Excess mortality in Germany 2020-2022

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Abstract

The present study estimates the burden of COVID-19 on mortality. The state-of-the-art method of actuarial science is used to estimate the expected number of all-cause deaths in 2020 to 2022, if there had been no pandemic. Then the number of observed all-cause deaths is compared with this expected number of all-cause deaths, yielding the excess mortality in Germany for the pandemic years 2020 to 2022.

The expected number of deaths is computed using the period life tables provided by the Federal Statistical Office of Germany and the longevity factors of the generation life table provided by the German Association of Actuaries. In addition, the expected number of deaths is computed for each month separately and compared to the observed number, yielding the monthly development of excess mortality. Finally, the increase in stillbirths in the years 2020 to 2022 is examined.

In 2020, the observed number of deaths was close to the expected number with respect to the empirical standard deviation. By contrast, in 2021, the observed number of deaths was two empirical standard deviations above the expected number. The high excess mortality in 2021 was almost entirely due to an increase in deaths in the age groups between 15 and 79 and started to accumulate only from April 2021 onwards. A similar mortality pattern was observed for stillbirths with an increase of about 11 percent in the second quarter of the year 2021.

Something must have happened in April 2021 that led to a sudden and sustained increase in mortality in the age groups below 80 years, although no such effects on mortality had been observed during the COVID-19 pandemic so far.

1 Introduction

In the last two years, the burden of the COVID-19 pandemic on mortality has been intensively discussed. Basically, since COVID-19 is an infectious disease that is caused by a new virus, it is expected that many people have died because of the new virus who otherwise would not have died. In fact, this expectation represents one of the central justifications for the taking of countermeasures against the spread of the virus. Due to this reason, several previous studies have tried to estimate the extent of the mortality burden that has been brought about by the COVID-19 pandemic.

At first glance, it seems obvious to simply estimate the burden of the COVID-19 pandemic on mortality based on the number of officially reported COVID-19-related deaths. However, this has been proven to be difficult due to several reasons.

1.1 Reported COVID-19-Deaths: The Problem

A first difficulty is the problem that it is unclear whether a reported COVID-death died because of a SARS-CoV-2-infection or only with a SARS-CoV-2-infection. For instance, according to a published analysis of the German COVID-19 autopsy registry from March 2020 to the beginning of October 2021 [1], only 86% of the autopsied deaths with a COVID-19 diagnosis died from COVID-19. In particular, a closer look at the diagnostics used in this study suggests that this may be an overestimation. For instance, 87 of the 1,095 autopsied persons with the autopsy result of an "unspecific cause of deaths" were excluded although such persons seem not to have died from COVID-19. In addition, 10 percent of the deaths treated as "died from COVID-19" died actually due to bacterial or fungal super-infections or due to therapy-associated reasons and are thus not directly caused by COVID-19. These examples highlight the general problem that the answer to the question whether COVID-19 was the actual cause of death depends on the used definition of 'causality'.

A second difficulty is that even if a person died from COVID-19, this does not rule out the possibility that the person would have died as well even if there had been no COVID-19 pandemic. Many of the people that have died from COVID-19 were highly frail [2], and these people might have died from other causes of deaths if they had not died from COVID-19. For instance, it has been shown that rhinovirus infections have a high mortality risk for vulnerable elderly people as well [3]. Thus, even if there had been no SARS-CoV-2-infection waves, these individuals might instead have died in one of the rhinovirus-infection waves. Accordingly, even if there is a large number of deaths that were caused by a SARS-CoV-2-infection, this would not necessarily mean that all these deaths are additional deaths that would not have occurred if there had been no COVID-19 pandemic.

1.2 Estimating the Burden of the COVID-19 Pandemic Based on All-Cause Mortality

An obvious way to solve such problems when estimating the burden of the COVID-19 pandemic on mortality is to compare the number of observed all-cause deaths independently of the underlying causes of deaths with the number of all-cause deaths that would have been expected if there had been no pandemic. If there is a new virus that causes additional deaths beyond what is usually expected, the number of observed all-cause deaths should be larger than the number of usually expected deaths, and the higher the number of observed deaths is above the number of usually expected deaths, the higher is the burden of a pandemic on mortality. In particular, beyond the advantage that the above-mentioned problems with the number of the reported COVID-19-related deaths are avoided, another advantage is that additional indirect negative impacts of a pandemic on mortality are covered as well, such as a possible pandemic-induced strain of the health care system.

Due to these reasons, it is not surprising that several attempts have been made to estimate the increase in all-cause mortality during the COVID-19-pandemic [4–10]. Since the death of a person is a clear diagnostic fact, and since highly reliable data on mortality are available for several countries, at first glance, one may expect that the question of whether more people have died during the COVID-19-pandemic than is usually expected can be clearly answered.

However, the existing attempts show very large differences in the estimated increase in all-cause mortality during the COVID-19-pandemic. This can be illustrated for Germany where highly reliable data on the number of all-cause deaths even at the level of individual days are available. The estimated increase in all-cause mortality during the pandemic years 2020 and 2021 varies from 203,000 additional deaths [5] to only

29,716 additional deaths [6, 7], and for the pandemic year 2020, it has even been estimated that less all-cause deaths have been observed than usually expected [8].

How can this large variability in the estimated increase in all-cause mortality be explained? While the number of observed all-cause deaths is a fixed and clearly defined number, the estimation of the usually expected deaths is relatively complex and entails several choices of mathematical models and parameters and which can lead to large differences in the estimated values

Against this background, the present article has three objectives:

1. To provide an overview and an evaluation of the choices that must be made.
2. To demonstrate that the amount of increase in all-cause mortality must be understood as an inherent fuzzy construct that varies depending on the chosen perspective.
3. To provide a best-practice method how to estimate and interpret the increase in all-cause mortality using the example of observed all-cause deaths in Germany in the years 2020 to 2022. As will be shown, a proper analysis of the increase in all-cause mortality reveals several previously unknown dynamics that will require a reassessment of the mortality burden brought about by the COVID-19 pandemic.

1.3 Estimating the Increase in All-cause Mortality: Population-Size and Historical-Trend Effects

There are two main effects that have to be taken into account when estimating the increase in all-cause mortality: effects of changes in the size of the population and effects of historical trends in mortality rates. To illustrate these effects and the resulting potential pitfalls, Fig. 1 shows for the over 80 years old population in Germany the number of deaths (Fig. 1A), the population size (Fig. 1B), and the mortality rate (i.e., percentage of deceased persons; Fig. 1C) for the years 2016 to 2021.

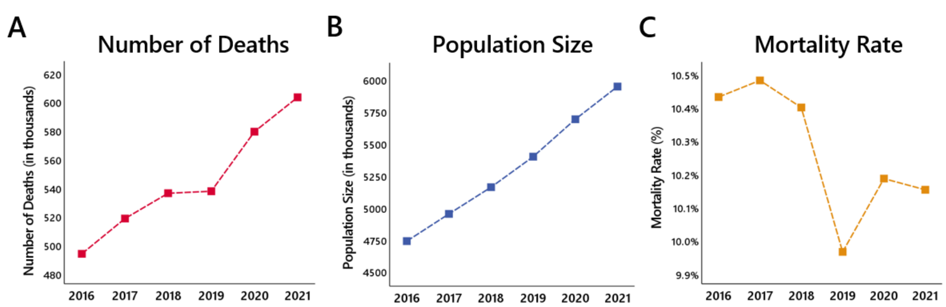

Fig. 1.: Population-size effects and historical-trend effects on the estimation of the increase in mortality. For the population over 80 years of age in Germany, (A) shows the number of deaths, (B) the population size, and (C) the mortality rate (i.e., percentage of deceased persons) for the years 2016 to 2021.

Changes in population size have to be taken into account due to the simple fact that the larger a population is, the more deaths occur. Ignoring existing changes in population size will lead to erroneous estimations. For instance, regarding the population over 80 years of age in Germany, the number of deaths increases from year to year (see Fig. 1A). Concluding from this pattern that mortality increased in the years 2020 and 2021 compared to previous years would make no sense because this increase is fully attributable to the increase of population size, as shown in Fig. 1B and 1C.

Historical trends in mortality rates have to be be taken into account due to the fact that mortality rates are not a stable values but influenced by environmental and societal changes and improvements in medical treatments. For instance, as can be seen exemplarily in Fig. 1C, in Germany, there is a historical trend of a continuous decrease in mortality rate that is observed in most age groups. If such a declining trend in mortality rates is not taken into account, the number of expected deaths are overestimated and thus the true mortality decrease is underestimated.

The pitfall of ignoring changes in population size is for example found in the estimations provided by the German Federal Statistical Office [11] where the increase in mortality is estimated based on a comparison of the observed number of deaths with the median value of the four previous years. As illustrated in Fig. 2A, estimating the number of expected deaths based on the median of the four previous years underestimates the number of expected deaths and thus overestimates the true increase in mortality. The invalidity of this method can be illustrated by the fact that in case of a continuously increasing population size, as is the case for the population over 80 years of age in Germany, such a method would conclude for *every* year that there was an unexpected increase in mortality compared to previous years.

The pitfall of ignoring longer historic trends is for example found in the estimations provided by the World Health Organization (WHO) [10] where the increase in mortality is estimated based on a thin-plate spline extrapolation of the number of expected deaths. As illustrated in Fig. 2B, such an estimation method is highly sensitive to short-term changes in the observed number of deaths. Accordingly, erratic estimations of expected deaths predictions can occur. For instance, regarding the WHO estimations for Germany, the spline extrapolation predicts – based on the short-term decline in deaths in 2019 compared to 2018 – that a similar decline would occur in the following years as well, although this completely contradicts the long-term historical trend.

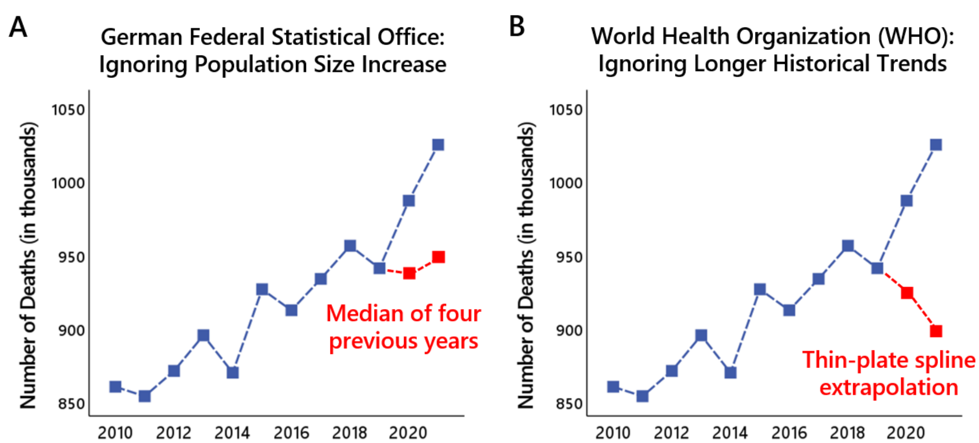

Fig. 2.: The pitfalls of ignoring population-size effects and historical-trend effects. The blue squares in (A) and (B) show the development of the number of deaths in Germany from 2010 to 2021 (all age groups). The red squares in (A) show the estimations of the number of expected deaths for the years 2020 and 2021 of the German Federal Statistical Office [11] which are based on the median of the four previous years. The red squares in (B) show the estimations of the number of expected deaths for the years 2020 and 2021 of the World Health Organization [10] which are based on a thin-plate spline extrapolation that is highly sensitive to short-time changes. As can be seen, both the ignoring of the increase in population size of the older age groups and the ignoring of longer historical trends leads to an underestimation of the expected deaths and thus to an overestimation of the true mortality increase in the years 2020 and 2021.

1.4 Methods That Take Into Account Population-Size and Historical-Trends Effects

A first and comparatively simple approach to take into account population-size and historical-trends effects is the attempt to predict the further course of the number of deaths from observed data in previous years using regression methods. For instance, in a study by Baum [4], the course of the observed increase in the number of deaths in Germany from 2001 to 2021 compared to the year 2000 was fitted with a polynomial function of order two, and the yearly residuals were used to estimate the yearly increase or decrease in mortality, resulting in an estimated increase in mortality in the years 2020 and 2021 of about 11,000 additional deaths each. While the advantage of this approach is on the one hand that no parameter choices have to be made as it is the case with the more complex estimation methods (see below), on the other hand this is at the same time the weakness of this approach: since every data point is given the same weight, unique outliers may lead to biased estimations, and developments depending on more complex circumstances cannot be incorporated in this approach.

To account for unique outliers, it has been tried to estimate the number of expected deaths by a time-series model based on the number of observed deaths in previous years, and to exclude past phases of unique excess mortality, as done in the EuroMOMO project [12]. However, beyond the problem that the resulting estimates depend on the specific model and parameter choices made (see below), a common problem for every approach that bases estimations on the raw number of observed deaths is that the resulting estimations do not take into account possible changes in the age structure within a population, which can lead to biased estimates.

