Original Article

The COVID-19 Disease Burden in Germany in 2020

Years of Life Lost to Death and Disease over the Course of the Pandemic

Alexander Rommel, Elena von der Lippe, Dietrich Plass, Thomas Ziese, Michaela Diercke, Matthias an der Heiden, Sebastian Haller, Annelene Wengler on behalf of the BURDEN 2020 Study Group

Summary

Background: The SARS-CoV-2 pandemic presented major challenges to the health sector in 2020. The burden of disease arising from COVID-19 can be expressed as the number of years of life lost to disease or death. For example, death at age 40 involves a loss of far more years of life than death at age 80.

Methods: The disability-adjusted life years (DALY) lost to COVID-19 were calculated as the sum of the years of life lost through death (YLL) and the number of years lived with disability (YLD), on the basis of laboratory-confirmed notifiable cases of SARS-CoV-2 infection in Germany in 2020 (documented as of 18 January 2021). The methodology was based on that used in the Global Burden of Disease Study. Pre-existing diseases do not enter into the determination of YLL; rather, the residual life expectancy that is applied in this calculation corresponds to a mean age-specific level of morbidity.

Results: 305 641 years of life were lost to COVID-19 in Germany in 2020. The percentage of DALY lost by persons under 70 was 34.8% in men and 21.0% in women. 99.3% of the COVID-19 disease burden was accounted for by death (YLL). The daily average years of life lost due to death was lower for COVID-19 than for the major non-communicable diseases. Persons who died of COVID-19 lost a mean of 9.6 years of life; those who were under 70 when they died lost a mean of 25.2 years of life. Men lost more years of life than women (11.0 vs. 8.1 years).

Conclusion: The effects of COVID-19 on public health can be expressed through the burden of disease indicators. This method yields additional information that should be put to use early in the course of future outbreaks.

Cite this as:
Rommel A, von der Lippe E, Plass D, Ziese T, Diercke M, an der Heiden M, Haller S, Wengler A, on behalf of the BURDEN 2020 Study Group:
The COVID-19 disease burden in Germany in 2020—years of life lost to death and disease over the course of the pandemic. Dtsch Arztebl Int 2021; 118.
DOI: 10.3238/arztebl.m2021.0147 (online first).

Department 2, Epidemiology and Health Monitoring, Robert Koch Institute, Berlin: Dr. rer. med. Alexander Rommel, Dr. rer. pol. Elena von der Lippe, Dr. med. Thomas Ziese, Dr. rer. pol. Annelene Wengler

Department 3, Infectious Disease Epidemiology, Robert Koch Institute, Berlin: Michaela Diercke M.Sc., Dr. rer. nat. Matthias an der Heiden, Dr. med. Sebastian Haller

Department II 1 Environmental Hygiene, German Environment Agency, Berlin: Dr. PH Dietrich Plass

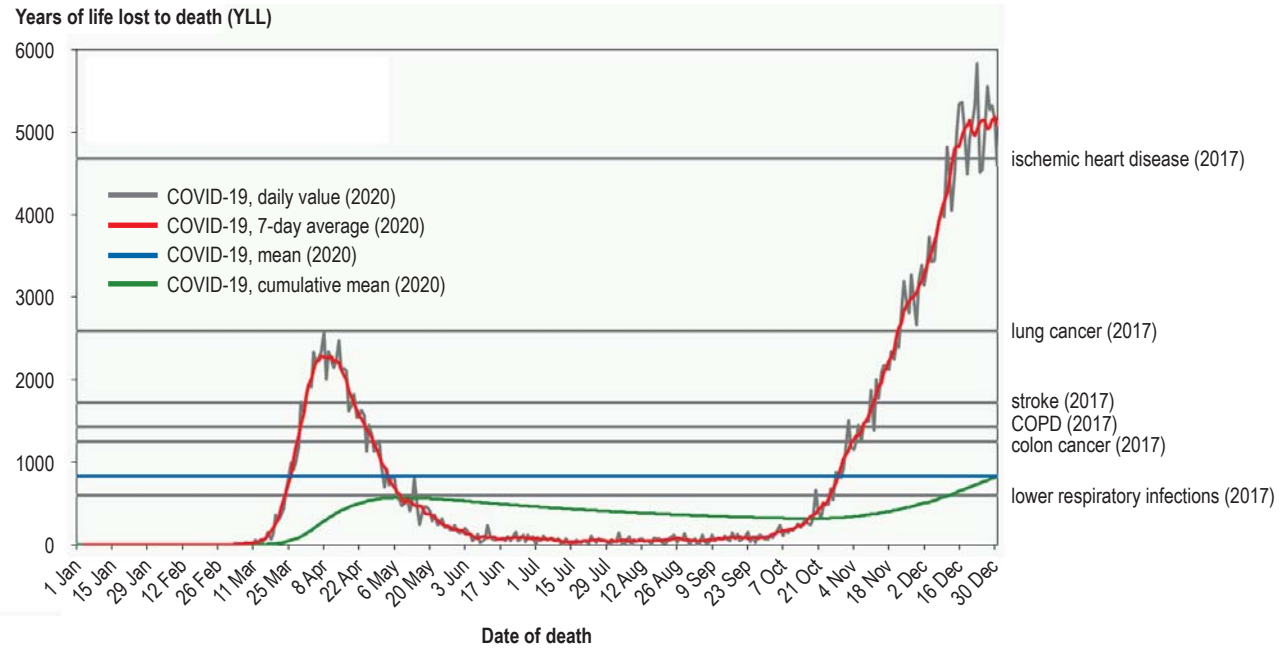
In 2020, living conditions around the world were markedly affected by the coronavirus SARS-CoV-2 and the disease it causes, COVID-19, as well as by the measures taken to contain it. The spread of the infection and of the resulting cases of severe disease and death had slowed down considerably by mid-year, only to come back with renewed force and severity in the autumn and winter months (1). Reliable information is essential so that the disease can be controlled and the risk for the population assessed. In addition to statistics on incidence, hospitalizations, and mortality, indicators of the burden of disease also need to be considered, as they summarize the impact of disease-related morbidity and mortality on population health (2, 3).

