children, and were more pronounced among men than women. Sweden had more excess deaths in 2020 than in 2021, whereas Finland, Norway and Denmark had the opposite. Our study provides new details on Nordic sex- and age-specific mortality during the first two years of the pandemic and shows that several metrics are important to enable a full understanding and comparison of the pandemic mortality.

1. Introduction

All-cause excess death estimates (total observed deaths minus deaths expected for a given period) include all deaths, and are therefore not affected by testing and COVID-19-death reporting strategies in different countries or territories(Beaney et al., 2020; Helleringer & Queiroz, 2022; Leon et al., 2020; Nogueira et al., 2020; Sanmarchi et al., 2021). Thus, they offer a less confounded basis for comparing the total mortality outcome of a health crisis such as the pandemic caused by the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) to expected deaths in absence of a crisis. However, even when total deaths are known, determining the expected deaths (baseline in absence of crisis) involves considerable uncertainty(Kepp et al., 2022; Nepomuceno et al., 2022; Schöley, 2021; Shkolnikov et al., 2022).

Recently, the World Health Organization (WHO)(Msemburi et al., 2023; World Health Organization, 2022a) and the Institute for Health Metrics and Evaluation (IHME)(Wang et al., 2022) published estimates of the excess mortality in 2020 and 2021, and The Economist(Solstad, 2021) and World Mortality Dataset (WMD)(Karlinsky & Kobak, 2021) have continuously provided updated excess mortality estimates. Recent critical reviews of the models have reported major sensitivity to the time-period used due to outlier mortality years(Kepp et al., 2022; Nepomuceno et al., 2022) and concern about the IHME model(Kepp et al., 2022), suggesting great caution when interpreting policies from

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such complex and heterogeneous results.

Expected deaths, and therefore excess deaths, are modelled on the basis of expectations and can include covariates such as age or sex. Mortality is most strongly related to age(O'Driscoll et al., 2021), and thus changes in the size of age subgroups over time (especially the oldest most fragile groups with the highest mortality) can affect baselines and excess mortality estimates(Aburto et al., 2022). Annual age-specific death rates (deaths divided by mean populations in a population group) can be used to estimate excess mortality while accounting for age effects. Thus, the total excess deaths of regions or population groups with distinct age and sex demographics cannot be meaningfully compared. In the same way, sex-specific mortality may affect total mortality in an age-dependent way and can be accounted for by comparing age- and sex-specific death rates, as recently attempted for some countries(Henry et al., 2022)(Brett, 2021).

We considered the Nordic countries an ideal focused test case due to 1) their unique combination of commensurable and complete health register data, minimising data weaknesses, and 2) high epidemiological comparability that minimizes confounding effects on mortality that could add noise to broader country comparisons(Honkaniemi et al., 2017; Knudsen et al., 2019; Laugesen et al., 2021). The Nordic countries are also ideal for analysing pandemic response due to their different pandemic policies(Kepp et al., 2022).

Some relevant studies in this area include a recent sensitivity study (Nepomuceno et al., 2022), studies of age- and sex specific life--expectancy(Aburto et al., 2022; Schöley et al., 2022), and a study showing how mortality trends may change over recent time periods (Woolf & Schoomaker, 2019). Also, the WHO study(Msemburi et al., 2023) confirmed that the Nordic countries had some of the lowest mortality impacts in Europe and documented a reverse excess mortality from 2020 to 2021 in Denmark and Finland vs. Sweden (referred to below as mortality reversal)(Aburto et al., 2022). Previous age- and sex-adjusted estimates for Sweden specifically for the first COVID-19 wave in 2020 have also been published(Modig et al., 2021). Several of these studies used five-year pre-pandemic data for building baselines, and these and other assumptions are tested below in a context of population structure.

Compared to our previous work (Kepp et al., 2022), this paper goes further in exploring limitations in the i) type of trend used, ii) number of years used, iii) impact of unusual pre-pandemic years in an age-sex specific context, iv) choice of population used for the crisis period (initial vs. mean population), but most importantly age- and sex-specific patterns of excess mortality in 2020 and 2021, as well as 2019.

The main aim of this paper was to demonstrate how estimates of excess mortality during the COVID-19 pandemic, and importantly uncertainties in these estimates, can be affected by age- and sex-specific trends. We investigated how changes in the population at risk induced during the first year of the pandemic impacted excess mortality in subsequent years. We also showed how comparisons of the age- and sex-patterns of excess mortality can provide information needed to isolate the direct effect of the pandemic from other concurrent effects on mortality. The method we developed is transparent, uses public data, and is easily subject to sensitivity tests.

2. Methods

2.1. Data

All data used were register-based, collected from the administrative records of the five Nordic countries (see Data availability section), and curated via the Nordic Council's data page (https://pxweb.nordicstatistics.org/pxweb/en/Nordic%20Statistics/). The data from individual departments are the same as those in this source. These highly accurate Nordic register data, collected for administrative and research purposes, are some of the most accurate in the world(Laugesen et al., 2021; Rosén, 2002) and defined as complete for the time period.

The age- and sex-specific death rates are given as deaths in age and sex group in the year divided by the mean population of the age and sex group in the same year, collected for total population, and men (M) and women (F) separately. These data can also be found for convenience in the file **Data1. csv**, which contains the most important register data used for calculations in this work.

These data were collected for 2010–2021 (12 years). We used 2010–2019, 2010–2018, and 2015–2019 for extrapolating expected deaths. We calculated excess deaths for 2020 and 2021 separately based on extrapolations from the data until 2019 and 2018. Mean populations and death rates in one-year groups were combined into five-year groups, except 0−5 years, which was divided into <1 years and 1−5 years, due to the especially high mortality of newborns, which makes the <1 year mortality group clearly distinct from children 1−4 years. Similarly, due to the small population size and the associated statistical noise, age groups above 95 years were combined, forming a total of 21 age groups for men and women, i.e., 42 subgroups per country.

We used the final annualized deaths, mean populations, and death rates within each age and sex group to avoid issues with, for example, the ISO week (International Organization for Standardization), which can affect excess death estimates by having years of different lengths. When extrapolating on the basis of full years, 2015 (starting point for many interpolations) and 2020 were ISO-leap years with 53 ISO-weeks with corresponding additional deaths, whereas 2016–2019 had 52 ISO weeks and correspondingly fewer deaths in the ISO calendar (Table S1).

2.2. Estimating expected deaths

The excess deaths D_{ex} for population subgroup i are defined as:

$$D_{ex} = D - D' \tag{1}$$

Where D are the actual deaths observed in the time-period for the population subgroup of interest, and D' are the expected deaths of the same population group during the same period, as estimated by some model based on the historic pre-pandemic data. D can also be written as:

$$D = d \bullet P \tag{2}$$

P is the mean size of the population sub-group i during the time-period, and d is the death rate for the group. To account for the impacts of population, expected deaths D' also need to be decomposed into population subgroups via an expected death rate d' and an expected population size in absence of crisis, P:

$$D' = d' \bullet P' \tag{3}$$

As the size of the population subgroup is a function of the death rate, one can expect an error for older groups with high mortality and small populations if the observed mean populations P are used, because the deaths may change the population non-monotonously during the time-period. Normally, the mean population is used, but for some age groups, many deaths early in the study period (e.g., first wave in 2020) could make the mean population of 2020 give a different result for some older fragile groups than the initial population of the year, whereas in the less mortal age groups, the effect would be smaller. Thus, it is of interest to establish the error (referred to as the *population error*) made when assuming that $P' = P$:

$$\textit{Population error in } D' = d' \bullet P - d' \bullet P' = d' \bullet (P - P') \tag{4}$$

In a crisis with substantial excess mortality, since $P < P'$, the population error can lead to underestimation of expected deaths and overestimation of excess deaths. To test the impact of the population changes during the crisis period, we applied P' both as the mean population of each subgroup in 2020 and 2021 and the initial 1st January populations in 2020 and 2021. It should also be noted that the appropriate choice of P' may depend on whether the full crisis period or perhaps a part of the period is of interest.