To take into account changes in the age structure within a population, so-called age-adjustments has a long tradition in mortality research [13], which is essential especially when estimating the number of expected deaths in populations where the proportion of elderly people changes over time. The basic method is to compute mortality rates for a reference period separately for different age groups, and to extrapolate from the age-dependent mortality rates and the population sizes of the different age groups in the to-be-estimated year the number of expected deaths in each of the age groups.

An example is a recent study by Levitt, Zonta, and Ioannidis [9] where the increase in mortality in the years 2020 and 2021 was estimated based on the reference period of the three pre-pandemic years 2017-2019 using age strata of 0-14, 15-64, 65-75, 75-85, and 85+ years, resulting in an estimated increase in mortality of about 16,000 additional deaths in the year 2020, and 38,800 additional deaths in the year 2021. In two studies by De Nicola et al. [5,6], a more refined method (see below) and a more fine-grained age adjustment was used, resulting in even lower estimates of increased mortality with about 6,300 additional deaths in 2020 and 23,400 additional deaths in 2021.

A problem in both the study by Levitt et al [9]. and the studies by De Nicola et al. [6, 7] is that possible historical trends in mortality rates are not taken into account. This was, in addition to an age-adjustment, done in a study by Kowall et al. [8] where the increase in mortality in the year 2020 was estimated for the countries Germany, Spain, and Sweden. Historical trends in mortality rates were estimated based on the observed decrease in mortality rates in the pre-pandemic years 2016-1019. For Germany, it was estimated that the number of observed deaths in 2020 was 0.9 percent higher than the number of estimated expected deaths, which is in the range of the estimations in the De Nicola et. study. Estimations with adjustments for changes in historical trends in mortality rates for the year 2021 have to date not been reported, at least to our knowledge.

1.5 The Inherent Fuzziness of Estimates of Increases in Mortality

As has already become apparent in the previous paragraphs, the estimation of the amount of increase in all-cause mortality entails several model and parameter choices that have to be made. While a proper analysis necessarily requires the taking into account of changes in population sizes and historical trends in mortality rates, there remain a number of degrees of freedom how to exactly do this. For instance, an open question is which previous years are used as a reference and which model is used for the extrapolation of the expected deaths based on these years.

What a large effect a small change in the chosen perspective can have on the estimation of the amount of mortality increase is illustrated in Fig. 3 using the German mortality figures. When trying to estimate the increase in the number of all-cause deaths in the years 2020 and 2021 by a comparison with the number of expected deaths that is estimated based on the course of deaths in the four pre-pandemic years 2016-2019, one can for instance take two different perspectives: one can consider the year 2018 as an unusual outlier above the typical course of the number of deaths, or one can consider the year 2019 as an unusual outlier below the typical course of the number of deaths. Depending on the chosen perspective, extrapolating the expected number of deaths with either excluding the year 2018 ("outlier upwards") or the year 2019 ("outlier downwards") leads to totally different results, with an estimation of a strong increase in mortality in the former case and an estimation of even a slight decrease in mortality in the latter case.

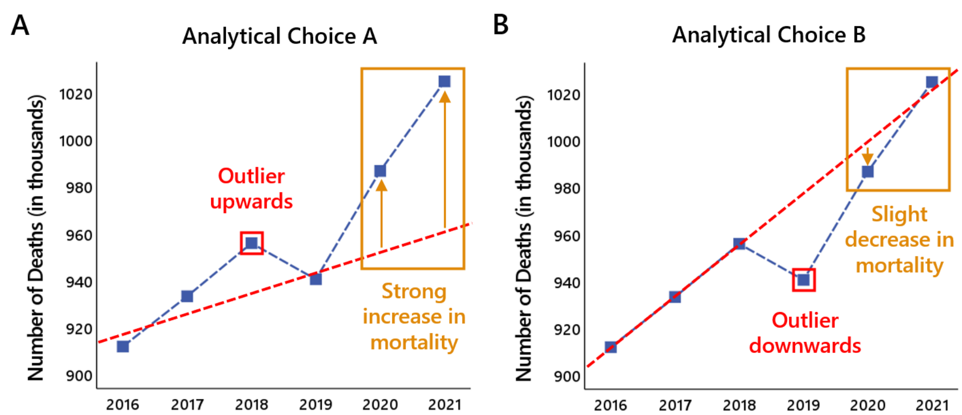

Fig. 3.: Possible large effect of small changes in the chosen perspective. The blue squares in (A) and (B) show the development of the number of observed all-cause deaths in Germany from 2016 to 2021 (all age groups). The expected all-cause deaths in the years 2020 and 2021 are estimated based on the observed deaths in the years 2016-2019 using a simple linear regression function, excluding the year 2018 as an "unusual outlier upwards" (A) or the year 2019 as an "unusual outlier downwards" (B), giving the impression of a strong increase in mortality in the former case and the impression of even a slight decrease in mortality in the latter case.

Since there is no truth criterion that would determine which of the choices is the best one to be made, there is no such thing as a "true" increase in mortality. Instead, the amount of increase in mortality must be understood as an inherent fuzzy construct that varies depending on the chosen perspective. This fact has at least three important implications:

First, when reporting estimates of the amount of increase in mortality, it is important to show how strongly the estimates vary with different model and parameter choices that can reasonably be made. In particular, possible choices and the resulting estimates should be communicated to readers in a way so that they are enabled to draw their own conclusions depending on their specific questions they would like to answer (see next point).

Second, when interpreting estimates of the increase in mortality, one has to be aware of the made model and parameter choices. In particular, when deciding which approach is chosen, one has to clarify which question is tried to answer, and to choose the approach that best fits the to-be-answered question. For instance, if one is interested in the question of how far the observed number of deaths is above the usually occurring deaths, excluding outlier years when estimating the amount of increase in mortality may be a reasonable decision. However, if one is interested in whether the observed number of deaths is above the extreme values of previous years, excluding outliers may be a less reasonable decision.

Third, despite the inherent fuzziness of the estimates of increases in mortality, the comparison of increases in mortality between two years may nevertheless reveal clear results. If the observed difference between the two years does not vary as a function of the chosen parameters and model, it can be assumed that the observed differences in estimated increases in mortality reflects the true fact that there was a larger increase in mortality in one of the years.

1.6 The Use of the Term "Excess Mortality"

In many of the previous studies, the observation that the number of observed all-cause deaths is larger than the number of expected all-cause deaths is designated by the term "excess mortality". However, such a use of terms is questionable. The number of deaths from year to year does not follow a straight line but varies around a common trend. Accordingly, as illustrated in Fig. 4, if one were to designate as "excess mortality year" all years in which more deaths are observed than expected according to the common trend, one would have to conclude that an "excess mortality" is observed in about 50 percent of all years, and a "mortality deficit" in the other 50 percent of all years.

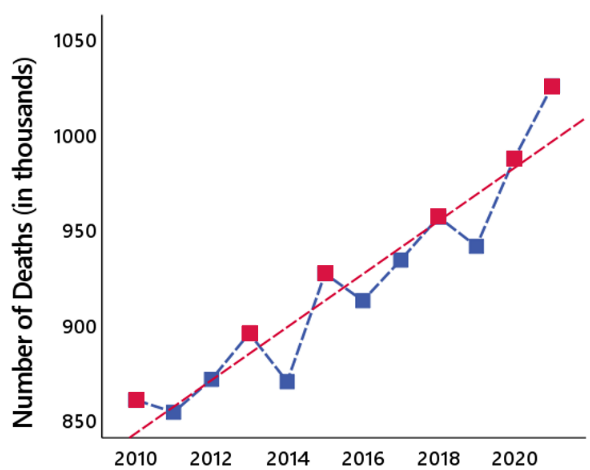

Fig. 4.: The inflationary use of the term "excess mortality". The colored squares show the number of all-cause deaths in Germany from 2010 to 2021. The dashed red line shows the common trend across the years (linear regression). If one were to designate as "excess mortality year" all years in which more deaths are observed than expected according to the

common trend (red-colored squares), one would have to conclude that an “excess mortality” is observed in six years, and a “mortality deficit” in the other six years.

Since about half of the years show mortality levels above the common trend, one could use the term “excess mortality” only for years that show an outstanding increase in mortality above a certain threshold. One straightforward possibility to establish such a threshold would be to compute the mean variation (empirical standard deviation) around the common trend across the years, and to designate as “excess mortality years” only those in which the number of observed deaths exceeds twice the mean variation.

Another possibility would be to search for previous years with peak deviations from the common trend, and then to compare the deviation observed in the year one is interested in with the peak deviations in previous years. Such a comparison was for instance made in a recent study by Staub et al. [14] where the historical dimension of the COVID-19 pandemic was examined for the countries Switzerland, Sweden, and Spain over a time span of more than 100 years, revealing that the peaks of monthly excess mortality in 2020 were greater than most peaks since 1918.

Nevertheless, also in this contribution we decided to use the terms “excess mortality” and “mortality deficit” for a mortality which is just above or below the estimated value, as in most other contributions. An attempt to define an outstanding “excess mortality year“ via mean variations will be made in Section 3 and Section 4.

1.7 The Present Study

The aim of the present study is to provide the state-of-the-art method of actuarial science to estimate the expected number of all-cause deaths and thus to estimate the increase in all-cause mortality for the pandemic years 2020 to 2022. In particular we evaluate the all-cause deaths in Germany. The following four questions are investigated:

(1) Yearly Increase in mortality in the years 2020 to 2022 in Germany: As described above, there are several studies that have attempted to estimate the increase in mortality in Germany in 2020 and 2021 based on different methods [5–8, 10]. However, there are several unanswered questions:

    First, only one study [5], which examined only the year 2020, took into account the historical trend in mortality rates. We use the best available mathematical model provided by the German Association of Actuaries, where well established longevity factors are used for estimating the trend.

    Second, although in most of the studies age-standardized estimations were made, age-dependent differences in mortality increase were not examined in detail. We use most recent life tables provided by the Federal Statistical Office of Germany to calculate age-dependent expectations, applying the standard model in actuarial mathematics which was already used by Euler and Gauß.

    Third, in none of the studies, it was examined how much the mortality estimates vary with different approaches. Here we calculate the model and parameter sensitivity by comparing the results achieved using different life tables and longevity factors.

    And fourth, in all of the previous studies, only the estimated increase in all-cause deaths was reported, without examining whether the estimated increase exceeds the usual variation in mortality found across previous years. We give an estimate for the empirical standard deviation which can be used to obtain confidence intervals.

(2) Monthly increase in mortality in the years 2020 to 2022 in Germany: The increase in mortality over the course of the year has so far only been investigated for 2020

in two studies [5,6]. The years 2021 and 2022 have not yet been investigated in this respect. Furthermore, no study has yet determined the increase in mortality over the course of the year for different age groups.

(3) Comparing the results to possible influencing factors: In none of the previous studies, possible factors that might contribute to the observed course of the increase in mortality were explicitly examined on a monthly base during the pandemic years 2020 to 2022.

(4) Monthly increase in the number of stillbirths in the years 2020 to 2022 in Germany: In all previous studies, the increase in mortality has only been examined for the age groups 0 and above. Whether changes in mortality are also found at the level of stillbirths has not been investigated so far.

2 Yearly expected mortality

2.1 Methods

The starting point for our investigations are the period life tables and population demographics available from the Federal Statistical Office of Germany. As usual in actuarial science, we denote by

- $l_{x,t}$ the number of x year old male at January 1st in year t;
- $l_{y,t}$ the number of y year old female at January 1st in year t;
- $d_{x,t}$ the number of deaths of x year old males in year t;
- $d_{y,t}$ the number of deaths of y year old females in year t;
- $q_{x,t}$ (an estimate for) the mortality probability for an x year old male in year t.
- $q_{y,t}$ (an estimate for) the mortality probability for a y year old female in year t.

Note that $d_{x,t}$ also contains deceased that have been $(x-1)$ years old at January 1st in year t and died as x year old. To compensate this problem, the 2017/2019 life table of the Federal Statistical Office of Germany [15] (like most German life tables) uses the method of Farr to estimate $q_{x,t}$ (and analogously $q_{y,t}$).

$$\hat{q}_{x,2019} = \frac{\sum_{t=2017}^{2019} d_{x,t}}{\frac{1}{2}\sum_{t=2017}^{2019}(l_{x,t}+l_{x,t+1}) + \frac{1}{2}\sum_{t=2017}^{2019} d_{x,t}} \tag{1}$$

The period life table 2017/19 of the Federal Statistical Office of Germany thus takes into account only the mortality probabilities in these three years.