The goal of the research described in this article is to estimate the years of life lost to COVID-19 in Germany, with the aid of three indicators. The first of these is the years of life lost owing to death from the disease ("years of life lost," YLL). YLL is a more comprehensive measure of the impact of a disease on population health than number of deaths, as death at a younger age involves the loss of more years of life that would otherwise have been left to live. The second indicator, "years lived with disability" (YLD), reflects the number of years of life in which the affected individuals suffer impaired health (morbidity) because of the disease; the manner in which YLD is calculated takes both the severity and the duration of the disease into account, so that this indicator reflects the impact of morbidity on population health more accurately than raw case numbers alone. The third indicator, "disability-adjusted life years" (DALY), is the sum of the first two. In the Methods and Results sections of this article, the three indicators—YLL, YLD, and DALY—will be addressed in that order.

Method

To calculate the disease burden, all laboratory-confirmed cases of SARS-CoV-2 in the year 2020 that had been reported to the Robert Koch Institute by 18 January 2021 were analyzed *(eMethods 1)*. The definition of cases required documentation of the date of reporting and death (if applicable), the patient's age and sex, and whether COVID-19 was one of the main causes of death (if the patient died) (4). Usually, there is a delay of two

FIGURE 1



The trend, over time, of years of life lost (YLL) among persons with COVID-19 in Germany (daily values and daily averages, 2020) and YLL due to selected other causes of death (daily averages, 2017)

Sources: data reported in 2020 as required by the Infection Protection Act (data as of 18 January 2021); other diseases – cause-of-death statistics, 2017, life tables 2016/2018; authors' own calculations

COPD, chronic obstructive pulmonary disease

to three weeks in the reporting of SARS-CoV-2 cases, as well as in the documentation of clinical or vital outcomes. With regard to the latter, the data for 2020 are nearly complete. The calculation of the COVID-19 disease burden was based on previous work done in the project BURDEN 2020—The Burden of Disease in Germany at the National and Regional Level (5).

Years of life lost to death (YLL)

The number of years of life lost to death (YLL) is calculated as the sum of the statistical residual life expectancy (in years) of all deceased persons. The resulting YLL are attributed to the underlying causes of death. Pre-existing conditions in COVID-19 deceased are not taken into account in this calculation *(eMethods 2 and 3)*. The analysis is based on the fatalities among the reported cases of SARS-CoV-2 *(eFigures 1 and 2)*. To avoid overestimating the YLL, only fatalities for which COVID-19 was notified as one of the underlying causes of death are included *(eMethods 1)*. The YLL due to other diseases, based on cause-of-death statistics from 2017 (the reporting year for the BURDEN 2020 study), were used to assess the relative contribution of COVID-19 to overall mortality. These reference diseases considered here were the five types of non-communicable disease (NCD) that caused the greatest YLL – ischemic heart disease; cancer of the trachea, bronchi, and lungs (in brief: lung cancer), stroke, chronic obstructive pulmonary disease (in brief: COPD), and colon and rectum cancer (in brief: colon cancer) – and, in addition, lower respiratory infections *(eMethods 2)*. Absolute figures, YLL per 100 000 inhabitants, and average values per capita are presented. To capture the dynamics of the COVID-19 pandemic over time, the YLL was plotted day by day and as 7-day and cumulative averages. For comparison, daily averages were displayed for COVID-19 (2020) and for the other diseases (2017). The seasonality of lower respiratory tract infections in particular is thus levelled out.