Linear regression of the trends in age- and sex-specific death rates for 2010–2019 were used to estimate the expected death rate in each age group in 2020 and 2021. The linear method avoids oversensitivity to gradient-based splines and includes some of the population structure effects (thus having the least change upon age-correction)(Nepomuceno et al., 2022) and averages out mortality displacements(Rocklöv et al., 2009; Saha et al., 2014; Zanobetti et al., 2000). These shifts in mortality may arise from a surplus or deficit of vulnerable people during a period due to recent mild or severe mortality events (e.g., a heat wave or influenza seasons) and seem important for the Nordic countries(Juul et al., 2022).

In addition, 2018 and 2019 were unusual mortality years for some Nordic countries such as Sweden and Denmark, due to their highly variable recent influenza seasons. For example, in 2018 Denmark had a severe influenza season, clearly visible in Fig. 1 (Nielsen et al., 2018; SSI, 2022). These outliers substantially affected 5-year trends and gave results distinct from 10-year-extrapolation(Kepp et al., 2022). We note that shorter age intervals increase estimate precision from a stratification perspective but also increases standard errors due to reducing population sizes and death counts, making the five-year age groups a reasonable compromise also favoured by the Nordic statistics departments.

2.3. Calculating excess deaths

The excess death count was calculated from the sum of the following terms for all subgroups, by combining equations (1) and (3):

$$D_{ex} = D - d' \bullet P' \tag{5}$$

As population cycles can be noisy (with cyclic and linear components) extrapolating expected population sizes in the absence of a crisis is uncertain. The impact will be largest on the small groups of high age with the highest mortality, with some methods attempting to correct for this(Schmertmann & Gonzaga, 2018). We calculated D_{ex} from two different P' (mean population or initial population of the crisis year) to investigate the impact of the population error in (4) and several different d' reflecting the inclusion or exclusion of time-periods in the estimates.

The extrapolated expected death rate of each subgroup d' was calculated using linear extrapolation from 2010 to 2019, 2015–2019, and 2010–2018 (to study the impact of the mortality year 2019 on the extrapolations), to establish the uncertainties in the estimates due to variations in the death rate trends affected by pre-pandemic mortality fluctuations. To explore the impact of using average pre-pandemic deaths for extrapolation rather than a trend, as is the practice in some approaches(Levitt et al., 2022), we also calculated excess deaths from expected deaths extrapolated from the average of pre-pandemic years. To further show the sensitivity to time-period, we calculated this for three, five and 10 years. Excess death estimates were obtained using the expected death rate multiplied by the actual mean population size of 2020 and 2021 for each population subgroup, providing an estimate of the excess deaths in persons for the subgroup.

We compared the excess deaths in three ways: 1) Crude excess deaths obtained from death rate extrapolations (age-and sex-adjusted total excess deaths); 2) death rates relative to expectations for the countries in their individual historic context, as many drivers may contribute to country-specific mortality patterns (age specific mortality ratios); and 3) direct comparison of death rates, standardized to the 2020 Danish population to facilitate country comparisons (age-standardized excess deaths).

The method applies the knowledge of the actual populations of 2020 and 2021 in each specific sex and age population subgroup, but the use of either the initial or mean populations shows that this choice is not critical (i.e., the population error is small in this case, see results).

For the main crude and age-adjusted excess mortality estimates for total populations, men and women, and standardized excess deaths, the statistical uncertainties were estimated as 1.96 times the standard error of the linear regression model. For the age- or age- and sex-adjusted estimates, these standard errors were calculated as the square root of the sum of the squared regression standard errors for death rate extrapolations multiplied by the mean populations of each of the 21 or 42 age/sex groups for the year.

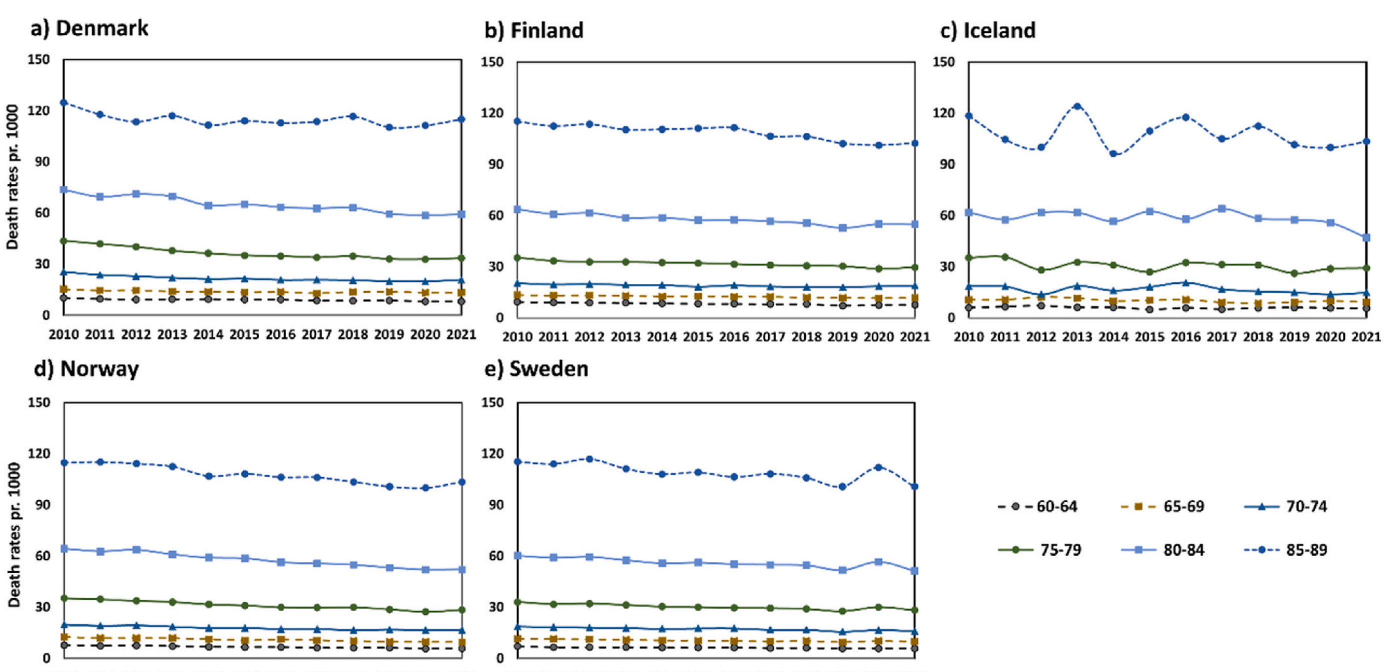

Fig. 1. Age-specific death rates per 1000 in the Nordic countries in 2010–2021 for age groups that contributed most to total excess deaths (60−89y). A) Denmark. **B)** Finland. **C)** Iceland. **D)** Norway. **E)** Sweden.