A much more complicated task is to compute generation life tables. Generation life tables observe the mortality development over a long period, roughly 100 years, smoothen the existing data, and in particular estimate the long term behaviour of the mortality probabilities. These probabilities have been decreasing within the last 100 years, and the common ansatz is to set

$$q_{x,t} = q_{x,t_0} e^{-F(x;t,t_0)},\ q_{y,t} = q_{y,t_0} e^{-F(y;t,t_0)}..$$

Here the German Association of Actuaries (DAV) uses a smoothed life table q_{x,t_0} in the base year t_0, and models the trend underlying future mortality, the longevity trend function $F(x;t,t_0)$, via regression for the male and female population, separately. In the year 2004 it turned out that the decrease of the mortality probabilities in the previous years has been steeper than expected, therefore the DAV life table DAV 2004 R [16] distinguishes between a higher short-term trend and a lower long-term trend. These trends are of high importance and used for life annuities, whereas for life insurances the trend (at least the short term trend) is mostly ignored. In addition, it seems that the longevity trend was flattening in the last years. Therefore, we have decided to use half the long-term trend function given by the DAV 2004 R,

$$F(x;t,t_0) = \frac{1}{2}(t-2019)F_{l,x},\ F(y;t,t_0) = \frac{1}{2}(t-2019)F_{l,y}$$

where the numbers $F_{l,x}$ and $F_{l,y}$ are contained in the DAV 2004 R table. We also decided to use the probabilities $\hat{q}_{x,2019}$ and $\hat{q}_{y,2019}$ of the life table 2017/2019 by the Federal Statistical Office of Germany as the base life table in a first step, thus $t_0 = 2019$. For a discussion concerning our model parameters, i.e. the influence on the longevity trend and our choice using half of it, and the choice of the (non-smoothed) life table 2017/19, we refer to Section 3. Also, it is well known that mortality probabilities for males and females differ substantially, therefore these two cases are computed separately.

Putting things together, we define the mortality probability of an x year old male in year t by

$$q_{x,t} = \hat{q}_{x,2019}e^{-\frac{1}{2}(t-2019)F_{l,x}},$$

and for a y year old female in year t by

$$q_{y,t} = \hat{q}_{y,2019}e^{-\frac{1}{2}(t-2019)F_{l,y}}.$$

Now, for each individual the probability to die at age x is given by $q_{x,t}$, and hence, in a first attempt, a population of $l_{x,t}$ individuals produces binomial distributed random numbers $D_{x,t}$ and $D_{y,t}$ of deaths for males, respectively females, with expected values

$$\mathbb{E}D_{x,t} = l_{x,t}q_{x,t},\ \mathbb{E}D_{y,t} = l_{y,t}q_{y,t}.$$

As is well known (and already discussed above in connection with Farr's method), this formula ignores those individuals which have been of age $(x-1)$ at the beginning of year t, and died as x year olds. To compensate for this missing piece, we follow the procedure proposed by De Nicola et al. [6]. Roughly half of the $x-1$ year old population at the beginning of the year which is of size $l_{x-1,t}$ dies after its birthday as x year old. For them we use the smoothed mortality probability

$$\frac{q_{x-1,t}+q_{x,t}}{2}.$$

The other half of the x year old deceased belongs to the population of x year old at the beginning of the year which is of size $l_{x,t}$. For them we use the smoothed mortality probability

$$\frac{q_{x,t}+q_{x+1,t}}{2}.$$

For more details see [6]. Hence for $x = 0, \dots, 101$ the random number $D_{x,t}$ of deaths of age x in year t is binomial distributed and satisfies

$$\mathbb{E}D_{x,t} = \frac{1}{2}\left(l_{x-1,t}\frac{q_{x-1,t}+q_{x,t}}{2} + l_{x,t}\frac{q_{x,t}+q_{x+1,t}}{2}\right) \tag{2}$$

where $l_{x-1,t}$ and $l_{x,t}$ are taken from the population table of the Federal Statistical Office of Germany [17]. For $x = 0$ we set $l_{-1,t} = l_{0,t+1}$ if available, $l_{-1,t} = l_{0,t}$ else, and $q_{-1,t} = q_{0,t}$. The same considerations lead to $\mathbb{E}D_{y,t}$.

The 2017/2019 life table by the Federal Statistical Office of Germany contains the mortality probabilities $q_{x,t}$ and $q_{y,t}$, and the underlying population table the population size $l_{x,t}$ and $l_{y,t}$ for the age $x = 0, \ldots, 100$. In principle it would be more precise to use life tables and population tables up to age 113 but these data are not available. The excess mortality is obtained by comparing the expected values $\mathbb{E}D_{x,t} + \mathbb{E}D_{y,t}$ to the observed data $d_{x,t} + d_{y,t}$ for $t = 2020, 2021$ and 2022 .

Some remarks are in order to contextualize the method.

- Modelling the longevity factors is a challenging task. For example, the Actuarial Association of Austria uses factors involving $\arctan\left(\frac{t}{100} - 20.01\right)$ which has serious advantages. The need for longevity factors depends heavily on the country, it seems for example that in Japan and in England the mortality trend has already vanished and the mortality probabilities are more or less constant.
- The mortality probability heavily depends on gender and differs for the male and female population. But the resulting excess mortality is nearly the same for the male and female population. Hence in the following we calculate the expected number of deaths separately and show only the total number of deaths. On the other hand, huge differences occur for the excess mortality in different age groups and therefore we present our results for each age group separately.
- The mortality probability not only depends on age and gender, but also significantly on social status, profession, health condition, region, etc. As is common, the German life tables give average mortality probabilities. Also, it is unclear - at least to the authors - whether the SARS-CoV-2-infection rate and mortality depends on these factors, too. For a deeper investigation of COVID-19 mortality increase this should be taken into account, but at the moment appropriate data are not available.

2.2 Results

Following the computations described in the previous section, we obtain the expected number of deaths in 2020, 2021 and 2022. The expectations $\mathbb{E}D_{x,t}$ and $\mathbb{E}D_{y,t}$ for each age $x, y = 0, 1, \ldots, 99$ and $t = 2020$, 2021 and 2022 are given in the supplement, Section 8.1 The Federal Statistical Office of Germany provides the (raw) number of deaths in 2021 only in certain age groups [18]. Therefore, the following table gives the number of deaths in the age groups

$$\bar{a} \in \{[0, 14], [15, 29], [30, 39], [40, 49], [50, 59], [60, 69], [70, 79], [80, 89], [90, \infty)\}.$$

We set

$$D_{\bar{a},t} = \sum_{x \in \bar{a}} D_{x,t} + \sum_{y \in \bar{a}} D_{y,t} \quad \text{and} \quad d_{\bar{a},t} = \sum_{x \in \bar{a}} d_{x,t} + \sum_{y \in \bar{a}} d_{y,t}.$$

To compare the expected $\mathbb{E}D_{\bar{a},t}$ and the observed values $d_{\bar{a},t}$, we use the relative difference

$$\frac{d_{\bar{a},t} - \mathbb{E}D_{\bar{a},t}}{\mathbb{E}D_{\bar{a},t}}.$$

Table 1: Expected deaths and yearly excess mortality.

	$t = 2020$			$t = 2021$			$t = 2022$
age range	expected observed	rel.diff.		expected observed	rel.diff.		expected observed
0-14	3.531			3.513			3.517
	3.306	-6,38%		3.490	-0,67%		–
15-29	3.944			3.817			3.755
	3.844	-2,53%		3.951	3,52%		–
30-39	6.626			6.585			6.546
	6.668	0,64%		6.938	5,35%		–
40-49	15.345			14.877			14.601
	15.507	1,06%		16.256	9,27%		–
50-59	58.641			57.705			56.471
	57.331	-2,23%		59.387	2,91%		–
60-69	117.432			118.456			119.983
	118.460	0,88%		126.477	6,77%		–
70-79	198.389			190.335			186.303
	201.957	1,80%		204.089	7,23%		–
80-89	378.459			392.535			404.994
	378.406	-0,01%		396.990	1,13%		–
90-∞	199.191			201.884			202.375
	200.093	0,45%		203.852	0,97%		–
total	981.557			989.707			998.545
	985.572	0,41%		1.021.430	3,21%		–

Clearly, for the year 2022 we can only present the expected number of deaths.

The deviation in 2020 and 2021 must be compared to the deviation inherent in the parameter choice of our model, and the empirical standard deviation which has occurred in the years before. This will be done in Section 3 and Section 4. It will turn out, that in year 2020 the observed number of deaths is extremely close to the expected number with respect to the empirical standard deviation, whereas in 2021 the difference is of order twice the empirical standard deviation.

The following graph illustrates, that the deviation of the observed mortality from the expected mortality is not uniform over the different age groups, and, in particular, the structure changes from 2020 to 2021. A closer look reveals that the excess mortality observed in 2021 is almost entirely due to an above-average increase in deaths in the age groups between 15 and 79. The highest values are reached in the age group 40-49, where an increase in the number of deaths is observed that is nine percent higher than the expected values.

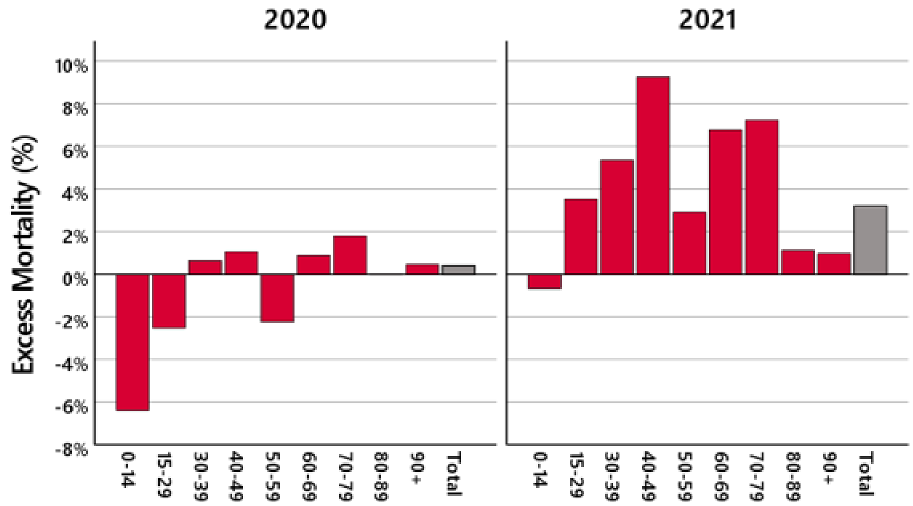

Fig. 5: Yearly excess mortality. The red bars show the excess mortality in 2020 (left panel) and 2021 (right panel) in different age groups, the grey bars the total excess mortality.

Some remarks are in order, to contextualize the results.

- Our results show that there is some kink around the age of 50. We do not have an explanation for this fact.
- One has to take into account that the year 2020 is a leap year. Therefore we have "added" an additional day by multiplying the result of the computations described above by $\frac{366}{365}$.
- For infants something unexplained happens. In the beginning of 2020 there were 774.870 people of age 0, during the year 2.373 children of age 0 died, yet at the end of 2020 there were 783.593 (!) people of age 1. This is maybe due to migration effects, but we do not have sufficient precise data to model this effect. And for our investigations concerning COVID-19 excess mortality, the infant mortality can be ignored.

3 The model uncertainty

There are several parameters for modelling mortality probabilities which essentially influence the results. One could replace the 2017/2019 life table of the Federal Statistical Office of Germany by the life tables 2016/18 or 2015/17. And one could use different longevity factors, or ignore them totally. The question, whether a serious excess mortality occurs for 2020 and 2021, heavily depends on this underlying data sets. In the next table we present the total expected number of deaths over all age groups

$$\mathbb{E}D_t = \sum_{x=0}^{101} \mathbb{E}D_{x,t} + \sum_{y=0}^{101} \mathbb{E}D_{y,t}$$

using different life tables and taking into account either none, or half, or the full longevity trend.

Table 2: Expected deaths for different life tables.

longevity trend	life table	$\mathbb{E}D_{2020}$	$\mathbb{E}D_{2021}$
none	2015/17	1.010.478	1.025.768
	2016/18	999.592	1.014.802
	2017/19	988.288	1.003.270
half	2015/17	989.964	998.213
	2016/18	986.021	994.294
	2017/19	981.557	989.707
full	2015/17	969.896	971.451
	2016/18	972.649	974.230
	2017/19	974.875	976.341
	observed	985.572	1.021.430

It turns out that the life tables have a significant effect on the question whether an excess mortality exists. For example, the use of the life table 2015/17 of the Federal Statistical Office of Germany without the longevity trend yields for both Corona-years 2020 and 2021 a mortality deficit. And even when keeping half the longevity trend, in 2021 the excess mortality of 31.723 deaths for the life table 2017/19 should be compared to the smaller excess mortality of 23.217 deaths when using the life table 2015/17, the total difference being 8.506 deaths. In other words, the life tables of the Federal Statistical Office of Germany have a serious fluctuation over the years which should be taken into account as the model uncertainty.

For a more convenient view we present the excess mortality using the relative difference.