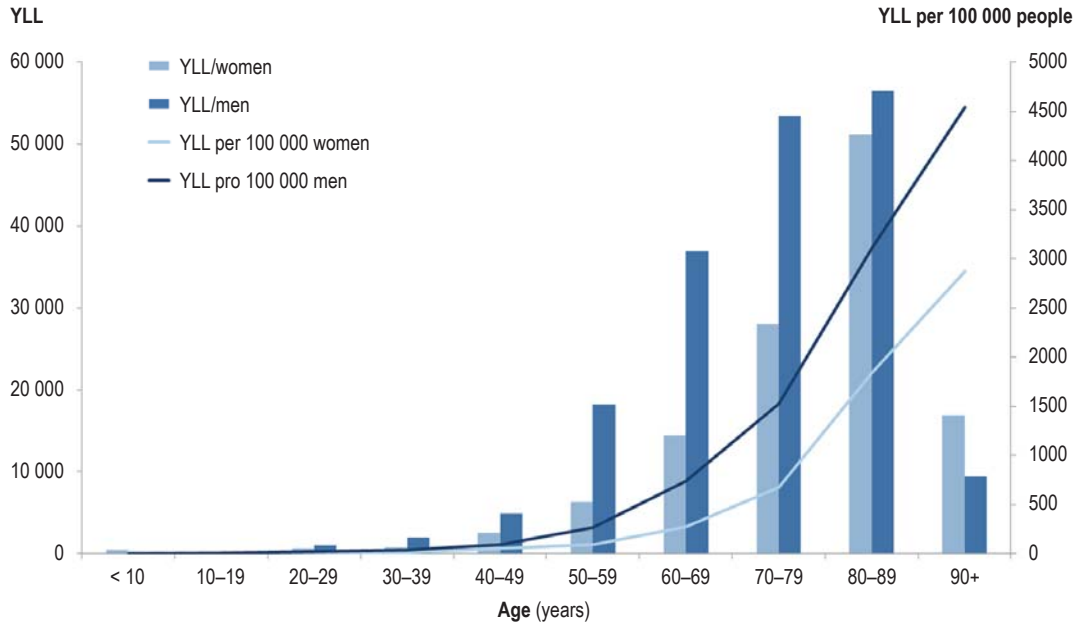
Years lived with disability (YLD) and overall burden of disease (DALY)

Four parameters serve as the basis for the calculation of the number of years lived with disability (YLD) in persons with acute COVID-19 *(eMethods 2)*:

- incident cases (SARS-CoV-2 infections excluding fatalities) *(eMethods 1)*
- severity distribution, classified as asymptomatic, mild, moderate, severe, or very severe disease course *(eFigure 3, eTable 1)*
- severity-specific weighting factors (disability weight): asymptomatic, 0; mild, 0.006; moderate, 0.051; severe, 0.133; and very severe/critical 0.655) *(eTable 1)*; and
- the severity-specific duration of illness *(eTable 1)*.

Potential late sequelae of COVID-19 are not considered. The summary measure DALY composed of

FIGURE 2



Years of life lost (YLL) among persons with COVID-19 in Germany in 2020 by age and sex
(absolute figures and per 100 000 people)
Sources: data reported in 2020 as required by the Infection Protection Act (data as of 18 January 2021); life tables 2016/2018; authors' own calculations

YLL and YLD is presented in absolute and relative figuresby age, sex, and geographical region.

Sensitivity analyses

A sensitivity analysis was conducted to determine the excess mortality due to the pandemic and the degree to which the YLL from COVID-19 reflected a real increase in disease burden *(eBox)*. Analyzing excess mortality in this manner also enables a comparison of the COVID-19 pandemic with earlier influenza waves. The reported case numbers and mortality figures for influenza are, in fact, marked underestimates, as influenza is generally diagnosed on clinical grounds alone and need only be reported to the authorities when the pathogen has been positively identified (6). It follows that it is difficult to make direct comparisons based on data from these sources. Another sensitivity analysis was used to assess the dependency of the YLD calculations on changes in the duration of illness.

Results

Underlying data

1 748 644 cases of laboratory-confirmed SARS-CoV-2 in the year 2020 had been reported to the Robert Koch Institute by 18 January 2021; the data elements used in the present analysis included the date of reporting and of death (in fatal cases), the age and sex of the patient, the severity of the disease, and the vital outcome *(eMethods 1, eFigures 1 and 2)*. The patients included 920 277 women (52.6%) and 828,367 men (47.4%). There was a total of 38,641 fatalities, with COVID-19 reported as the cause of death in 31 638 (81.9%). Of the patients who died, 52.6% were men, and 89.0% were at least 70 years old.