3. Results

3.1. Trends in Nordic population age structure relevant to excess mortality estimates

The age structure of the Nordic countries differed somewhat at the onset of the pandemic, making age correction important (Fig. S1, Table S2). Notably, the 70–74-year age group was similar in size to almost all the younger age groups and clearly larger than for children up to 19 years in Finland, somewhat smaller in Denmark and Sweden (plateau-shaped distributions), but considerably smaller in Norway and Iceland with more gradual shifts in age group sizes, and a monotonic increase over recent years among 75–79-year-olds that largely contributed to mortality. In 2020, the percentage of the full populations aged 70 or above were 9.8% in Iceland, 12.6% in Norway, and 14.5%, 14.9%, and 16.1% in Denmark, Sweden, and Finland, respectively.

In addition to these effects, periodic birth cycles (variations in the size of the birth cohorts(Andersson et al., 2009; Tarone & Chu, 1996)) and migration effects affect the population structure over the time-period used to estimate expected deaths (Fig. S2–S3) and can be accounted for by using age-specific death rates for each year specifically taking into account the fact that the size of the age group sub-population will not change monotonically over time.

Importantly, the trends in the age-specific death rates in Fig. 1 have stronger linear trends than the crude death rates (with examples of regression lines shown in Fig. S4). This indicates (as discussed below) that the non-monotonous changes in age-specific populations due to birth cycles produce complex age-dependencies on total excess death estimates. Denmark had slightly higher overall death rates for most age groups. Since the age-specific death rates display declining trends, methods using neutral baselines, such as pre-pandemic averages without trend(Levitt et al., 2022) may substantially under-estimate excess deaths (by overestimating expected deaths), as we show below.

3.2. Estimates of age-specific total excess mortality in the Nordic countries

Fig. 1 shows the age-specific death rates of the age groups that contributed the most to the deaths, due to their combined mortality and population sizes. Despite the variation in crude death rates, the pre-pandemic trends indicate that the health demographics tended to improved over recent years for the age groups that contributed mostly to total deaths. This was also observed for Finland despite its increasing crude death rates, making this is a general Nordic tendency. These trends need to be accounted for when estimating expected deaths in each age group, as achieved with our methodology.

Table 1 summarizes the main results using our method. The crude estimates were based on the death rates without age specification but accounting for the mean population changes over time and thus differ slightly from the 10-year estimates published previously(Kepp et al., 2022) that used crude deaths without account for changing populations over time. The other estimates include the 21 (age-weighted) or 42 (age- and sex-weighted) subgroups, i.e., accounting for changes in the size of each subpopulation group during the pre-pandemic extrapolation period and during the pandemic. The excess death estimates for Iceland were highly uncertain due to the small population producing large fluctuations in pre-pandemic deaths and results that were highly sensitive to the regression model and time-period used.

To make the crude excess deaths more comparable, the estimates of Table 1 are listed per million people in Table 2. This enables comparison of the total excess death burden per million for the countries but still cannot be used to compare country performance, which requires expectations based on population age structure. Norway, Sweden and Iceland had similar expected death rates for the 75–79-year age group (27.5–27.6 per thousand in 2020 and 26.9–27.0 in 2021, due to the improving health trend, Fig. S4), whereas in Finland they were 29.5 and 29.1 per thousand, and in Denmark 30.8 and 29.7 (data in Table S3). In other words, the death rates for this age group tend to be higher in Finland and Denmark than in the other countries. Age correction had a particularly large effect for Norway (Table 2). This was mainly due to estimates of 593 excess deaths among 70–79-year-olds in Norway in 2020–2021, whereas the corresponding figure was 2514 in Denmark. For the 75–79-year age group, Denmark and Norway had estimated 1512 and 204 excess deaths, respectively.

Norway and Denmark had larger relative shifts of population into the 75–79-year age group than the other countries (Fig. S5), i.e., their crude excess death rates became relatively smaller when this was accounted for. However, in Denmark this tendency was partly compensated by the steep decline in expected death rates (Fig. S4), which lowered the expected death rates to a greater extent, resulting in a higher number of final excess deaths than in Norway. In Finland and Sweden, the two tendencies (more slowly declining death rates as in Norway, Fig. S4, and somewhat less population shifted into the mortal age groups in 2020–2021 than in Norway) make the effect of age correction relatively smaller than for Norway (Iceland's data are too uncertain for strong

Table 1
Estimated total excess deaths from expected deaths in 2020 and 2021 extrapolated from linear trends in death rates (2010–2019 except * based on 2010–2018) using mean subgroup populations.[a]

	Denmark	Finland	Iceland	Norway	Sweden
Crude					
2020	1018	772	−98	681	7505
2021	3460	2557	−121	2411	1774
2020 + 2021	***4478*** ± ***237***	***3330*** ± ***100***	***−219*** ± ***20***	***3092*** ± ***110***	***9279*** ± ***284***
Age-weighted					
2019*	590	−711	−57	200	−3462
2020	893	597	−50	37	7040
2021	3270	2299	−75	1421	810
2020 + 2021	***4163*** ± ***125***	***2896*** ± ***73***	***−124*** ± ***18***	***1459*** ± ***58***	***7850*** ± ***137***
Age-/sex-weighted					
2020	937	666	−50	79	7146
2021	3340	2399	−72	1485	974
2020 + 2021	***4277*** ± ***138***	***3065*** ± ***90***	***−122*** ± ***19***	***1564*** ± ***79***	***8120*** ± ***156***

[a] Estimates shown with ±1.96 standard error for 2020 and 2021. The full uncertainties are larger than these regression-specific errors, due to sensitivity to years included in the models.

Table 2
Total estimated excess deaths per 1 million population (mean population of 2020 and 2021).[a]

	Denmark	Finland	Iceland	Norway	Sweden
Crude					
2020	175	140	−268	127	725
2021	591	462	−325	446	170
2020 + 2021	***765*** ± ***41***	***601*** ± ***18***	***−594*** ± ***53***	***572*** ± ***20***	***895*** ± ***27***
Age-weighted					
2020	153	108	−136	7	680
2021	558	415	−200	263	78
2020 + 2021	***711*** ± ***21***	***523*** ± ***13***	***−336*** ± ***49***	***270*** ± ***11***	***758*** ± ***13***
Age-weighted and standardized					
2020	152	116	−205	9	624
2021	546	379	−310	287	91
2020 + 2021	***698*** ± ***47***	***495*** ± ***18***	***−515*** ± ***62***	***296*** ± ***18***	***715*** ± ***26***

[a] Estimates shown with ±1.96 standard error for 2020 and 2021. The full uncertainties are larger than these regression-specific errors, due to sensitivity to years included in the models.

conclusions). Thus, age correction had large effect when the population of the high-mortality groups changed in a way that was not compensated by trends in death rates.

The standard errors in Table 1 only reflect statistical uncertainty and do not include other sources of uncertainty such as choice of time-period and method variations, as analysed below. The excess crude deaths should be interpreted in the context of the rapidly increasing population sizes of the 75–84-year age groups over recent years (Fig. S2). Moreover, the standard errors in Tables 1–3 show that the linear regression models became more robust when age-specific death rates were used, because the death rates included more explained variance when stratified by age. However, this tendency was partly reversed when stratified by sex, which however had a relatively small overall effect on the excess death estimates.

Excess death estimates differ widely for different published models (Karlinsky & Kobak, 2021; Kepp et al., 2022; Levitt et al., 2022; Solstad, 2021; Wang et al., 2022; World Health Organization, 2022a). As explained before (Kepp et al., 2022), much of this relates to model variations, including time period used, as variations are observed even for Nordic countries with best-possible data(Laugesen et al., 2021). As this complicates the comparison of countries, an analysis of comparative country performance also requires equalizing the population structures by a standard population such as that proposed by WHO(Ahmad et al., 2001). In Table S4 this population is compared to the Scandinavian standard population by Doll and Cook(Doll & Cook, 1967) and that of Denmark in 2020.