Table 3: Excess mortality for different life tables.

longevity trend	life table	2020	2021
no	2015/17	-2,46%	-0,42%
	2016/18	-1,40%	0,65%
	2017/19	-0,27%	1,81%
half	2015/17	-0,44%	2,33%
	2016/18	-0,05%	2,73%
	2017/19	0,41%	3,21%
full	2015/17	1,62%	5,14%
	2016/18	1,33%	4,84%
	2017/19	1,10%	4,62%

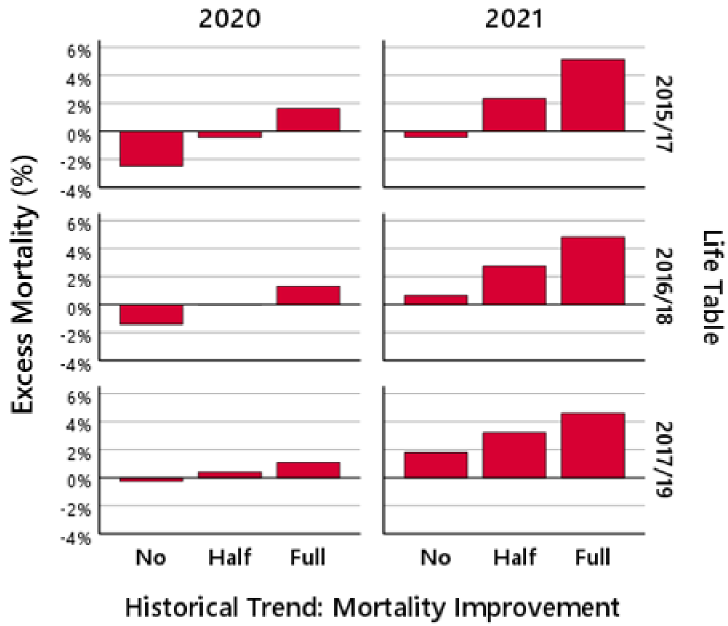

Fig. 6: The model sensitivity. The bars show the mortality deficit, respectively the excess mortality in 2020 (left panel) and 2021 (right panel) for different life tables and longevity trends.

In the light of these results, we have decided to choose a model which avoids the extremes and includes half of the longevity factor in Section 2.1. In this case, the range between the three models – which is an indicator for the model uncertainty – is in both years approximately 8.500 deaths per year.

Yet in all these results obtained by life tables of recent years of the Federal Statistical Office of Germany, and in most other models [4–8], the main point coincides with our results: for 2020 the number of deaths is close to the expected value, whereas for 2021 there is a noticeable excess mortality.

A more detailed analysis of all the age groups introduced in Section2.2 shows that independently of the model used the increase of the excess mortality from 2020 to 2021 is about approximately 6% for the age groups 0-79, except for the age group 40-49 where it is 8%. These more detailed results are given in the supplement, Section 8.2.

4 The empirical standard deviation

As remarked in Section 2.2, to contextualize the deviation in 2020 and 2021 it must be compared to the model uncertainty, and to the empirical standard deviation occurred in the years before. Since the precise value of the empirical standard deviation – like the expectation – heavily depends on the underlying mathematical model, and since we are only interested in a rough approximation of the empirical standard deviation we use an extremely simple model: we approximate the expected number of deaths using a linear regression model and calculate the empirical standard deviation in this model.

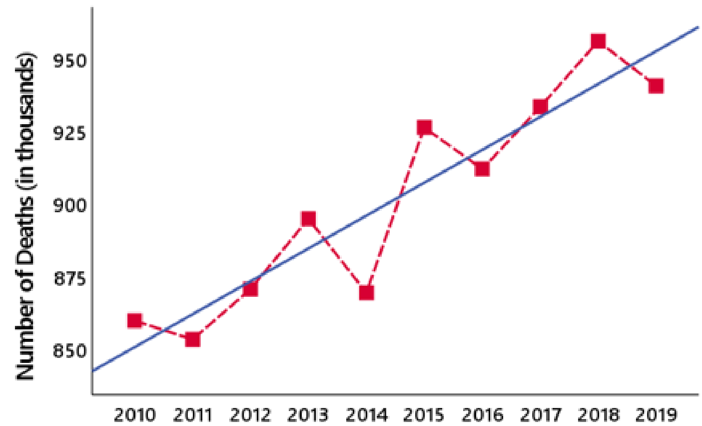

Fig. 7: The empirical standard deviation. The red squares show the number of all-cause deaths in Germany from 2010 to 2019. The blue line shows the regression line.

The regression leads to

$$d_t = \sum_{x=0}^{100} d_{x,t} + \sum_{x=0}^{100} d_{y,t} \approx L(t) = -21.936.713,9 + 11.336,2 \cdot t$$

which shows that each year we expect an increase of approximately 11.300 deaths in Germany. Observe that we have taken into account that the years 2012 and 2016 have been leap years and the number of deaths has been normalized to 365 days per year.

Table 4: Linear regression of the observed deaths.

year t	lin. reg. $L(t)$	observed d_t
2010	849.062	858.768
2011	860.398	852.328
2012	871.735	867.206
2013	883.071	893.825
2014	894.407	868.356
2015	905.743	925.200
2016	917.079	908.410
2017	928.416	932.263
2018	939.752	954.874
2019	951.088	939.520

Calculating in this simple model the empirical standard deviation gives

$$\hat{\sigma}(d_t) = 14.162\,. \tag{3}$$

We do not claim that this is the precise value of the standard deviation $\sigma(D_t)$, yet we are convinced that this at least reflects the order of magnitude. To check whether this order of magnitude is plausible we also computed the empirical standard deviation for the years 2000-2009 using again the linear regression model. For these years the empirical standard deviation is approximately 12.600 which is the same order as (3).

At first sight this empirical standard deviation is somehow surprising and seems to be in contrast to the model used for modelling $D_{x,t}$ described in Section 2.1. As is common, we assumed that the number of deaths follows a simple binomial distribution. This is the most natural assumption. It would imply that the variance $\mathbb{V}D_{x,t} = l_{x,t}(1-q_{x,t})q_{x,t}$ is approximately the number of deaths $l_{x,t}q_{x,t}$, since for the large majority of x the mortality probabilities are close to zero. Hence in Germany this assumption and the independence property of the binomial model would lead to a total variance is of order one million, and a standard deviation of approximately 1.000. Thus in actuarial science we introduce a further randomization of $q_{x,t}$ which keeps the expectation unchanged – and thus our results in Sections 2.1–3 are still valid – but increases the variance to the observed 14.000.

We compare the excess mortality of 4.000 deaths in 2020 and 31.700 deaths in 2021 to the empirical standard deviation $\hat{\sigma}(D_t)$. In 2020 this leads to

$$d_{2020} - \mathbb{E}D_{2020} \approx 0,28\hat{\sigma}(D_{2020})$$

and for 2021

$$d_{2021} - \mathbb{E}D_{2021} \approx 2,24\hat{\sigma}(D_{2021}).$$

In many applications an observed deviation beyond twice the standard deviation is called significant because for normal distributed random variables the 5% confidence interval leads to this bound. A bound of 2.24 times the standard deviation leads to a 2.5% confidence interval, which roughly speaking means that this event occurs 2-3 times every hundred years.

On the other hand one could also take into account half of the model uncertainty of approximately 4.250 deaths. This leads to

$$d_{2021} - \mathbb{E}D_{2021} \approx 4.250 + 1,94\hat{\sigma}(D_{2021})$$

and thus the deviation in 2021 would be in a 5% confidence interval.

5 Monthly expected mortality

5.1 Methods

In the following two sections, we present a more detailed analysis of the number of deaths during the years 2020 to 2022. It is well known that the mortality probabilities are not constant but differ from month to month with peaks at the beginning and the end of the year and also sometimes in summer when the weather is too hot (and depending on many other circumstances).

Unfortunately, the data basis for such investigations provided by the Federal Statistical Office of Germany is somehow weak. Therefore, again several approximation steps have to be applied. We denote by $d_{x,t,m}$, respectively $d_{y,t,m}$, the number of deaths of x year old male and y year old female in year t in month m. The Federal Statistical Office of Germany offers tables for $d_{\bar{x},t,m}$ and $d_{\bar{y},t,m}$ in the age groups $\bar{x}, \bar{y} \in \{[0,14],[15,29],[30,34],[35,39],\ldots,[90,94],[95,\infty)\}$ which we use for the years $t = 2016,\ldots,2021$, see [18]. We ignore again migration issues.

Denote by f_m the estimated proportion of deaths in month m, $m = 1,\ldots,12$. I.e., we distribute $d_{\bar{x},t}$ onto the monthly number of deaths $d_{\bar{x},t,m}$ via

$$f_{\bar{x},m} = \frac{1}{4}\sum_{t=2016}^{2019} \frac{d_{\bar{x},t,m}}{d_{\bar{x},t}}, \quad \sum_{m=1}^{12} f_{\bar{x},m} = 1,$$

where we modify the formula slightly to take into account that 2016 was a leap year. We list the obtained estimates in the supplement, Section 8.3. Then we distribute the expected number of deaths for year $t = 2020, 2021, 2022$ according to the factors $f_{\bar{x},m}$ and $f_{\bar{y},m}$ and obtain the approximation

$$\mathbb{E}D_{\bar{x},t,m} = f_{\bar{x},m}\mathbb{E}D_{\bar{x},t}, \quad \mathbb{E}D_{\bar{y},t,m} = f_{\bar{y},m}\mathbb{E}D_{\bar{y},t},$$

for the expected number of deaths in month m. For $\bar{a}$ a suitable interval in $[0, \infty)$ consistent with the age groups defined by the Federal Statistical Office of Germany, we set

$$\mathbb{E}D_{\bar{a},2021,m} = \sum_{\bar{x}\subset\bar{a}} \mathbb{E}D_{\bar{x},t,m} + \sum_{\bar{y}\subset\bar{a}} \mathbb{E}D_{\bar{y},t,m}.$$

Again, for 2020 we take into account that this is a leap year with one additional day in February. These expected values should be compared to the observed data $d_{\bar{a},t,m}$ for $m = 1, \ldots, 12$. The remarks made at the end of Section 2.1 apply similarly to the computations made in this section.

5.2 Results

Following the computations described in the previous section, we calculate the expected number of deaths $\mathbb{E}D_{\bar{a},2021,m}$ for all months $m = 1, \ldots, 12$ in the years $t = 2020, 2021, 2022$. We emphasize that the observed number of deaths is the currently available data set of the Federal Statistical Office of Germany and for the years 2021 and 2022 it is still preliminary. We concentrate in this section on four age ranges $\bar{a} = [0, 14]$, $[15, 59]$, $[60, \infty)$ and $[80, \infty)$.

To compare the expected and the observed values, we again use the relative difference

$$\frac{d_{\bar{a},2021,m} - \mathbb{E}D_{\bar{a},2021,m}}{\mathbb{E}D_{\bar{a},2021,m}}$$

and show our results in Fig. 8.

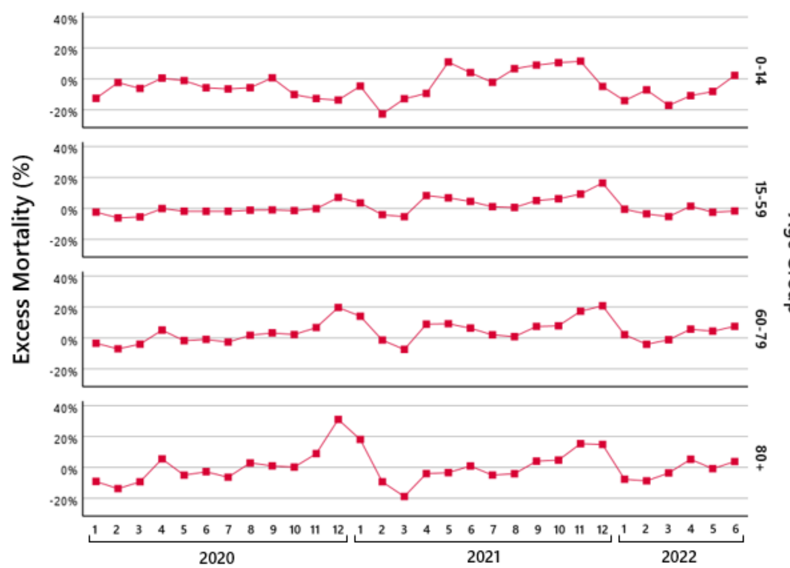

Fig. 8: Development of the monthly excess mortality. For four age groups the red squares show the monthly excess mortality from January 2020 to June 2022.

5.2.1 Children

In the the age group $[0, 14]$ the number of deaths is (luckily) very small and dominated by the relatively large infant mortality in the first year of life. The expected number of deaths in a month is approximately 300, and hence in the binomial model – which as we know from the investigations in Section 4 heavily under-estimates the standard deviation – we would already expect oscillations at least of the order

$$2\sigma(D_{[0,14],t,m}) \geq 2\sqrt{D_{[0,14],t,m}} \approx 35.$$

Yet such deviations already lead to an excess mortality of more than 10%. The graph in Fig. 8 and the table in the supplement, Section 8.4, with the calculated values show in fact oscillations of this size. Hence we think that any conclusion relying on these numbers has to be taken with great care. The maybe only notable results are first the well accepted fact that children are extremely robust with respect to SARS-CoV-2-infections and the curve seems to be independent of the usual SARS-CoV-2-infection waves. Second, the presumably different social behavior during the Corona crises seems to lead to a mortality deficit in the younger age groups which is visible here. An exception are the months May to November 2021 with a visible positive excess mortality for half a year.