Years of life lost to death (YLL)

A total of 303 608 years of life were lost to death from COVID-19 in Germany in 2020, of which 121 114 (39.9%) were lost by women and 182 494 (60.1%) by men. On average, each patient who died lost 9.6 years of life; women lost fewer years of life than men (8.1 vs. 11.0). The YLL per day had reached approximately 2300 by 8 April 2020, stayed at approximately that level until 17 April, and then sank to a very low level from late April onward, only to rise again in October *(Figure 1)*. Assuming negligible seasonal variation in mortality caused by NCD, it can be inferred from the cause-of-death statistics that the number of YLL due to COVID-19 was, for a few days, higher than the number of daily average YLL caused in 2017 by the main types of NCD and by lower respiratory infections *(Figure 1, red line)*. The cumulative averages suggest that, by December 2020, the burden of disease owing to deaths from COVID-19 had returned to a level below the daily averages from 2017 for these reference diseases (*Figure 1*, green line). From December onward, the

TABLE

Reported cases (infections, deaths) and disease burden due to COVID-19 (YLL, YLD, DALY), by age group and sex*1

		Women				Men			
		All ages	< 70 *2	< 50 *2	< 30 *2	All ages	< 70 *2	< 50 *2	< 30 *2
Mortality									
Deaths	absolute	14 984	974	95	16	16 654	2517	184	20
	%	100%	6.5 %	0.6 %	0.1 %	100%	15.1%	1.1%	0.1%
YLL	absolute	121 114	24 966	4286	1046	182 494	63 086	7986	1183
	%	100%	20.6%	3.5%	0.9%	100%	34.6%	4.4%	0.6%
Morbidity									
Infections	absolute	905 293	764 432	528 391	258 508	811 713	727 945	507 533	260 049
	%	100%	84.4%	58.4%	28.6%	100%	89.7%	62.5%	32.0%
YLD	absolute	1005	726	433	185	1028	768	409	170
	%	100%	72.2%	43.1%	18.4%	100%	74.8%	39.8%	16.5%
Mortality and morbidity									
All infections	absolute	920 277	765 406	528 486	258 524	828 367	730 462	507 717	260 069
	%	100%	83.2%	57.4%	28.1%	100%	88.2%	61.3%	31.4%
DALY	absolute	122 119	25 692	4719	1231	183 522	63 854	8395	1353
	%	100%	21.0%	3.9%	1.0%	100%	34.8%	4.6%	0.7%

*1 Sources: data reported in 2020 as required by the Infection Protection Act (data as of 18 January 2021), life tables 2016/2018; authors' own calculations
*2 In years; age categories overlap and do not add up to 100%. For example, the category < 50 is included in the category < 70.
DALY, disability-adjusted life years; YLD, years lived with disability; YLL, years of life lost

cumulative average YLL due to COVID-19, and thus also the average YLL for the entire year (blue line), exceeded the YLL for lower respiratory infections from 2017, but was still below the YLL for the main types of NCD.

Among persons with COVID-19, the number of YLL due to the disease rose at first with advancing age. Men, except for those aged 90 and above, displayed a markedly larger absolute loss of years of life to COVID-19 than women. The YLL was markedly lower, in absolute terms, in persons of both sexes aged 90 and above, but it continued to rise with age in relative terms *(Figure 2)*.

Reflecting the greater residual life expectancy in persons who died at a younger age, a considerable portion of the YLL due to COVID-19 in 2020 was accounted for by persons under age 70: 20.6% in women and 34.6% in men. These persons lost an average of 25.2 years of life *(Table)*.

The sensitivity analysis reveals an estimated excess mortality from late February to early April 2020 (on the heels of the 2019/2020 influenza wave), and from late October 2020 onward *(eFigure 4)*, particularly among persons aged 70 and above *(eFigure 5)*. Between these two periods, the observed mortality was similar to the expected course of mortality, except for excess mortality owing to a heat wave in August 2020. Compared to previous years, the excess mortality in the spring of 2020 was approximately at the level of the 2019 influenza wave, and the excess mortality in the autumn of 2020 approximately at the level of the 2017/2018 influenza waves *(eFigure 6)*. The reported deaths from COVID-19 and the calculated excess mortality generally agreed closely; yet, in times of especially increased mortality — in calendar weeks 14 and 15 (30 March - 13 April) and from calendar week 49 (30 November - 6 December) onward — the excess mortality exceeded the reported deaths from COVID-19 *(eFigure 4)*.