The real populations deviated substantially from both standard populations, and thus, the standard deaths (death rate multiplied by standard population of the age group) do not reflect a true mortality burden. We therefore used the Danish 2020 population as standard population and converted age-standardized mortality rates into deaths per million as would have occurred since 2010 if all countries had a Danish 2020 population (Fig. 2). This puts the pandemic excess deaths in a historic context and confirms the large mortality shifts in Sweden during 2019, 2020, and 2021. The historic higher mortalities of Finland and Denmark are well-known, but the reasons for them are still debated (Knudsen et al., 2019).

Table 3
Estimated age-adjusted excess deaths extrapolated from 2010 to 2019 and stratified by sex.[a]

	Denmark	Finland	Iceland	Norway	Sweden
Men					
Not age-weighted					
2020	681	659	−47	594	4608
2021	1733	1654	−60	1280	1852
2020 + 2021	2414 ± 170	2313 ± 92	−107 ± 19	1874 ± 77	6460 ± 158
Age-weighted					
2020	666	657	−24	249	4479
2021	1726	1632	−40	776	1547
2020 + 2021	2392 ± 103	2289 ± 63	−64 ± 15	1025 ± 52	6025 ± 98
Women					
Not age-weighted					
2020	336	114	−51	84	2895
2021	1727	905	−61	1126	−84
2020 + 2021	2062 ± 167	1019 ± 79	−111 ± 12	1211 ± 99	2810 ± 254
Age-weighted					
2020	271	9	−26	−171	2667
2021	1614	767	−32	710	−573
2020 + 2021	1885 ± 92	776 ± 65	−58 ± 13	539 ± 59	2095 ± 121

[a] Estimates shown with ±1.96 standard error for 2020 and 2021. The full uncertainties are larger than these regression-specific errors, due to sensitivity to years included in the models.

Denmark had the highest age-standardized death rates, consistent with previous findings(Knudsen et al., 2019), whereas Sweden briefly reached the Finnish death rates in 2020. The age-standardized mortality of Denmark, Iceland and Norway was the lowest in 2020 of all years analysed, following the historic trend. Also, despite the mortality reversal, 2021 was still at least the third-best year of the years 2010–2021 studied for all Nordic countries, a perhaps surprising result. In Sweden, the high mortality in 2020 was comparable to that in 2015 but lower than in the years before 2015. The age-specific and age-standardized excess death estimates derived from the linear 10-year trends (Fig. S6) are shown in the last part of Table 2.

3.3. *Sex-specific mortality patterns*

We also analysed sex-and age-weighted mortality and repeated all extrapolations separately and recalculated expected deaths and excess deaths for men and women (Table 3). The age- and sex-specific death rates indicate that for all five countries, men had higher pandemic excess mortality than women, consistent with the picture observed for registered COVID-19 deaths, with most excess deaths arguably being due to COVID-19. The age- and sex-weighted excess mortality estimates are shown in Fig. 3. As the periodic variations in the age sub-populations of women and men are largely synchronized (similar birth cycles), this is indicative of real mortality effects rather than a population size effect. We also found that age-correction effects, when large, were important for both sexes (Table 3), except in Finland, where this mostly affected the estimates for women.

Excess mortality was strongly asymmetrical: Sweden experienced by far the highest excess mortality in 2020, whereas Norway, Finland, and Denmark experienced the highest in 2021. Although this has been observed before and is also visible also in the raw death series(Kepp et al., 2022), these effects suggest mortality displacement also when one adjusts for age- and sex. Mortality was higher for men, especially in Sweden during 2020. Denmark and Norway deviated from this pattern in 2021 with men and women having similar excess mortality. This suggests that other concurrent effects may have contributed to the excess mortality in these two countries in 2021.

3.4. *Comparison of old age mortalities*

The age-standardized deaths in Fig. 2 enable direct comparison with account for population structure differences but do not clarify whether the death rates were high or low relative to each country's specific mortality expectations. This is important because mortality has many causes specific to each country, which means that age-specific deaths were already different before the pandemic (Fig. 1).

Fig. 4 shows the age-specific mortality ratios based on age-adjusted deaths and the populations of each age group over time (actual death rate divided by the expected death rate in the age group). Although age-specific mortality increased steeply with age and total excess deaths were strongly dominated by those aged 75+, the *relative* death rate changes during the pandemic involved different age groups in the different countries. However, higher-than-expected death rates were observed in 2020 in Sweden among people aged 80+ and in 2021 in Denmark among people aged 70–79. The Danish and Finnish mortalities were uniformly higher than expected in 2021 than in 2020 in all age groups of 60 years and above.

The lower mortality in Sweden in 2021 relative to 2020 was largely driven by the age groups of 75 years and above. The linear method to some degree accounts for mortality displacement by balancing the death rate fluctuations, but some effect is likely due to pandemic response. Because of the reverse mortality shift in 2020 and 2021, Sweden performed much better over the two-year period or in 2021 than if evaluated just for 2020, and thus selectively examining one period could produce completely different interpretations and would neglect mortality displacement effects. We observed very low but also very

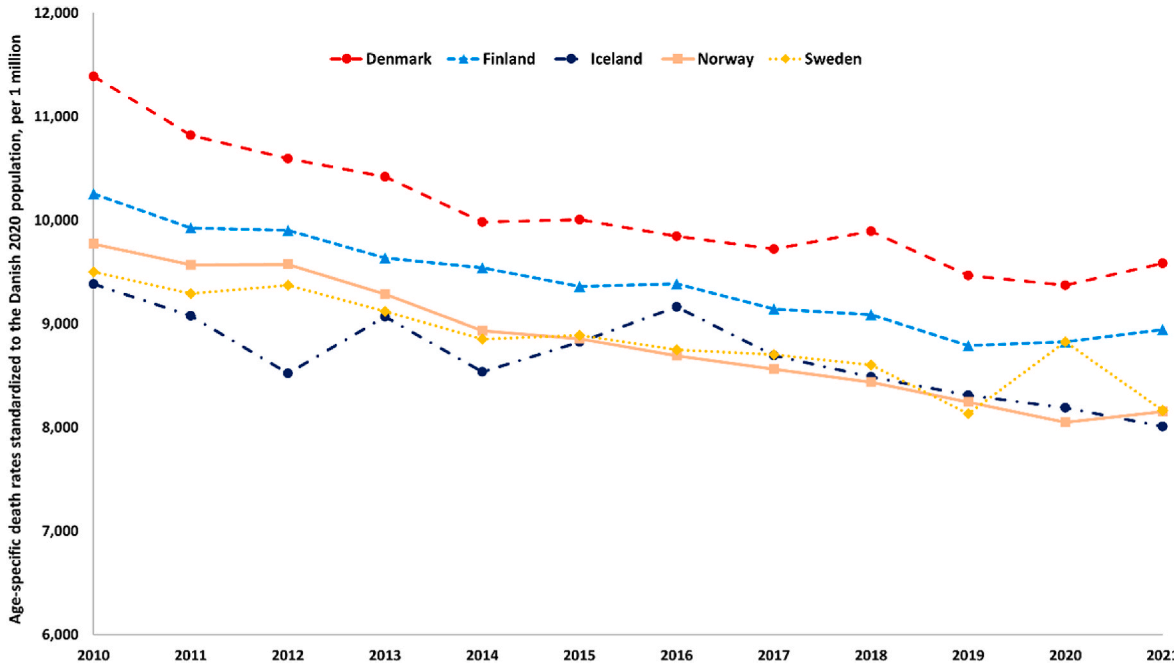

Fig. 2. Age-standardized total deaths per million, using the Danish 2020 population as standard population.