5.2.2 Adults

The age group $[15, 59]$ is the largest group we discuss in this section with approximately 7.000 expected deaths per month. For this age group we list the results in detail. Using the binomial model, deviations from the expected value in the range of twice the standard deviation are to be expected, which is of order 170 deaths or 2,4% relative difference. Some of the deviations listed in the following table are clearly beyond this threshold, yet the remarks made in Section 4, that the standard deviation is underestimated by the binomial model, should be kept in mind.

Table 5: Expected deaths and monthly excess mortality.

	$t = 2020$		$t = 2021$		$t = 2022$	
	expected observed	rel.diff.	expected observed	rel.diff.	expected observed	rel.diff.
m=1	7.575 7.395	-2,38%	7.455 7.717	3,52%	7.309 7.270	-0,53%
m=2	7.257 6.811	-6,14%	6.896 6.615	-4,07%	6.761 6.523	-3,52%
m=3	7.703 7.280	-5,49%	7.583 7.175	-5,38%	7.435 7.039	-5,33%
m=4	6.969 6.960	-0,13%	6.860 7.429	8,30%	6.727 6.823	1,43%
m=5	7.025 6.898	-1,81%	6.915 7.385	6,80%	6.781 6.613	-2,47%
m=6	6.792 6.664	-1,89%	6.684 6.987	4,53%	6.554 6.444	-1,67%
m=7	6.946 6.816	-1,88%	6.838 6.912	1,08%	6.706 –	–
m=8	6.887 6.807	-1,16%	6.779 6.819	0,60%	6.647 –	–
m=9	6.593 6.528	-0,99%	6.489 6.820	5,09%	6.363 –	–
m=10	6.941 6.841	-1,45%	6.833 7.258	6,22%	6.700 –	–
m=11	6.833 6.818	-0,22%	6.728 7.351	9,27%	6.598 –	–
m=12	7.034 7.532	7,08%	6.926 8.064	16,43%	6.793 –	–

Whereas the numbers in year 2020 are mostly unremarkable, and reflect the minimal number of deaths by the first COVID-19 wave in April 2020 and a serious excess mortality in December 2020 in this age range, something unexpected is happening in 2021 and 2022.

The significant excess mortality in December 2020 continues slightly in January 2021 and then is mostly compensated until March 2021. That is, by the end of March, the cumulative excess mortality was close to zero. In April and May 2021, a significant increase in excess mortality is observed, followed by a decrease up to August. However, other than at the beginning of the year, excess mortality remains above zero so that the increase in excess mortality in April and May is not compensated for. In September there is again a significant excess mortality, which increases in November and is more than doubled in December 2021.

In 2022 the results are inconspicuous with a maybe notable mortality deficit in March. Note that the numbers in 2022 are from the most current data set of the Federal Statistical Office of Germany, this is still preliminary and in particular in these months there will still be changes within the next weeks and months.

5.2.3 Old ages

The last group consists of the ages ≥ 60, where large parts of the vulnerable population belong to, and a SARS-CoV-2-infection can be particularly dangerous. We list the expected deaths, the observed deaths and the relative difference in the supplement, Section 8.6.

That this age group largely belongs to the vulnerable population is clearly visible in the data for 2020. Fig. 8 shows for the age group $[60, 79]$ and $[80, \infty)$ a decent peak for April 2020, and a significant peak around December 2020. The peak of December 2020 continues in January 2021, but then turns into a mortality deficit until April 2021, where suddenly the downwards trend stops. In September and October we see a decent, and in November and December 2021 again a serious excess mortality. The year 2022 starts with a mortality deficit which again in April turns into an excess mortality. Although the trend in both age groups looks parallel, it is interesting to split this age group into the two groups $[60, 79]$ and $[80, \infty)$ and point our the differences.

The curve for the age group $[80, \infty)$ in Fig. 8 is below and somehow parallel to the curve for the age group $[60, 79]$. The main difference is the deviation of the age group $[60, 79]$ in April and May 2021 where a jump in the mortality behaviour for the this age group is visible. The expected number of deaths, the observed deaths and the difference are given in the supplement, Section 8.7 and Section 8.8.

The age group $[80, \infty)$ beyond the expected life time in Germany (which is approximately at the age of 80), seems to be somehow resistant to all mortality causes at a larger scale. At certain moments some people die some months before or after the 'expected' time of death, but the curve for the excess mortality always oscillates around the 0% axes. A visible mortality deficit at the beginning of 2020 is nearly compensated in April 2020, the huge peak at the turn of the year 2020/2021 is more or less compensated by the mortality deficit in January to July 2020 and then in February to August 2021, the peak around November and December 2021 is nearly compensated in February to March 2022.

It is interesting to make this shift visible by calculating the cumulative excess mortality since January 2020 in absolute numbers. Maybe due to the non-existing flue in 2019 and 2020 we start with a negative value. In July 2020 up to 20.000 people more than expected are still alive, which is compensated in December 2020 to February 2021, where the curve is 10.000 above the expectation, and then the curve fluctuates to -10.000, to $+10.000$ and back to 0 which is the expectation. This shows that a mortality deficit or a excess mortality in the age group $[80, \infty)$ just shifts the time of death by some months.

This is in extreme contrast to the situation for the age group $[60, 79]$. The cumulative excess mortality is increasing up to 30.000 deaths at the end of year 2022, a result we have not seen before in any publication and we find worth noting!

The difference between both age groups is demonstrated in Fig. 9.

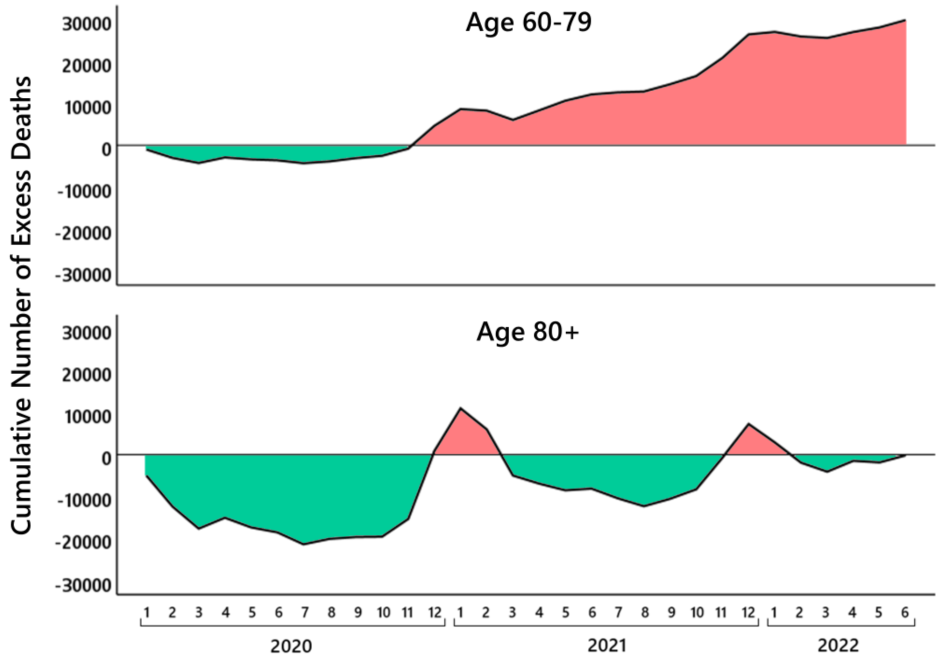

Fig. 9: The cumulative excess mortality. The green areas show the regions of a cumulative mortality deficit, the red areas of a cumulative excess mortality from January 2020 to June 2022. The age group $[80, \infty)$ is oscillating, the age group $[60, 79]$ nearly monotone increasing.

5.3 Stillbirths in the years 2019 to 2022 in Germany

In all previous studies on excess mortality during the COVID-19 pandemic, only the increase in mortality for the age groups 0 and above has been examined. In the following, it is examined whether similar increases in mortality than that found for the age groups 0 and above are also found at the level of stillbirths.

One problem with analyzing excess mortality at the level of stillbirths in Germany is that the definition of a 'stillbirth' has been changed at the end of 2018. Until then, a stillborn child was considered a stillbirth if a birth weight of at least 500 grams was reached. Since the end of 2018, a stillborn child is considered a stillbirth if at least 500 grams or the 24th week of pregnancy was reached, which led to a diagnostically related increase in stillbirths. This means that the figures on stillbirths are only validly comparable from 2019 onwards.

Furthermore, when analyzing the number of stillbirths [19], it is important to note that they must be placed in relation to the number of total births [20], because an increase or decrease in the number of total births is automatically accompanied by an increase or decrease in stillbirths. Fig. 10 shows the number of live births per quarter since 2019 in the upper panel, the number of stillbirths in the middle panel, and the number of stillbirths per 1000 births in the lower panel.

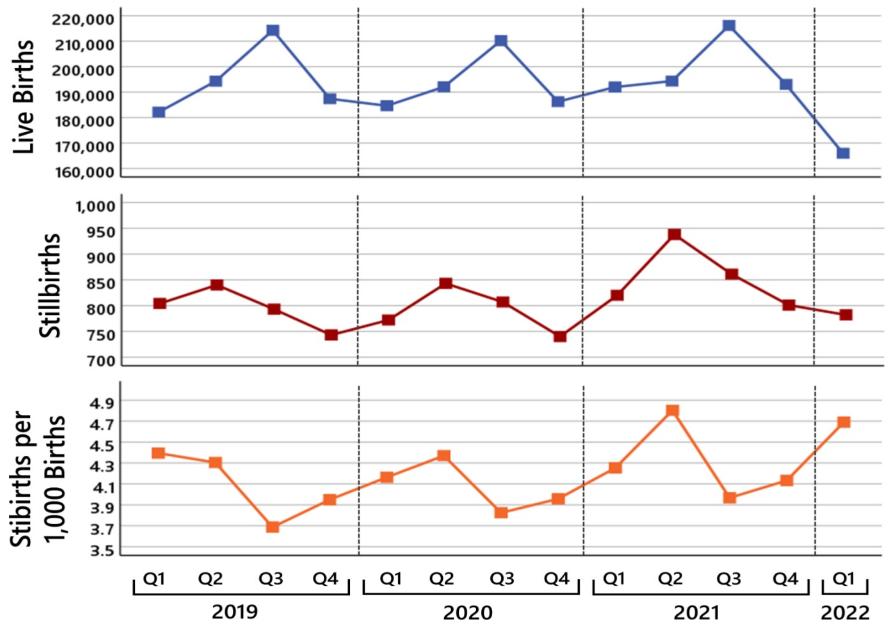

Fig. 10: Monthly stillbirths in the years 2020 to 2022 in Germany. The upper panel shows the number of live births per quarter since 2019, the middle panel the number of stillbirths per quarter since 2019, and the lower panel the number of stillbirths per 1000 births per quarter since 2019.

As can be seen, regarding the number of live births, a relatively large decrease of 10.1 percent is observed in the first quarter of 2022 compared to the mean across the first quarters in the years 2019 to 2021. Regarding the number of stillbirths per 1000 births, the year 2020 is comparable to the year 2019. However, in the year 2021, a sudden increase of 10.7 percents is observed in the second quarter of the year 2021 compared to the mean across the years 2019 and 2020. The number of stillbirts remains increased in the following quarters, reaching an increase of 9.9 percent in the first quarter of 2022.

Taken together, these findings indicate that a simiar increases in mortality than that found for the age groups 0 and above are also found at the level of stillbirths. Whereas in the year 2020 no noticable excess mortality at the level of stillbirths is observed, in the year 2021, starting in April, a striking excess mortality is observed.

6 Discussion

In the previous sections we estimated the expected number of all-cause deaths and the increase in all-cause mortality for the pandemic years 2020 to 2022 in Germany. The results revealed several previously unknown mortality dynamics that require a reassessment of the mortality burden brought about by the COVID-19 pandemic.

The analysis of the yearly excess mortality showed a marked difference between the pandemic years 2020 and 2021. Whereas in the year 2020 the observed number of deaths was extremely close to the expected number with respect to the empirical standard deviation, in 2021, the observed number of deaths was far above the expected number in the order of twice the empirical standard deviation. An age-dependent analysis showed that the strong excess mortality observed in 2021 was almost entirely due to an above-average increase in deaths in the age groups between 15 and 79, reaching more than nine percent in the age group 40-49. A detailed analysis of the monthly excess mortality showed that the high excess mortality observed in the age groups between 15 and 79 in the year 2021 started to accumulate only from April 2021 onwards.

An analysis of the number of stillbirths revealed a similar mortality pattern than observed for the age group between 15 and 79 years. Whereas in 2020 the number of stillbirths per 1,000 births was similar than in the year before, an increase of about 11 percent was observed in the second quarter of the year 2021 compared to the previous years.

Taken together, these findings raise the question what happened in 2021 that led to a sudden and sustained increase in mortality in April in the age groups below 80 years and to a sudden and sustained increase in the number of stillbirths, although no such effects on mortality had been observed during the COVID pandemic so far. In the following sections, possible explanatory factors are explored.