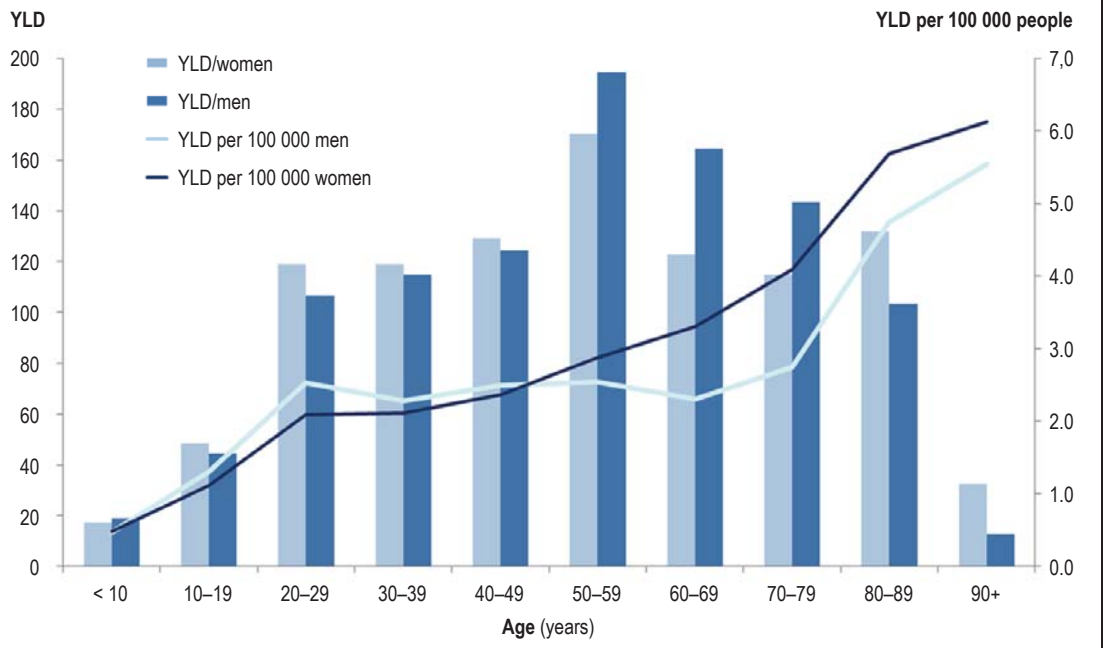
Years of life lived with disability (YLD)

Persons who contracted COVID-19 in Germany in 2020 but did not die lost a total of 2033 years of life due to impaired health. Women suffered slightly fewer YLD than men (1005 vs. 1028). The number of YLD rose with age, then declined again in advanced age *(Figure 3)*. Persons aged 50 to 59 were the most severely affected. These results reflect the age distribution of the reported cases *(eFigure 1)*. Accordingly, in both men and women, more than 70% of YLD were accounted for by persons under age 70 *(Table)*.

In relative terms, however, the number of YLD rose steadily with age because of the age-specific severity distribution *(eFigure 3)* and was greatest among persons aged 90 and above *(Figure 3)*. Over the period of observation, 2.45 YLD arose per 100 000 persons. When considered separately for the two sexes, this figure was slightly lower for women than for men (2.39 vs. 2.51 YLD per 100 000 persons).

The sensitivity analyses revealed that the calculated YLD was sensitive to the assumed duration of

FIGURE 3



Years lived with disability (YLD) among persons with COVID-19 in Germany in 2020 by age and sex (absolute figures and per 100 000 people)
Source: data reported in 2020 as required by the Infection Protection Act (data as of 18 January 2021); authors' own calculations

illness. Assuming five days of illness at all levels of severity yielded a figure of 574 YLD (0.69 per 100 000 persons); the corresponding figure for an assumption of 15 days was 1723 YLD (2.08 per 100 000 persons) and, for 28.4 days, as in a study from South Korea (7), 3262 YLD (3.93 per 100 000 persons). Nonetheless, as most of the disease burden due to COVID-19 was accounted for by YLL, rather than YLD, the variability of YLD depending on the assumed duration of illness made little difference to the overall calculated burden of disease (DALY).

The overall burden of disease due to COVID-19 (DALY)

A total of 305 641 years of life were lost by the population of Germany in 2020 because of COVID-19 (DALY; 368.2 per 100 000 persons). 99.3% of the DALY were accounted for by YLL. However, YLD accounted for approximately 40% of DALY among persons with COVID-19 aged 10 to 19, but lessened with age to become less than 1% among persons aged 60 to 69. A considerable portion of the overall DALY was accounted for by persons under age 70 *(Table)*.

The COVID-19 disease burden was higher in western and southern regions of Germany, and lower in the north and northeast. These regional differences persisted after standardization for age *(Figure 4, eFigure 7)*. The disease burden was especially high in areas ("spatial planning regions," *Raumordnungsregionen,* ROR) located in the states of Bavaria and Saxony. This was mainly due to the high case numbers experienced during the first and second waves of infection in Bavaria and Baden-Württemberg, and in the second wave in Saxony.