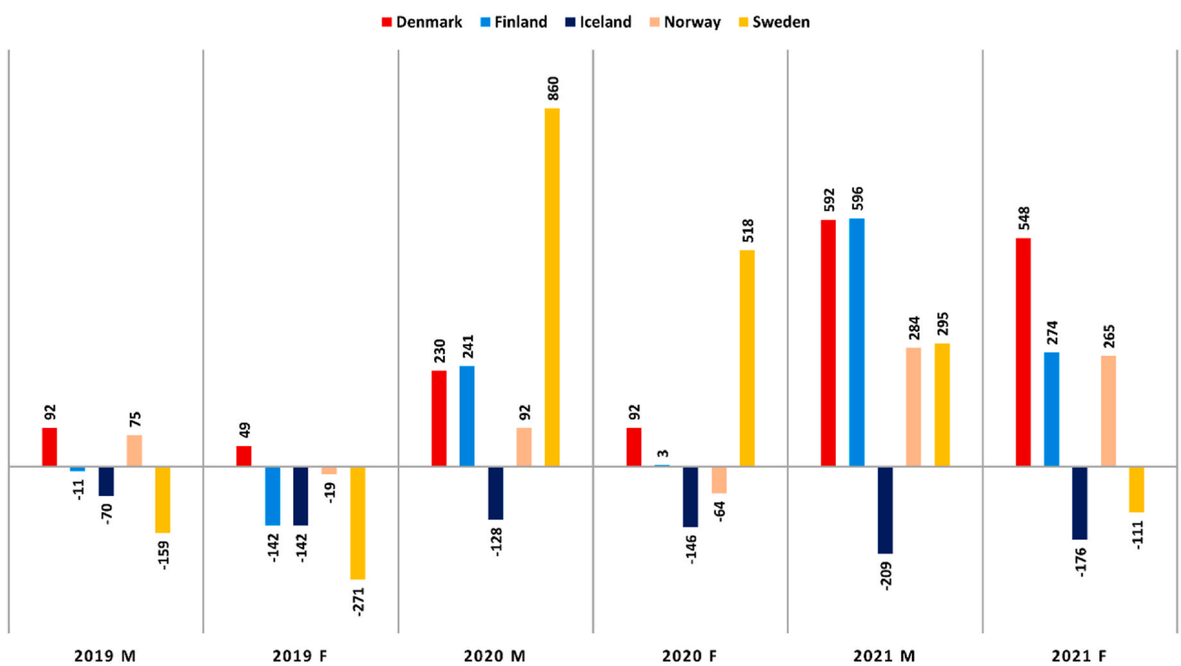

Fig. 3. Estimated excess deaths per 1 million population, stratified by sex. The estimates for 2019 are also based on the trend of age- and sex-specific death rates for 2010–2019, scaled to the 2019 mean populations of each age and sex group.

uncertain and thus less significant mortality effects in several age groups in Iceland.

Fig. 5 shows our estimated excess death rates (actual minus expected death rates) for all age groups, including 2018 and 2019 for comparison, using the same 2010–2019 linear model. These comparisons account for the increase in old age groups before and during the pandemic and document the inverse pattern for Sweden. Moreover, the excess death rate in Denmark in 2020 was substantially lower than in the severe influenza year 2018, whereas 2018 and 2021 were similar in age-dependent impact when measured according to this metric. The impact in Norway and Finland was also mainly visible in 2021. Fig. S7 summarizes the excess death estimates, excess death rates, and mortality ratios of all the age groups.

3.5. Infant mortality

Fig. 6 shows the death rates of young age groups in the Nordic countries, excluding newborns (<1 year). Fig. S8 summarizes the infant excess mortality ratios (actual death rates divided by the expected death rates) among boys (Fig. S8a) and girls (Fig. S8b; Iceland omitted due to very small numbers and large fluctuations). Despite these mortality ratios being substantially different from 1, and some excess implied for

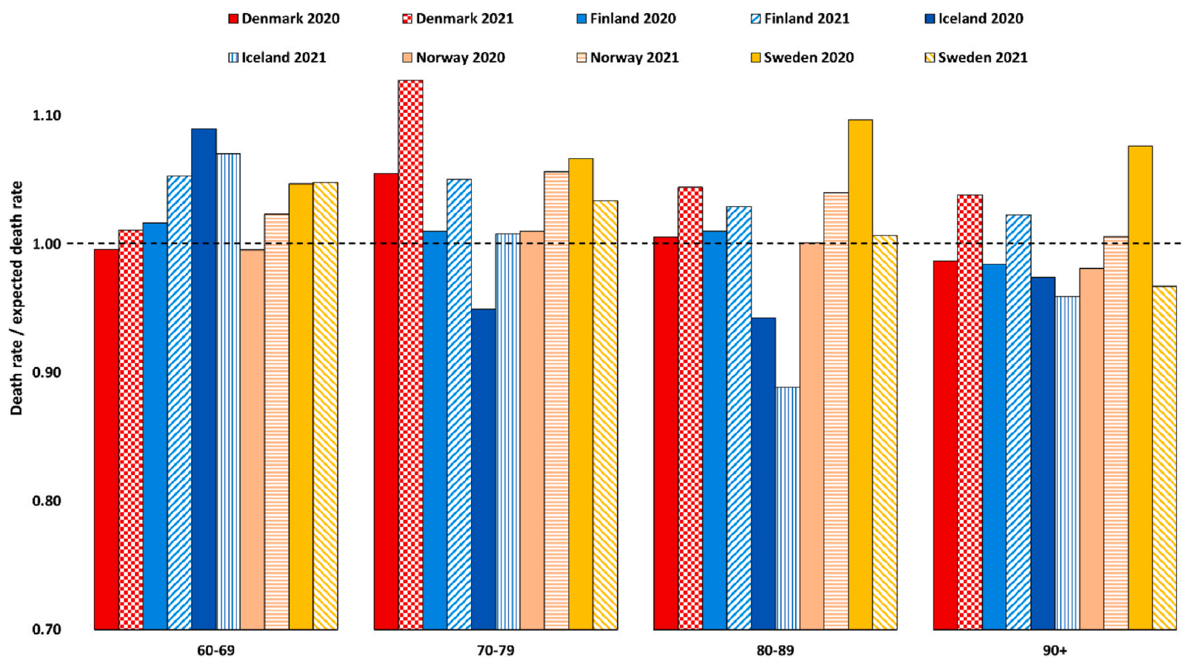

Fig. 4. Age-specific death rates for 10-year age groups divided by expected age-specific death rates for the Nordic countries in 2020 and 2021 (extrapolation from 2010 to 2019 to 2020 and 2021, taking into account the populations of the age groups in 2020 and 2021).