6.1 Possible factors influencing mortality

As already mentioned, apart from the population structure the number of deaths in a year depends on several different factors, the most important being maybe the severity of the flue, and the number of extremely hot weeks. The fluctuations between different years, and thus the approximation of the empirical standard deviation $\hat{\sigma}(D_t)$ in Section 4, includes all these factors. It is unclear, rather subjective, and most probably impossible to precisely define 'extreme events', to calculate the influence of such extreme events and to adjust mortality to 'entirely normal' years. Thus our calculations gives the expected number of deaths taking into account all these extreme and non-extreme effects which are contained in the different life tables. We tried to quantify the sensitivity of our approach in Section 3 and Section 4 against the background of extreme events in the last years.

For the pandemic years 2020 and 2021, it is clear that the number of deaths has been influenced directly and indirectly by COVID-19. First, clearly there has been a serious number of COVID-19 deaths, either as the only reason for death or in combination with several other causes, which also might have caused death independently of COVID-19, see e.g. the discussion in Section 5.2.3 and in the forthcoming Section 6.2. Second, the vaccination campaign which started in 2021 should be visible in a reduced excess mortality, or even better as a mortality deficit. An attempt to compare our results to the number of vaccinations is the content of Section 6.3.

Third, the indirect effects on mortality due to the COVID-19 measures are extremely harder to quantify. Several aspects may contribute to an excess mortality or a mortality deficit. In Germany strict control measures since 2020 limited personal freedom, schools were partially closed, there were severe lockdowns. This substantially influenced the risk of road accidents and other outdoors casualties. On the other hand many clinical services have been delayed or avoided in 2020 and 2021. All these and many more factors influenced mortality in different directions and on different time scales, but most of them are hard to measure, many effects are highly correlated, and it seems to be impossible to quantify the overall impact of the control measures on the number of deaths. Hence we decided not to discuss this issue.

6.2 COVID-19 deaths and mortality

In this section we compare the excess mortality since March 2020 to the observed and reported number of COVID-19 deaths by the German Robert Koch Institute. The Robert Koch Institute provides the number of COVID-19 deaths [21] for the age groups $[0, 9]$, $[10, 19]$, ... Because the Federal Statistical Office of Germany uses different age groups, direct comparisons are made impossible, e.g. for the age group $[20, 59]$. Therefore we compare the number of COVID-19 deaths of the age group $[20, 59]$ to the mortality of the age group $[15, 59]$ and assume that the number of COVID-19 deaths in the group $[15, 19]$ can be neglected. Even when the reporting system in Germany seems to be imprecise and partially insufficient, there should be a serious correlation between the reported number of deaths and the excess mortality. We show the development of the number of reported COVID-19 deaths and the excess mortality in Fig. 11.

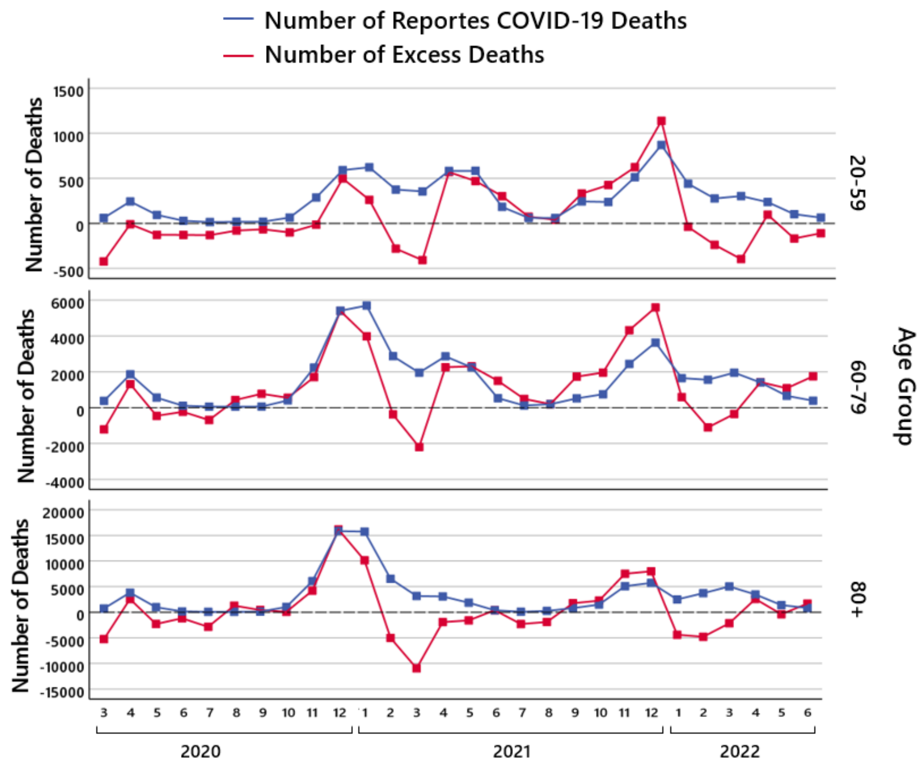

Fig. 11: COVID-19 deaths versus excess mortality. The blue squares show the number of reported COVID-19 deaths, the red squares the mortality deficit, respectively the excess mortality from January 2020 to June 2022 in three different age groups.

The age group $[20, 59]$ starts with a mortality deficit until November 2020, although the number of COVID-19 deaths is positive. In December 2020 both numbers coincide. After that, the number of COVID-19 deaths stays on a high level while mortality decreases and a noticeable mortality deficit occurs until summer 2021. In April, a marked increase in excess mortality is observed that is not accomponied by a comparable increase in COVID-19 deaths. From June 2021 onwards, the number of excess deaths stays above the number of COVID-19 deaths, until both curves decouple in January 2022.

A similar picture occurs for the age group $[60, 79]$ with more distinct deviations between both curves. One difference to the age group $[80, \infty)$ is that in the older age group the peak in April 2021 is nearly invisible: there is no increase in COVID-19 deaths despite a marked increase in the excess mortality curve.

It is elucidating to compare the cumulative number of COVID-19 deaths to the cumulative number of excess deaths in Fig. 12. In all age groups, the cumulative number of reported COVID-19 deaths is increasingly higher than the cumulative number of excess deaths. In the age group between 20 and 59 years, of the approximately 7.500 COVID-19 deaths reported until the end of June 2022, approximately 5.500, did not show up as excess deaths. In the age group between 60 and 79 years, of the approximately 42.000 COVID-19 deaths reported until the end of June 2022, approximately 10.000 did not show up as excess deaths. The strongest divergence is found in the age group over 80 years, where of the approximately 90.000 COVID-19 deaths reported until the end of June 2022 approximately 78.000 did not show up as excess deaths. Taken together, of the 140.000 reported COVID-19 deaths in the agre groups over 20 years, more than 93.000 did not show up as excess deaths and are thus contained in the 'expected' number of deaths.

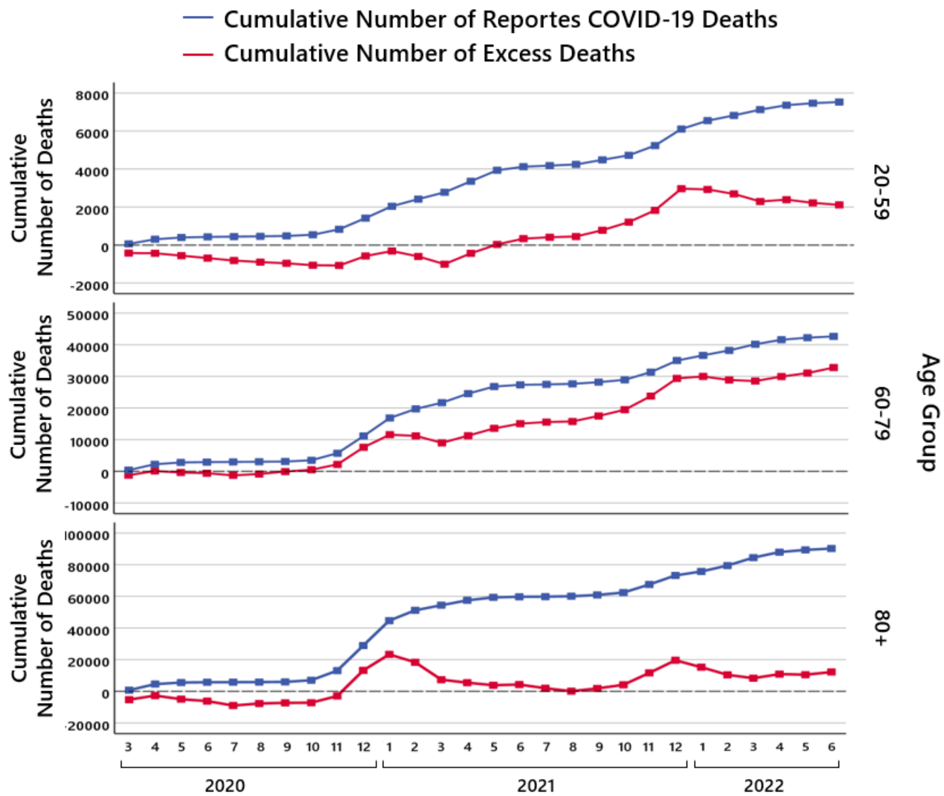

Fig. 12: Cumulative COVID-19 deaths versus cumulative excess mortality. For three different age groups the blue squares show the cumulative number of reported COVID-19 deaths, the blue squares the cumulative mortality deficit, respectively the excess mortality in three different age groups from March 2020 to June 2022.

It thus is obvious that the number of reported COVID-19 deaths contains a large number of 'expected' deaths and it seems to be misleading to measure the risk of the COVID-19 pandemic just using the reported deaths. One should rather use the excess mortality curve than the number of reported COVID-19 deaths, or a combination of both, to carve out the moments of high risk and to evaluate the total risk of a pandemic.

Beyond the problem that the number of reported COVID-19 deaths cannot be validly used to assess the effects of the COVID-19 pandemic on mortality, it seems also unlikely that the high excess mortality in 2021 in the age groups under 80 years can be explained by COVID-19 deaths, because the marked increases in excess mortality in April to June 2021 - the mortality increases abruptly by 13% from March to April 2021 in the age group between 15 and 59 - and also in October to December 2021 were not accomponied by comparable increased in the number of COVID-19 deaths. Furthermore, it seems also very unlikely that the abrupt increase of the mortality is due to delayed or avoided clinical services, which should lead to much smoother changes, or due to side effects of COVID-19 measures. Thus, it remains to investigate the factors which could lead to the surprising jumps in excess mortality in April to June 2021 and also in October and November 2021.

6.3 COVID-19 vaccination and mortality

In April 2021 an extensive vaccination campaign started in Germany. Comparing the number of vaccinations [22] to the excess mortality should show the sum of two effects of the vaccination: on the one hand a decreasing excess mortality because of successful immunisation, and on the other hand an increasing mortality if the vaccinations would cause side effects in the form of deaths.

The following Fig. 13 shows on the left scale the number of excess deaths, respectively death deficit, and on the right scale the number of vaccinations.

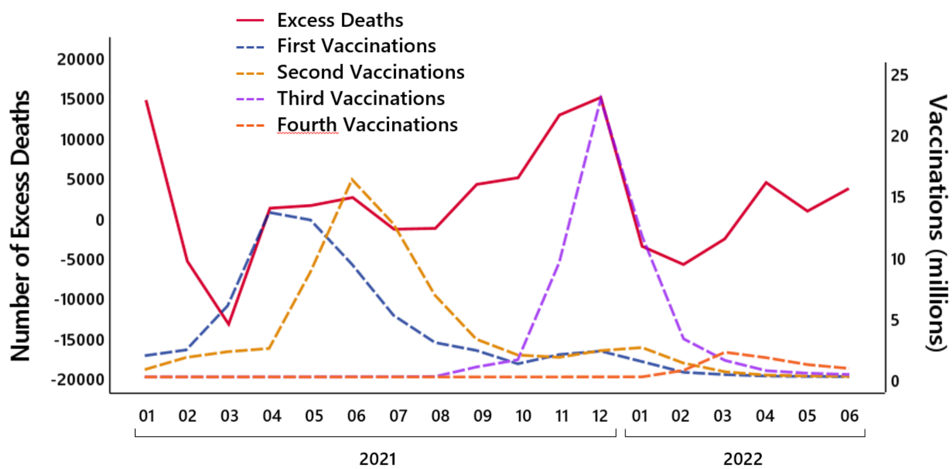

Fig. 13: Number of vaccinations versus excess mortality. The red line shows the death deficit, respectively the excess deaths, the four dashed lines the number of vaccinations from January 2021 to June 2022.

The figure shows that the strong increase in mortality in April 2021 and the further development of the excess deaths covaries with the strong increase of the number of vaccinations. Furthermore, the peaks of the excess mortality nearly coincides with the peaks of the vaccination campaign. Such a strong covariation suggests that the increase in excess mortality might be related to the increase in vaccinations. Since covariation does not neccessarily imply causation, further studies are needed to investigate this assumption. However, a further hint that vaccinations may indeed have increased mortality in the negative is the fact that the age group $[0, 29]$ has a peak in the excess mortality in June 2021 instead of April 2021, see the table and the graph in the supplement, Section 8.5. Data of the Robert Koch Institute show that for this age group the peak in the vaccination campaign is in fact only in June 2021.