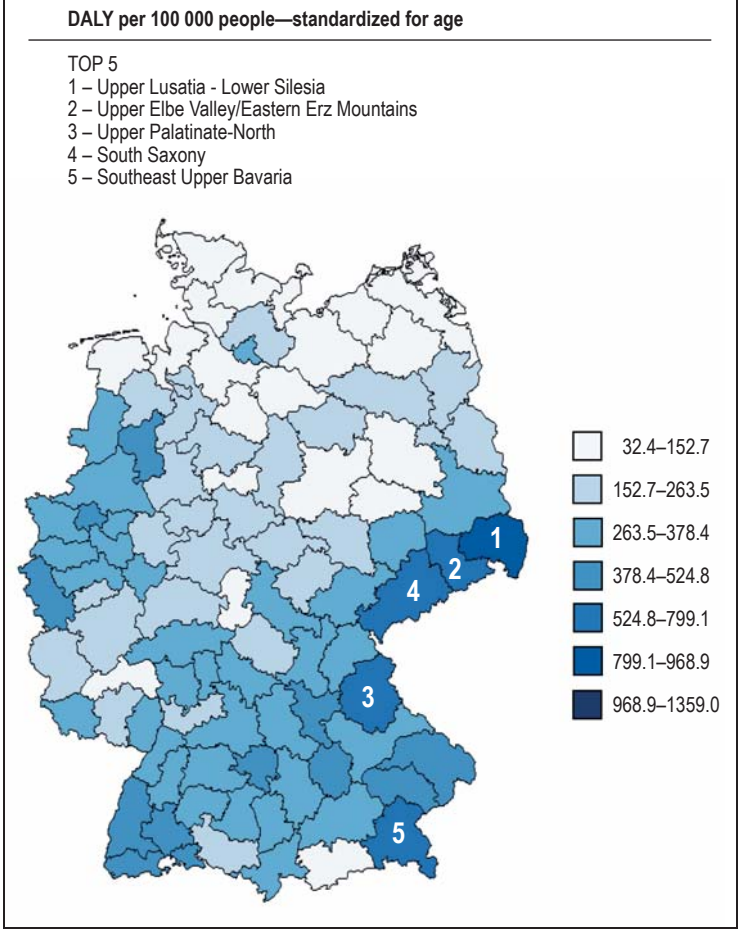
Discussion

An estimated total of 305 641 disability-adjusted life years (DALY) were lost to COVID-19 in Germany in 2020. 99.3% of this disease burden was accounted for by fatal cases (303 608 YLL), and 0.7% by years lived with disability (2033 YLD). The persons who died of COVID-19 lost a mean of approximately 9.6 years of life; more years of life were lost by men than by women (11.0 vs. 8.1 years). The percentage of years of life lost to death among persons under age 70 was 34.6% among men and 20.6% among women.

These differences between the sexes with respect to years of life lost reflect the fact that men died of COVID-19 more frequently than women and were also more likely to die before age 70 (8). This accords with the finding that, although women contract the infection somewhat more commonly, men are more likely to develop severe disease at a younger age (9). As younger persons have a longer residual life expectancy, this results in higher YLL figures for men than for women.

The dynamic temporal course of YLL and its decline over time were determined in part by pandemic control measures and seasonal effects (10). A new, noticeable rise in infections starting in August 2020 made little difference to the overall burden of

FIGURE 4



Overall COVID-19 disease burden (DALY) in Germany in 2020 at the level of the spatial planning regions *(Raumordnungsregionen)*, per 100 000 population; a comparison with a plot based on non-age-standardized data is shown in eFigure 7.
Sources: data reported in 2020 as required by the Infection Protection Act (data as of 18 January 2021), life tables 2016/2018, European standard population 2013; authors' own calculations
DALY, disability-adjusted life years

disease (as measured in DALY) until early October, because it mainly affected younger persons and the percentage of mild disease courses was higher *(Figure 1, eFigures 1 and 3)* (11). The cumulative YLL due to COVID-19 in 2020 was lower than the usual number of years of life lost owing to other major causes of death, but the excess mortality analysis reveals that, by the end of the year, the COVID-19 pandemic in Germany had reached the approximate level of severity of a severe influenza wave.

The above comparison with the YLL due to other diseases in 2017 is, however, only a preliminary attempt to contextualize the COVID-19 disease burden. This manner of presenting the findings smooths out important seasonal variation in lower respiratory infections and also, to a lesser extent, in certain types of non-communicable disease (12). Moreover, persons with COVID-19 can die from multiple causes; the recording of only the main cause of death of the list of underlying causes, as is done in Germany, is problematic (13, 14). However, future analyses based, e.g., on cause-of-death statistics for 2020 will be able to reveal whether COVID-19 was given as the official cause of death in numbers comparable to the reported fatal cases of COVID-19. It will also become possible to determine the extent to which mortality from other causes may have changed, and thus also to determine whether the calculated excess mortality may actually have been affected in the opposite direction by other trends. The restrictions on interpersonal contact, for example, have been found to be associated with lower mortality from traffic accidents (15); meanwhile, a hesitancy to visit hospital emergency rooms may have increased mortality, for instance from cardiovascular diseases (16, 17).