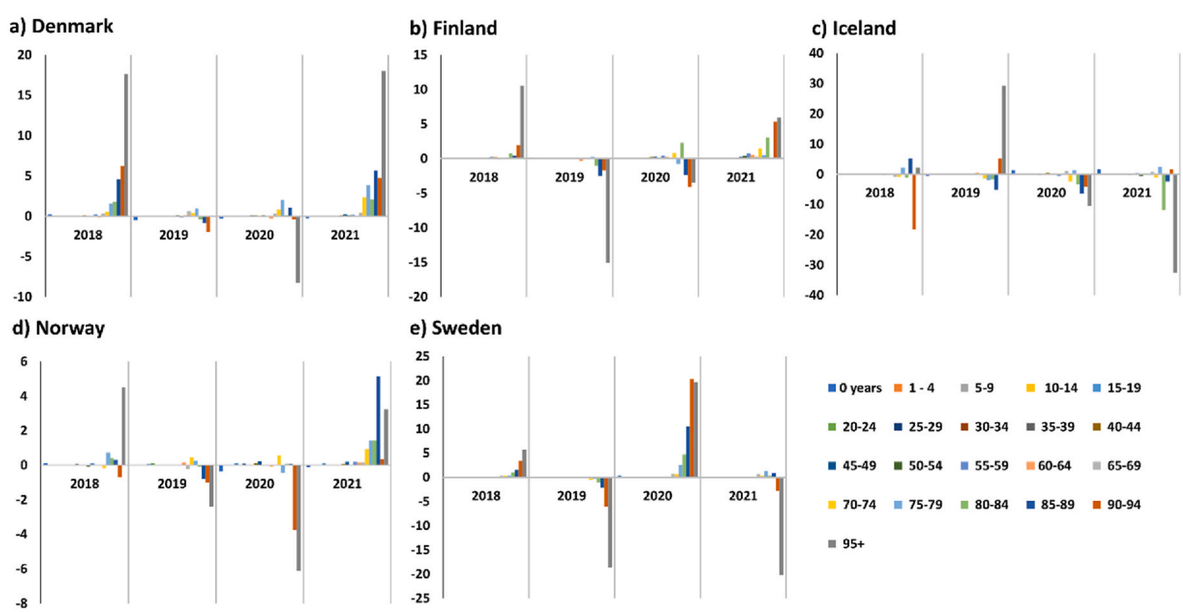

Fig. 5. Age-specific excess death rates 2018, 2019, 2020, and 2021. a) Denmark. **b)** Finland. **c)** Iceland. **d)** Norway. **e)** Sweden.

some 5–9-year groups and teenagers in 2021 (Fig. S8), the fluctuations in death rates were very large, making these results sensitive to time-period used (Fig. 6; Figs. S7c, S7f, S7i, S7l, S7o). For the 10-year model, 95% confidence intervals (1.96 SE) were as large as the combined 2020 + 2021 excess death estimates for age 1–19 years in Denmark (3 ± 5, absolute excess death estimate), Iceland (4 ± 3) and Sweden (1 ± 7). For Finland (30 ± 6) and Norway (77 ± 8) excess deaths were significant with the 10-year model but not with the five-year model (Finland: 38 and Norway: 14 excess deaths), showing that the very small numbers and fluctuations (e.g., the larger number at the start of the period for Norway, Fig. 6) make results specifically for children very model-dependent and thus unreliable.

We conclude that mortality patterns for children, including newborns, are consistent with the fluctuations observed before the pandemic. The mortality ratios for the 45–49-year and 50–54-year age groups were always above 1, except in the 50–54-year group for Iceland in 2021 (Fig. S9). However, the fluctuations in the mid-age groups (Fig. S10) and very old age groups of 90 years or older (Fig. S11) make estimates more uncertain but these also affect only to a lesser extent to the total excess death estimates.

4. Discussion

4.1. Main findings

We sought to examine the age and sex specific excess mortality in the

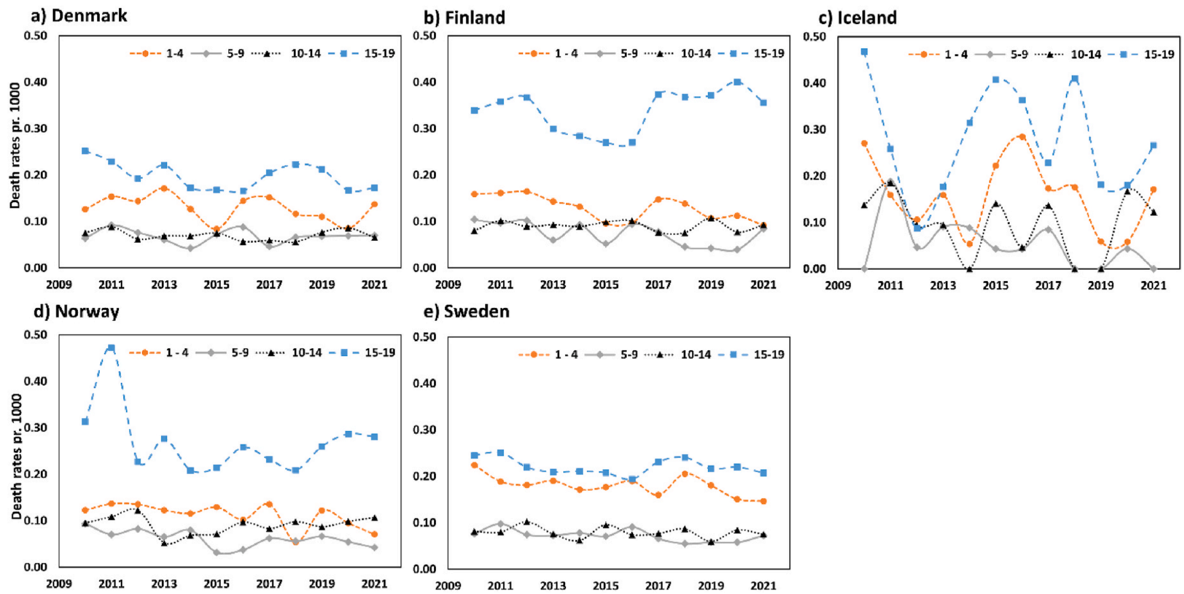

Fig. 6. Death rates for children, 2010–2021. a) Denmark. **b)** Finland. **c)** Iceland. **d)** Norway. **e)** Sweden.

Nordics during the pandemic. We found that total age- and sex-adjusted excess deaths, the ratios of actual to expected death rates in the country of interest and age-standardized mortality, were all important metrics to assess pandemic-caused excess mortality when comparing countries. Our findings suggest substantial excess mortality displacement, higher excess mortality among men, and interesting country-specific differences between 2020 and 2021. Finland, Norway, and Denmark had most excess mortality in 2021 and Sweden had the most in 2020. Denmark and Norway deviated from the general sex-specific mortality pattern in 2021 with similar excess mortality among males and females. Regarding age-specific mortality patterns, death rates were particularly higher than expected among Swedes older than 80 and Danes older than 70. Due to the small population size and associated model uncertainties, no excess mortality in children and youth could be statistically confirmed. Our study also has several methodological implications, as discussed further below.

4.2. Comparison to other models

We now compare our excess mortality estimates to other models and discuss sensitivities to reasonable variations in the data used. Fig. 7 compares our age- and sex-adjusted excess death estimates per million to the estimates from the WHO excess mortality working group(World Health Organization, 2022a), IHME(Wang et al., 2022), the WMD model (Karlinsky & Kobak, 2021), the Economist model(Solstad, 2021), the Bayesian model ensemble (BME)(Kepp et al., 2022; Kontis et al., 2020, 2022), and a recently published age-adjusted model(Levitt et al., 2022).