Because we computed excess mortality in monthly intervals, it is possible to compare the excess mortality in the months April 2020 to March 2021, where vaccination for the population was not available, to the second year of Corona April 2021 to March 2022, where large groups of the population have been vaccinated. We show in the following table the excess mortality in this time periods for four age groups.

Table 6: Expected deaths and excess mortality 04/20–03/22.

	04/20–03/21			04/21–03/22		
age range	exp. obs.	abs.diff.	rel.diff.	exp. obs.	abs.diff.	rel.diff.
0-14	3.519 3.238	-281	-7,98%	3.514 3.492	-22	-0,64%
15-59	83.954 83.371	-583	-0,69%	82.556 85.857	3.301	4,00%
60-79	313.125 323.349	10.224	3,27%	308.066 327.576	19.510	6,33%
80-∞	581.040 593.678	12.638	2,18%	598.103 599.021	918	0,15%
0-∞	981.638 1.003.636	21.998	2,24%	992.239 1.015.946	23.707	2,39%

The maybe most surprising fact is that the second year produces in all age groups a significant mortality *increase*, which is in sharp contrast to the expectation that the vaccination should decrease the number of COVID-19 deaths. The only exception is the last age group $[80, \infty)$, where in the first year a large number of excess deaths was observed. However, when interpreting this finding, it has to be taken into account that there was a huge mortality deficit from 2019 and until October 2020 which was compensated in November, December 2020 and January 2021. This effect could not occur a second time within one year. Even if for the age group $[80, \infty)$ the strong mortality decrease would be a direct effect of the vaccination, we doubt whether this would justify the vaccination of the whole population independent of age. In total, the decrease of the mortality of people of age ≥ 80 and the increase of mortality of comparatively young people, yields a negative net effect.

The German Paul-Ehrlich-Institut, which is responsible for judging the known and unknown risks with respect to new vaccinations, uses a method for risk-evaluation called "expected vs. observed", but both authors of this contribution have not been able to understand the strange way the method is used by the Paul-Ehrlich-Institut. In the analysis of the Paul-Ehrlich-Institut, the expected number of all-cause deaths in the vaccinated group is compared to the observed number of suspected vaccine-related deaths, instead of the observed number of all-cause deaths. Therefore, since the number of the expected all-cause deaths includes all other (vaccine-independent) causes of deaths such as, for instance, heart diseases, strokes, accidents, such an analysis would only reveal a safety signal if the number of reported suspected vaccine-related deaths is *larger than the total number of all-cause deaths.*

The table above represents how an "expected vs. observed" analysis should be done: the first column gives the number of deaths and the excess mortality in a Corona year without vaccination, the second column shows the number of deaths and the excess mortality in a Corona year with vaccination. One would expect that a vaccination reduces excess mortality and possible negative side-effects are overcompensated by the positive effect of the immunisation. Obviously the contrary happened according to the table above. The numbers are totally surprising and should lead to several more detailed investigations from different scientific fields, to find the sources for this alarming signal.

7 Conclusion

The present study used the state-of-the-art method of actuarial science to estimate the expected number of all-cause deaths and the increase in all-cause mortality for the pandemic years 2020 to 2022 in Germany.

In 2020 the observed number of deaths was extremely close to the expected number, but in 2021 the observed number of deaths was far above the expected number in the order of twice the empirical standard deviation. The analysis of the age-dependent monthly excess mortality showed, that a high excess mortality observed in the age groups between 15 and 79 starting from April 2021 is responsible for the excess mortality in 2021. An analysis of the number of stillbirths revealed a similar mortality pattern than observed for the age group between 15 and 79 years.

As a starting point for further investigations explaining this mortality patterns, we compared the excess mortality to the number of reported COVID-19 deaths and the number of COVID-19 vaccinations. This leads to several open questions, the most important beeing the covariation between the excess mortality and the COVID-19 vaccinations.

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8 Supplementary Material

8.1 Yearly Mortality Excess

In Section 2.2 we have stated the total expected number of deaths $\mathbb{E}D_t$ in 2020–2022 only for certain age groups, in the following table we list the detailed expected number of deaths $\mathbb{E}D_{x,t}$ for males and $\mathbb{E}D_{y,t}$ for females and for each age x, y separately.

age	$\mathbb{E}D_{x,2020}$	$\mathbb{E}D_{y,2020}$	$\mathbb{E}D_{x,2021}$	$\mathbb{E}D_{y,2021}$	$\mathbb{E}D_{x,2022}$	$\mathbb{E}D_{y,2022}$
0	1051	837	1053	838	1051	837
1	411	330	403	322	408	327
2	70	56	68	54	67	53
3	50	41	49	40	49	39
4	43	37	43	37	42	37
5	38	34	39	34	39	35
6	35	29	35	29	36	30
7	32	24	32	24	33	24
8	29	21	29	21	30	21
9	29	19	29	19	29	19
10	29	22	28	21	28	21
11	29	26	28	26	28	26
12	31	29	31	28	30	28
13	37	31	37	31	37	30
14	49	35	48	35	49	35
15	65	43	64	42	64	42
16	85	49	83	48	82	47
17	112	53	110	52	108	51
18	146	62	140	60	138	59
19	171	68	162	65	158	64
20	185	72	175	69	168	66
21	191	73	185	70	178	69
22	198	73	190	70	186	69
23	207	76	202	74	197	71
24	215	80	216	80	214	79
25	218	82	217	82	221	83
26	221	86	215	84	217	84
27	232	98	226	95	222	93
28	251	113	243	109	239	107
29	281	136	263	127	257	124

age	$\mathbb{E}D_{x,2020}$	$\mathbb{E}D_{y,2020}$	$\mathbb{E}D_{x,2021}$	$\mathbb{E}D_{y,2021}$	$\mathbb{E}D_{x,2022}$	$\mathbb{E}D_{y,2022}$
30	313	159	301	153	283	143
31	342	173	338	170	326	164
32	373	181	370	180	368	178
33	396	191	401	192	400	192
34	400	208	408	210	416	213
35	415	224	420	226	430	230
36	463	240	461	238	468	241
37	516	264	507	258	508	257
38	553	298	547	294	540	288
39	589	327	587	324	583	319
40	634	338	643	343	643	341
41	677	354	691	363	704	369
42	714	389	715	391	733	401
43	761	424	765	426	768	429
44	825	457	835	464	842	468
45	911	512	907	510	921	519
46	1020	577	1002	565	1000	566
47	1185	667	1119	633	1101	622
48	1432	815	1296	742	1226	706
49	1686	969	1565	902	1419	824
50	1981	1136	1851	1068	1722	997
51	2346	1334	2188	1250	2048	1178
52	2725	1519	2602	1452	2431	1363
53	3142	1719	3026	1657	2896	1587
54	3572	1932	3477	1887	3355	1823
55	4027	2174	3934	2126	3837	2080
56	4500	2426	4432	2385	4338	2336
57	4867	2614	4917	2631	4851	2592
58	5216	2799	5287	2821	5353	2847
59	5601	3009	5678	3039	5768	3070
60	5967	3229	6074	3287	6169	3327
61	6275	3395	6460	3496	6588	3566
62	6605	3551	6780	3639	6991	3756
63	6991	3784	7081	3818	7280	3921
64	7305	4009	7438	4053	7541	4097
65	7615	4256	7734	4271	7880	4325
66	7923	4519	8039	4539	8168	4564

age	$\mathbb{E}D_{x,2020}$	$\mathbb{E}D_{y,2020}$	$\mathbb{E}D_{x,2021}$	$\mathbb{E}D_{y,2021}$	$\mathbb{E}D_{x,2022}$	$\mathbb{E}D_{y,2022}$	
67	8321	4819	8324	4810	8449	4839	
68	8767	5190	8694	5159	8700	5154	
69	9254	5657	9147	5614	9079	5590	
70	9731	6065	9673	6072	9571	6038	
71	9780	6144	10155	6440	10098	6458	
72	9640	6194	10183	6552	10582	6879	
73	9276	6133	10055	6621	10635	7015	
74	8621	5867	9697	6532	10528	7064	
75	10089	7013	8972	6208	10108	6923	
76	12388	8682	10482	7408	9333	6560	
77	13162	9438	12930	9297	10965	7951	
78	15407	11605	13810	10284	13590	10141	
79	18457	14696	16206	12756	14551	11313	
80	20017	16839	19386	16175	17062	14053	
81	20467	18190	21048	18632	20434	17918	
82	20225	19066	21459	20099	22110	20602	
83	20114	20102	21052	20796	22377	21961	
84	20104	21285	20790	21697	21806	22506	899
85	19414	21854	20524	22790	21299	23292	
86	16879	20329	19502	23152	20686	24195	
87	14702	19213	16687	21203	19333	24195	
88	14305	20118	14286	19596	16274	21718	
89	13939	21297	13524	20135	13539	19632	
90	12811	21495	12710	20897	12381	19758	
91	11210	20458	11421	20568	11357	20012	
92	9394	18809	9797	19013	9982	19172	
93	7378	16790	7937	16852	8243	17080	
94	5678	14855	6000	14498	6427	14573	
95	4077	12447	4461	12477	4696	12182	
96	2841	9845	3118	10055	3380	10057	
97	2086	7628	2116	7584	2284	7723	
98	1509	5910	1502	5676	1495	5643	
99	1057	4389	1062	4296	1046	4087	
100	1085	4294	1236	4835	1368	5108	
≥ 101	646	2497	805	2970	929	3393	
total	488.440	493.117	494.269	495.439	500.190	498.355	

8.2 Mortality prediction using different life tables

In the following table we list the expected number of deaths for certain age groups using the life tables 2015/17, 2016/18, 2017/19 of the Federal Statistical Office of Germany and half the longevity factors of the DAV.

age range $\bar{a}$	expected 2015/17	expected 2016/18	expected 2017/19	observed $d_{\bar{a},2020}$
0-14	3.565	3.585	3.531	3.306
15-29	4.070	3.996	3.944	3.844
30-39	6.718	6.655	6.626	6.668
40-49	15.673	15.557	15.345	15.507
50-59	60.494	59.796	58.641	57.331
60-69	116.457	117.236	117.432	118.460
70-79	197.146	197.428	198.389	201.957
80-89	387.256	382.712	378.459	378.406
90-∞	198.585	199.056	199.191	200.093
total 0-∞	989.964	986.021	981.557	985.572

age range $\bar{a}$	expected 2015/17	expected 2016/18	expected 2017/19	observed $d_{\bar{a},2021}$
0-14	3.538	3.559	3.513	3.490
15-29	3.938	3.866	3.817	3.951
30-39	6.677	6.614	6.585	6.938
40-49	15.190	15.081	14.877	16.256
50-59	59.526	58.844	57.705	59.387
60-69	117.481	118.264	118.456	126.477
70-79	188.917	189.319	190.335	204.089
80-89	401.711	396.993	392.535	396.990
90-∞	201.236	201.753	201.884	203.852
total 0-∞	998213	994294	989.707	1.021.430

8.3 Monthly expected mortality: allocation factors

We list the estimated proportion of deaths in month m and different age ranges $\bar{x}, \bar{y}$. The first table lists the results $f_{\bar{x},m}$ for the male population, the second $f_{\bar{y},m}$ for the female population.