In other studies of the COVID-19 disease burden, the residual life expectancy entering into the calculation of YLL was adjusted for pre-existing conditions (18). In the present study, however, as in the Global Burden of Disease study on which it was based, a disease-independent age-specific residual life expectancy was used for all persons who died at any particular age (19). The mean attainable residual life expectancy thus becomes the benchmark for the years of life lost. This yielded a quantification of the loss of life years that could, ideally, have been avoided by optimal prevention and treatment *(eMethods 3)*.

The high relative contribution of YLL to the COVID-19 disease burden approximately corresponds to the high relative contribution of YLL to the disease burden from lower respiratory infections, according to the Global Burden of Disease study (20). However, the size of YLD is sensitive to the underlying assumptions of the method *(eMethods 3)*. Moreover, due to underreporting the cases analyzed do not represent all actual cases of SARS-CoV-2 infection (3, 21), and the estimation of severity grades is fraught with uncertainty, as, for many patients, a description of symptoms is lacking *(eMethods 1)*. Finally, evidence increasingly suggests that patients' health may be impaired in the long term by hitherto unrecognized late sequelae of COVID-19 (22). Thus, the present study likely underestimates YLD to some extent *(eMethods 3)*. In the near future, seroprevalence studies (23, 24) and clinical research will lead to a more accurate assessment of the frequency, severity-grade distribution, and late sequelae of COVID-19.

The present analysis is the first quantification of the COVID-19 disease burden in Germany. The impact of COVID-19 on population health, considering fatal cases, incident cases, severity grades, and duration of illness over the course of the pandemic, can be summarized in a few indicators and compared with other common diseases. It thereby becomes clear how the uncontrolled spread of the virus can temporarily affect population health. Moreover, the impact of COVID-19 on the health of younger persons, and its different effects in men and women, become clearer than from the number of reported cases alone. Calculating the disease

burden thus yields additional information for the monitoring of current pandemics, which can also be put to use early on in the course of future outbreaks.

Acknowledgement
These analyses are based on joint previous work carried out in theproject BURDEN 2020—The Burden of Disease in Germany at the National and Regional Level by the BURDEN 2020 Study Group: Alexander Rommel, Elena von der Lippe, Annelene Wengler, Michael Porst, Aline Anton, Janko Leddin, Thomas Ziese (Robert Koch Institute), Helmut Schröder, Katrin Schüssel, Gabriela Brückner, Jan Breitkreuz (Scientific Institute of AOK, Dietrich Plass, and Heike Gruhl (German Environment Agency).

Note on funding
These analyses are based in part on previous work of the project BURDEN 2020—The Burden of Disease in Germany at the National and Regional Level. That study was supported by the Innovation Fund of the German Joint Federal Committee (project number 01VSF17007).

Conflict of interest statement
The authors state that they have no conflict of interest.

Manuscript submitted on 6 October 2020, revised version accepted on 3 February 2021.

Translated from the original German by Ethan Taub, M.D.