Our estimates are close to those of WHO(Msemburi et al., 2023; World Health Organization, 2022a), especially for Denmark (4277 vs. 3716) and Finland (3065 vs. 2857). For Iceland, the difference of 111

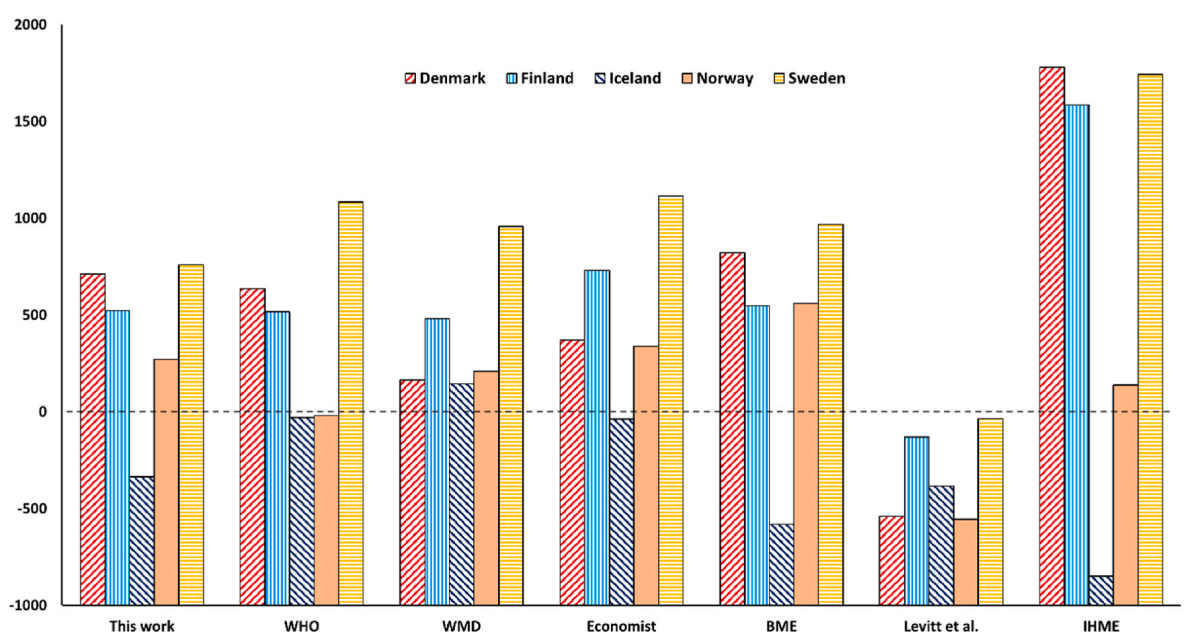

Fig. 7. Comparison of excess death estimates for 2020 and 2021, per million population. All the estimates are divided by the total mean populations of 2020 and 2021.

people should be interpreted with caution due to the large uncertainty due to the low number of deaths. The most notable differences were observed for Norway (1564 this work; −101 from WHO) and somewhat for Sweden (8120 this work; 11,255 WHO). Differences between deaths reported by the Nordic statistics departments and the WHO taskforce explain some of this discrepancy (Table S5). However, the similarity is encouraging as our model is conceptually simple and transparent (it practically derives excess deaths from up to 42 subgroup models, but these all use the same linear regression on public accessible death and population data without parameters beyond time-period). A revision for Sweden has been reported to remedy an oversensitivity of the WHO estimates to splines(Van Noorden, 2022), but it is not clear how this affects the four other countries.

Our estimates, despite correction for age and sex, are also relatively close to the estimates of the WMD(Karlinsky & Kobak, 2021), the Economist(Solstad, 2021) and BME models(Kontis et al., 2020, 2022), but quite distinct from the IHME and Levitt models. Whereas the divergence from the IHME model was previously explained as being due to errors at the baselines leading to substantial overestimation of the Danish and Finnish excess deaths(Kepp et al., 2022), the poor agreement with Levitt et al. is notable as this model also used age-adjusted estimates, although these were based on fewer age groups and a shorter extrapolation time-period (Levitt et al., 2022). The potential reasons for these differences are discussed below.

Our study can also be compared to life-expectancy estimates(Aburto et al., 2022; Schöley et al., 2022). The life expectancy deficit was calculated from the differences between observed life expectancy and a Lee–Carter mortality forecast using the death rates for the fourth quarter of 2015–2019(Schöley et al., 2022). These provide comparative mortality but used relatively few age groups and five-year data. Although the sensitivities documented in the present work probably also affect life-expectancy estimates and our method uses a longer time-period, which reduced mortality fluctuations of 2018 and 2019, the two approaches agree in terms of the historic mortality trend, mortality reversal from 2020 to 2021, the little if any mortality effect in children, and Sweden experiencing comparatively less mortality in 2021 than in 2020 in contrast to its neighbours(Schöley et al., 2022). This lends confidence to these complementary approaches. Our 2020 estimates are also in reasonable agreement with those of Islam et al.(Islam et al., 2021) who studied age- and sex-specific excess mortality each week of 2020 using an over-dispersed Poisson model. Although their data source also differs, we believe the main differences are due to their use of a shorter pre-pandemic timeline, using trends in annual mortality rates from 2016 to 2020.

4.3. Sensitivity tests and factors that substantially influence estimates

Below we discuss the uncertainties in our estimates and relate our results to other models. We also refer to sensitivity tests performed in previous studies(Kepp et al., 2022; Nepomuceno et al., 2022). Most notable is the impact of unusual mortality years driven by irregular influenza seasons before the crisis, which affect baselines and favours using longer time periods. For example, for the severe 2018 mortality year in Denmark, we estimated 1723 excess deaths when using the 10-year age-specific method interpolated for 2018, close to the estimate of the 2017–2018 influenza deaths (mostly falling in 2018) by the Danish Statens Serum Institut, SSI (1,608)(Nielsen et al., 2018; SSI, 2022). Correspondingly, Sweden had a very mild 2019 season, which would also affect five-year models in the opposite direction.

First, to estimate the maximal impact of unusual mortality years and mortality displacement, we performed the same age-adjusted excess death estimates excluding 2019 (i.e., extrapolation from 2010 to 2018, Table S6). This led to a 12% higher excess death estimate for Denmark, 22% lower for Finland, 41% lower for Iceland, 12% higher for Norway, and 35% lower for Sweden. These estimates indicate that the impacts of mortality displacement were plausible large and illustrate that a linear method, while having some averaging out of annual fluctuations, does not account fully for it, making sensitivity tests necessary. New models that account for mortality displacement seem warranted but are beyond the scope of our study.

Second, the impact of the population error (See Methods) was estimated using January 1 initial populations instead of mean populations of each age and sex group for 2020 and 2021. As the subgroup populations change monotonically with irregularities reflecting birth cycles (Fig. S5), simple linear extrapolation of expected subgroup populations was not possible, and it is arguably more accurate to use the populations at the onset of the crisis years as a sensitivity test (2020 and 2021). This effect was typically around 1% (from −0.8% to +1.2%) for the studied Nordic countries (Table S7) and thus did not substantially affect our estimates.

Third, although the Nordic countries had less total excess deaths than many other countries(Bryan et al., 2020; Karlinsky & Kobak, 2021; World Health Organization, 2022a), the negative age-specific excess deaths for 2020–2021 found by Levitt et al.(Levitt et al., 2022) were very distinct from all other estimates (−3157 for Denmark, −716 for Finland, −142 for Iceland, −2994 for Norway, and −367 for Sweden)(Levitt et al., 2022). To understand the large discrepancy, we calculated the excess deaths using our 21 age groups (Levitt et al. used five age groups) and the data from the Nordic Council's web page, using the average deaths of 2017–2019 to estimate baselines and excess deaths (Table S8). The resulting age-specific excess deaths were close to those of Levitt et al. considering that we use somewhat different death and population data (−2541 for Denmark, −1507 for Finland, −196 for Iceland, −3110 for Norway, and 386 for Sweden). We conclude that the negative excess deaths of Levitt et al.(Levitt et al., 2022) are probably erroneous and due to averaging the pre-pandemic baseline, thus not accounting for the declining pre-pandemic age-specific death rates. This led to an overestimation of expected deaths and a substantial underestimation of excess deaths. A five-year average, the time-period normally applied, would have made these estimates even more negative and implausible (Table S9), i.e., the choice of only three years for extrapolation partly reduces the error.