$\bar{x} \diagdown m$	1	2	3	4	5	6	7	8	9	10	11	12
0-15	8,9	7,9	9,3	8,3	7,7	8,3	8,7	8,6	7,7	8,2	8,2	8,3
15-30	8,9	7,8	8,3	7,9	8,6	8,6	9,1	8,7	8,0	8,2	8,0	7,9
30-35	9,2	8,1	9,0	8,7	8,3	8,2	8,9	8,4	7,4	8,5	7,9	7,6
35-40	7,9	8,0	9,0	7,9	9,0	8,1	8,2	8,7	8,0	8,2	8,2	8,8
40-45	8,9	8,4	9,1	8,0	8,6	8,1	8,5	8,5	7,9	7,7	8,3	8,1
45-50	9,3	8,4	9,1	8,5	8,3	8,3	8,4	8,2	7,8	8,0	7,8	7,9
50-55	9,1	8,6	9,2	8,3	8,4	8,1	8,0	8,2	7,8	8,3	8,0	8,2
55-60	9,0	8,4	9,3	8,5	8,2	8,0	8,2	8,0	7,7	8,3	8,1	8,3
60-65	9,1	8,5	9,1	8,2	8,2	8,0	8,2	8,2	7,5	8,2	8,2	8,6
65-70	8,9	8,4	9,2	8,1	8,3	7,7	8,2	8,3	7,7	8,3	8,2	8,7
70-75	9,2	8,9	9,5	8,3	8,1	7,7	8,1	8,0	7,5	8,1	8,0	8,7
75-80	9,3	8,9	9,7	8,3	8,1	7,7	7,9	7,8	7,4	8,0	8,1	8,7
80-85	9,2	8,8	9,5	8,1	8,1	7,5	7,8	7,8	7,5	8,2	8,4	9,1
85-90	9,4	9,2	9,7	8,1	8,0	7,4	7,8	7,7	7,3	8,1	8,2	9,1
90-95	9,6	9,1	9,7	8,1	7,8	7,3	7,6	7,5	7,3	8,2	8,5	9,4
95-∞	9,7	9,0	9,9	8,0	7,8	7,3	7,5	7,4	7,1	8,2	8,6	9,5

$\bar{y} \diagdown m$	1	2	3	4	5	6	7	8	9	10	11	12
0-15	8,7	8,7	9,7	8,0	8,2	8,3	8,1	7,8	8,0	8,2	7,3	9,0
15-30	8,8	8,6	8,7	7,9	8,6	7,6	8,1	8,7	8,5	8,1	8,1	8,4
30-35	8,5	7,6	8,9	8,3	8,4	8,5	7,9	8,8	8,8	7,8	7,7	8,8
35-40	8,1	7,7	8,6	8,5	8,9	8,3	8,0	8,0	7,8	8,6	8,9	8,6
40-45	9,1	8,7	9,2	8,0	8,3	8,0	8,0	8,0	7,8	8,6	8,0	8,5
45-50	9,2	8,4	9,4	8,2	8,2	7,9	8,1	8,0	8,1	8,3	7,9	8,3
50-55	8,9	8,4	9,0	8,1	8,3	8,1	8,3	8,1	7,9	8,3	8,1	8,5
55-60	8,9	8,4	9,0	8,1	8,2	7,9	8,3	8,1	7,8	8,2	8,3	8,8
60-65	8,9	8,5	9,5	8,2	8,3	7,9	8,1	8,1	7,6	8,1	8,1	8,7
65-70	8,9	8,6	9,3	8,0	8,2	7,6	8,2	8,1	7,8	8,1	8,2	8,8
70-75	9,2	9,0	9,6	8,4	8,1	7,5	8,0	7,8	7,6	8,1	8,0	8,7
75-80	9,3	9,0	9,7	8,3	8,0	7,6	7,9	7,9	7,5	8,0	8,1	8,7
80-85	9,1	8,9	9,7	8,0	8,0	7,5	7,9	8,0	7,5	8,1	8,3	9,0
85-90	9,6	9,2	10,0	8,2	7,9	7,3	7,8	7,8	7,4	7,9	8,1	8,8
90-95	9,7	9,5	10,0	8,1	7,9	7,3	7,8	7,7	7,2	7,9	8,1	8,9
95-∞	9,5	9,3	10,0	8,0	7,8	7,2	7,7	7,8	7,3	8,1	8,3	9,1

8.4 Monthly development: age group 0-14

We list the total expected monthly number of deaths $\mathbb{E}D_{\bar{a},t,m}$ for children, $\bar{a} = [0, 14]$, the observed number of deaths and the relative difference.

	$t = 2020$		$t = 2021$		$t = 2022$	
	expected observed	rel.diff.	expected observed	rel.diff.	expected observed	rel.diff.
m=1	311 272	-12,60%	311 296	-4,68%	311 267	-14,11%
m=2	298 291	-2,37%	287 222	-22,70%	287 267	-7,13%
m=3	334 313	-6,16%	333 290	-12,88%	333 276	-17,17%
m=4	288 289	0,50%	287 260	-9,39%	287 256	-10,88%
m=5	280 277	-1,09%	279 310	10,92%	280 257	-8,14%
m=6	292 275	-5,77%	291 303	4,05%	292 298	2,22%
m=7	297 278	-6,51%	297 290	-2,27%	297 –	–
m=8	290 273	-5,71%	289 308	6,60%	289 –	–
m=9	275 277	0,69%	275 299	8,92%	275 –	–
m=10	289 260	-10,14%	289 319	10,49%	289 –	–
m=11	275 240	-12,76%	275 306	11,46%	275 –	–
m=12	302 261	-13,69%	302 287	-4,89%	302 –	–

8.5 Monthly development: age groups 0-29 and 30-79

We list the total expected monthly number of deaths $\mathbb{E}D_{\bar{a},t,m}$ for the younger population $\bar{a} = [0, 29]$ and the age group $[30, 79]$, the observed number of deaths and the relative difference.

	$t = 2020$		$t = 2021$		$t = 2022$	
$\bar{a} = [0, 29]$	expected observed	rel.diff.	expected observed	rel.diff.	expected observed	rel.diff.
m=1	659 601	-8,80%	648 587	-9,42%	643 611	-4,97%
m=2	623 621	-0,32%	592 498	-15,83%	587 564	-3,92%
m=3	666 633	-5,00%	656 585	-10,79%	651 637	-2,14%
m=4	598 577	-3,58%	589 593	0,74%	584 559	-4,30%
m=5	619 588	-5,05%	609 638	4,82%	604 595	-1,43%
m=6	618 604	-2,26%	608 690	13,53%	603 589	-2,32%
m=7	644 613	-4,80%	633 652	2,99%	628 –	–
m=8	631 630	-0,12%	620 620	-0,02%	615 –	–
m=9	596 582	-2,34%	586 642	9,58%	581 –	–
m=10	609 580	-4,81%	599 681	13,64%	595 –	–
m=11	592 549	-7,27%	582 625	7,36%	577 –	–
m=12	619 572	-7,60%	609 630	3,43%	604 –	–

	$t = 2020$		$t = 2021$		$t = 2022$	
$\bar{a} = [30, 79]$	expected observed	rel.diff.	expected observed	rel.diff.	expected observed	rel.diff.
m=1	36.117 34.971	-3,17%	35.422 39.736	12,18%	35.040 35.608	1,62%
m=2	34.364 32.850	-4,41%	33.914 32.816	-3,24%	33.341 31.751	-4,77%
m=3	37.276 35.668	-4,31%	36.777 34.007	-7,53%	36.157 35.395	-2,11%
m=4	32.644 33.986	4,11%	32.244 34.852	8,09%	31.695 33.234	4,85%
m=5	32.327 31.788	-1,67%	31.963 34.533	8,04%	31.403 32.331	2,96%
m=6	30.641 30.295	-1,13%	30.302 31.825	5,03%	29.756 31.440	5,66%
m=7	31.959 31.164	-2,49%	31.628 31.943	1,00%	31.068 –	–
m=8	31.698 32.045	1,10%	31.353 31.405	0,17%	30.803 –	–
m=9	30.054 30.791	2,45%	29.719 31.556	6,18%	29.200 –	–
m=10	32.155 32.622	1,45%	31.782 33.920	6,73%	31.237 –	–
m=11	32.007 33.720	5,35%	31.624 36.366	14,99%	31.081 –	–
m=12	34.107 40.023	17,35%	33.681 40.188	19,32%	33.123 –	–

We visualize the different trends of the excess mortality, respectively mortality deficit in Fig. 14 for the two age groups.

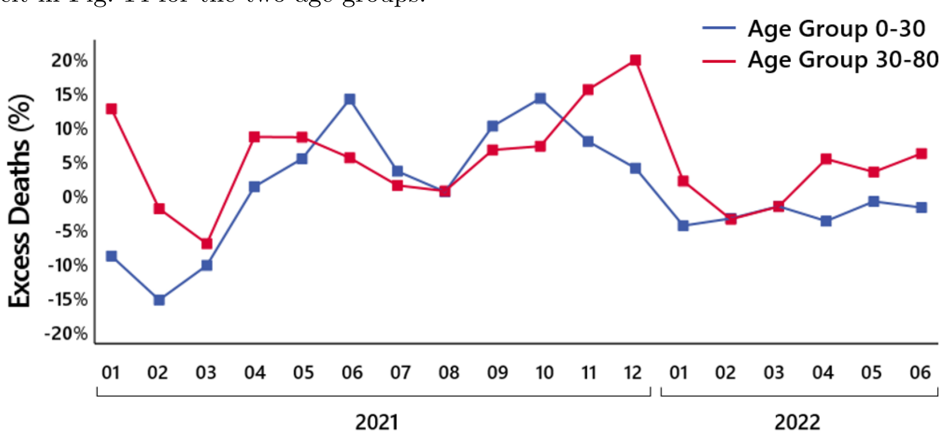

Fig. 14: Development of the monthly excess mortality. The blue squares show the monthly excess mortality for the age group $[0, 29]$, the red squares the monthly excess mortality for the age group $[30, 79]$ from January 2020 to June 2022.

8.6 Monthly development: age group 60+

We list the total expected monthly number of deaths $\mathbb{E}D_{\bar{a},t,m}$ for the elderly population, $\bar{a} = [60, \infty)$, the observed number of deaths and the relative difference.

	$t = 2020$		$t = 2021$		$t = 2022$	
	expected observed	rel.diff.	expected observed	rel.diff.	expected observed	rel.diff.
m=1	83.255 77.313	-7,14%	84.439 98.566	16,73%	85.435 81.643	-4,44%
m=2	82.343 72.928	-11,43%	80.638 75.253	-6,68%	81.586 75.698	-7,22%
m=3	86.268 79.803	-7,49%	87.482 74.336	-15,03%	88.498 86.003	-2,82%
m=4	72.682 76.581	5,36%	73.693 74.028	0,46%	74.540 78.557	5,39%
m=5	71.408 68.660	-3,85%	72.405 73.123	0,99%	73.236 73.941	0,96%
m=6	66.626 65.220	-2,11%	67.539 69.441	2,82%	68.300 71.736	5,03%
m=7	70.238 66.701	-5,04%	71.222 69.411	-2,54%	72.040 –	–
m=8	69.932 71.662	2,47%	70.907 69.213	-2,39%	71.717 –	–
m=9	66.232 67.438	1,82%	67.158 70.655	5,21%	67.925 –	–
m=10	72.050 72.680	0,87%	73.076 77.300	5,78%	73.919 –	–
m=11	73.002 78.931	8,12%	74.052 85.904	16,00%	74.911 –	–
m=12	79.435 100.999	27,15%	80.598 94.178	16,85%	81.548 –	–

8.7 Monthly development: age group 60-79

We list the total expected monthly number of deaths $\mathbb{E}D_{\bar{a},t,m}$ for the population between age 60 and 79, $\bar{a} = [60, \infty)$, the observed number of deaths and the relative difference.

	$t = 2020$		$t = 2021$		$t = 2022$	
	expected observed	rel.diff.	expected observed	rel.diff.	expected observed	rel.diff.
m=1	28.904 27.905	-3,46%	28.330 32.310	14,05%	28.089 28.682	2,11%
m=2	28.374 26.369	-7,07%	26.853 26.477	-1,40%	26.623 25.525	-4,13%
m=3	29.920 28.708	-4,05%	29.319 27.127	-7,48%	29.065 28.717	-1,20%
m=4	25.999 27.314	5,06%	25.497 27.756	8,86%	25.289 26.714	5,63%
m=5	25.654 25.201	-1,77%	25.168 27.476	9,17%	24.969 26.056	4,35%
m=6	24.187 23.960	-0,94%	23.725 25.225	6,32%	23.536 25.287	7,44%
m=7	25.372 24.683	-2,72%	24.905 25.393	1,96%	24.715 –	–
m=8	25.164 25.595	1,71%	24.695 24.898	0,82%	24.504 –	–
m=9	23.793 24.568	3,26%	23.347 25.079	7,42%	23.165 –	–
m=10	25.547 26.101	2,17%	25.064 27.024	7,82%	24.866 –	–
m=11	25.504 27.211	6,69%	25.012 29.334	17,28%	24.808 –	–
m=12	27.404 32.802	19,70%	26.876 32.467	20,80%	26.657 –	–

8.8 Monthly development: age group 80+

We list the total expected monthly number of deaths $\mathbb{E}D_{\bar{a},t,m}$ for the population above the age of the average life expectancy, $\bar{a} = [80, \infty)$, the observed number of deaths and the relative difference.

	$t = 2020$		$t = 2021$		$t = 2022$	
	expected observed	rel.diff.	expected observed	rel.diff.	expected observed	rel.diff.
m=1	54.351 49.408	-9,10%	56.109 66.256	18,08%	57.347 52.961	-7,65%
m=2	53.969 46.559	-13,73%	53.786 48.776	-9,31%	54.963 50.173	-8,71%
m=3	56.348 51.095	-9,32%	58.163 47.209	-18,83%	59.433 57.286	-3,61%
m=4	46.684 49.267	5,53%	48.195 46.272	-3,99%	49.250 51.843	5,26%
m=5	45.753 43.459	-5,01%	47.237 45.647	-3,37%	48.267 47.885	-0,79%
m=6	42.439 41.260	-2,78%	43.814 44.216	0,92%	44.764 46.449	3,76%
m=7	44.866 42.018	-6,35%	46.318 44.018	-4,96%	47.325 –	–
m=8	44.767 46.067	2,90%	46.212 44.315	-4,10%	47.213 –	–
m=9	42.438 42.870	1,02%	43.811 45.576	4,03%	44.761 –	–
m=10	46.503 46.579	0,16%	48.012 50.276	4,72%	49.053 –	–
m=11	47.499 51.720	8,89%	49.040 56.570	15,35%	50.103 –	–
m=12	52.032 68.197	31,07%	53.722 61.711	14,87%	54.891 –	–