Fourth, many models somewhat arbitrarily use five years (2015–2019) to estimate baselines. Table S10 shows the effect of using five instead of 10 years for excess deaths per million, and compares five-year average projection from death rates, five-year linear projection from death rates, five-year linear projection from raw deaths, 10-year projection, and the WMD estimates, which uses five-year linear extrapolation of crude deaths to establish baselines(Karlinsky & Kobak, 2021). To enable comparison, none of the estimates in Table S10 are age-corrected. Table S10 also clearly illustrates the extreme uncertainty of estimating Iceland's excess deaths, as the major fluctuations gave very different results depending on data used.

Despite the minor differences due to different uses of death data, our five-year crude death model without age correction reproduces the WMD model quite well (Table S10)(Karlinsky & Kobak, 2021). A five-year trend puts very large emphasis on 2018 and 2019 mortalities, including the high 2018 mortality in Denmark due to the severe influenza season(Nielsen et al., 2019). This emphasis increased the baseline and reduced excess death estimates relative to a longer extrapolation. Such effects of time-period have been noted before(Nepomuceno et al., 2022). Since the trends are linear over the full extrapolation period a longer period is preferred, as 5-year trends are very sensitive to 2018 and 2019(Kepp et al., 2022). The same effects as in the WMD estimates on especially Denmark and Sweden were also seen by Demetriou et al. who also used 2015–2019 to estimate baselines(Demetriou et al., 2022).

Our previous work has shown(Kepp et al., 2022) that the IHME estimates for the Nordic countries(Wang et al., 2022) are unreliable, as their expected deaths for 2020 and 2021 were inconsistent with the pre-pandemic trends in the Nordic register data, in addition to other comparative anomalies. Fig. 2 further puts IHME's model in an age-specific context, with, for example, its 10,800 excess deaths for

Denmark in 2020 + 2021(Wang et al., 2022), i.e., 1850 deaths per million or almost 1000/million per year, which is inconsistent both with crude death data(Kepp et al., 2022) and as shown here, equally so age- and sex-corrected data.

Whereas the IHME substantially *over*-estimates Nordic excess deaths (Kepp et al., 2022), we conclude here that horizontal baseline methods such as that by Levitt et al.(Levitt et al., 2022) substantially *under*-estimate excess deaths, with all other estimates clustering far from this and from those of IHME (Fig. 7). Pre-pandemic averaging is also used by EUROSTAT(Eurostat, 2022) and similar methods(Blangiardo et al., 2020; Bogos et al., 2021) and our findings may also raise concerns about their accuracy.

4.4. Limitations and future work

The estimates provided here account for mortality displacement and outlier years better than other estimates published so far and separate excess deaths into 42 age and sex groups, using final annualized register data without ISO calendar effects. However, our work still has several limitations. First of all, considerable uncertainty was related to time period used(Nepomuceno et al., 2022), but also, in terms of interpretation of excess deaths, other covariates relevant to the outcomes than age and sex, such as socioeconomics or care status(Ebeling et al., 2022). As the sensitivities to time-period are larger than the statistical uncertainties of any specific model, the standard errors in Tables 1–3 are smaller than the true uncertainty in the model estimates(Kepp et al., 2022). Our sensitivity analyses in the supplementary information serve as important indications of the additional uncertainty in our estimates.

We also note that our method can only be applied to countries that have sex- and age-specific death rates and mean populations available since 2010. This is not commonly the case yet but hopefully will be in the future. Moreover, death rates and populations need to be fully commensurable (i.e., definition-wise the same) to avoid comparative artefacts. We are aware of the differences in the most applied mortality data, which is probably due to the variations in the definition and collection protocols, and future work may thus need to explore the reasons for these variations.

Although the fluctuations in death rates for children and mid-age groups were too large for us to accurately estimate any excess mortality, we did see indications of excess mortality in mid-age groups that appeared to differ between countries (Table S11). Our study did not analyze life years lost, only excess deaths for age groups in total, but the excess death distributions across the age groups in Table S11 suggest that the situation in Norway and Finland would become comparatively worse than Denmark, Sweden, and Iceland in a life-year-lost analysis, partly due to variations in birth cycles making age groups relatively different in size. We welcome such studies comparing the two metrics moving forward.

5. Conclusions

We investigated the impact of sex and age on the pandemic excess mortality in the five Nordic countries, using final annualized register death data. Our estimates agree with those of the WHO taskforce (World Health Organization, 2022b) and life expectancy studies(Schöley et al., 2022). This is encouraging as our approach used public accessible high-quality Nordic register data(Laugesen et al., 2021) with no underlying assumptions except linear extrapolation and time period. The method is thus fully transparent, interpretable, easily reproducible, and subject to sensitivity tests, and we believe it provides the highest resolution detail so far on age- and sex-specific Nordic mortality during the pandemic.

Our study indicates plausibly important effects of mortality displacement, higher mortality among men, and important country-specific variations in mortality patterns. We show that three complementary metrics (total age- and sex adjusted excess deaths, ratios of actual vs. expected death rates in the context of each country's mortality patterns, and age-standardized mortality) are all important to a discussion of pandemic mortality outcome. We also recommend that official methods (e.g., EUROSTAT) use multiple historic trends as a good practice, as extrapolation-based excess death estimates are very sensitive to the time-period used, especially for shorter periods with associated recent unusual mortality years.

As some specific highlighted conclusions from this analysis, Sweden had more excess deaths in 2020 than 2021 whereas Finland, Norway, and Denmark had the opposite. Higher-than-expected death rates were observed in 2020 in Sweden among people aged 80+ and in 2021 in Denmark among people aged 70–79. In Sweden, the pandemic put death rates back to 2015, but overall, death rates were still among the lowest ever in the Nordic countries during 2020 and 2021, consistent with a pre-pandemic trend of improving population health, a perhaps surprising but positive conclusion. We note the importance of longer time periods and accounting for the age-specific pre-pandemic death rate trends, which is missing in averaging methods such as EUROSTAT and Levitt et al. Finally, we expect our model to be useful in the future for decomposing excess deaths in specific age-sex groups in a context of essential sensitivity estimates.

Author statement

KPK conceived the work and performed the main data analysis. All authors contributed to the analysis and interpretation of results and the writing of the paper. All authors read and approved the final manuscript.

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Ethics statement

The study used anonymous, public total annual death and population data from the statistics departments of the Nordic countries, and thus did not require any ethics approval.

Financial disclosure

No financial disclosure of relevance reported by any authors.

Declaration of competing interest

No conflicts of interest were declared in relation to this work.

Data availability

All the data required to reproduce this work are available at the web pages of Statistics Denmark, Statistics Norway, Statistics Sweden, Statistics Finland, and Statistics Iceland, as well as on the public sites as summarized below: Comparative Nordic data: mean population sizes, mortality rates: https://pxweb.nordicstatistics.org/pxweb/en/Nordic%20Statistics/Nordic%20Statistics_Demography_Population%20change/ Populations January 1 divided on sex and age groups: https://pxweb.nordicstatistics.org/pxweb/en/Nordic%20Statistics/Nordic%20Statistics_Demography_Population%20size/POPU01.px/.

Appendix A. Supplementary data

The total, sex, and age-specific deaths, mean populations, and death rates for 2010–2021 are compiled in the file **Data1.csv** for easy use. The supporting information pdf file contains additional Table S1−S11 and Fig. S1−S11 as discussed in the main text.

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ssmph.2023.101377.

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