References

1. Robert Koch-Institut: COVID-19-Dashboard. Auswertungen basierend auf den aus den Gesundheitsämtern gemäss IfSG übermittelten Meldedaten. https://experience.arcgis.com/experience/478220a4c454480e823b17327b2bf1d4 (last accessed on 9 February 2021).
2. Kyu HH, Abate D, Abate KH, et al.: Global, regional, and national disability-adjusted life-years (DALYs) for 359 diseases and injuries and healthy life expectancy (HALE) for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. Lancet 2018; 392: 1859–922.
3. Schilling J, Lehfeld A, Schumacher D, et al.: Krankheitsschwere der ersten COVID-19-Welle in Deutschland basierend auf den Meldungen gemäss Infektionsschutzgesetz. Journal of Health Monitoring 2020; 5: 2–20.
4. Robert Koch-Institut: Coronavirus-Krankheit-2019 (COVID-19) (SARS-CoV-2). Falldefinitionen des Robert Koch-Instituts zur Übermittlung von Erkrankungs- oder Todesfällen und Nachweisen von Krankheitserreger, 2020. www.rki.de/DE/Content/Infekt/IfSG/Falldefinition/falldefinition_node.html;jsessionid=C1B5C767C894C5333B699B89D5C2F16D.internet082 (last accessed on 9 February 2021).
5. Rommel A, von der Lippe E, Plass D, et al.: BURDEN 2020—Burden of disease in Germany at the national and regional level. Bundesgesundheitsbl 2018; 61: 1159–66.
6. Robert Koch-Institut: Verlorene Lebensjahre (YLL).https://diabsurv.rki.de/Webs/Diabsurv/DE/diabetes-in-deutschland/4–37_Verlorene_Lebensjahre_YLL.html (last accessed on 9 February 2021).
7. Jo MW, Go DS, Kim R, et al.: The burden of disease due to COVID-19 in Korea using disability-adjusted life years. J Korean Med Sci 2020; 35: e199.
8. Kremer HJ, Thurner W: Age dependence in Covid-19 mortality in Germany. Dtsch Arztebl Int 2020; 117: 432–3.
9. Sobotka T, Brzozowska Z, Muttarak R, Zeman K, di Lego V: Age, gender and COVID-19 infections. medRxiv 2020.05.24.20111765.
10. Dehning J, Zierenberg J, Spitzner FP, et al.: Inferring change points in the spread of COVID-19 reveals the effectiveness of interventions. Science 2020; 369: eabb9789.
11. Robert Koch-Institut: Täglicher Lagebericht des RKI zur Coronavirus-Krankheit-2019 (COVID-19), 08.09.2020. www.rki.de/DE/Content/InfAZ/N/Neuartiges_Coronavirus/Situationsberichte/Gesamt.html (last accessed on 8 February 2021).
12. Leerhoff H: Gevatter Tod duldet keinen Aufschub. Zeitschrift für amtliche Statistik, Berlin Brandenburg 2020; 3: 56–8.
13. Wengler A, Rommel A, Plass D, et al.: ICD-Codierung von Todesursachen: Herausforderungen bei der Berechnung der Krankheitslast in Deutschland. Bundesgesundheitsbl 2019; 62: 1485–92.
14. Wengler A, Gruhl H, Plass D, Leddin J, Rommel A, von der Lippe E: Redistributing ill-defined causes of death—a case study from the Burden 2020-Project in Germany. Preprint under consideration at Archives of Public Health 2021; 79. www.researchsquare.com/article/rs-117779/v1 (last accessed on 9 February 2021).
15. Statistisches Bundesamt: Pressemitteilung: Strassenverkehrsunfälle im 1. Halbjahr 2020: So wenige Tote und Verletzte wie noch nie seit der deutschen Vereinigung. www.destatis.de/DE/Presse/Pressemitteilungen/2020/08/PD20_320_46241.html (last accessed on 9 February 2021).
16. Slagman A, Behringer W, Greiner F, et al.: Medical emergencies during the COVID-19 pandemic—an analysis of emergency department data in Germany. Dtsch Arztebl Int 2020; 117: 545–52.
17. Dreger H, Bruch L, Maier B, Schühlen H: Acute myocardial infarction admissions in Berlin during the COVID-19 pandemic. Dtsch Arztebl Int 2020; 117: 597–8.
18. Hanlon P, Chadwick F, Shah A, et al.: COVID-19—exploring the implications of long-term condition type and extent of multimorbidity on years of life lost: a modelling study [version 1; peer review: 1 approved, 2 not approved]. Wellcome Open Research 2021; 5: 75. https://wellcomeopenresearch.org/articles/5–75 (last accessed on 9 February 2021).
19. GBD 2017 Causes of Death Collaborators: Global, regional, and national age-sex-specific mortality for 282 causes of death in 195 countries and territories, 1980–2017: a systematic analysis for the Global Burden of Disease Study 2017. Lancet 2018; 392: 1736–88.
20. Institute for Health Metrics and Evaluation: GBD Results Tool. ghdx.healthdata.org/gbd-results-tool?params=gbd-api-2017-permalink/b77b387bc96dedd5df63059253c4912f (last accessed on 9 February 2021).
21. Robert Koch-Institut: Epidemiologischer Steckbrief zu SARS-CoV-2 und COVID-19. www.rki.de/DE/Content/InfAZ/N/Neuartiges_Coronavirus/Steckbrief.html#doc13776792bodyText2 (last accessed on 9 February 2021).
22. Carfì A, Bernabei R, Landi F: Persistent symptoms in patients after acute COVID-19. JAMA 2020; 324: 603–5.
23. Santos-Hövener C, Busch MA, Koschollek C, et al.: Seroepidemiologische Studie zur Verbreitung von SARS-CoV-2 in der Bevölkerung an besonders betroffenen Orten in Deutschland – Studienprotokoll von CORONA-MONITORING lokal. Journal of Health Monitoring 2020; 5: 1–18.
24. Poethko-Müller C, Prütz F, Buttmann-Schweiger N, et al.: Studien zur Seroprävalenz von SARS-CoV-2 in Deutschland und international. Journal of Health Monitoring 2020; 5: 1–-16.
25. Statistisches Bundesamt: Sterbetafeln 2016/2018, nach Bundesländern. Durchschnittliche Lebenserwartung (Periodensterbetafel). www-genesis.destatis.de/genesis/online (last accessed on 9 February 2021).
26. James SL, Abate D, Abate KH, et al.: Global, regional, and national incidence, prevalence, and years lived with disability for 354 diseases and injuries for 195 countries and territories, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. Lancet 2018; 392: 1789–858.
27. Haagsma JA, Maertens de Noordhout C, Polinder S, et al.: Assessing disability weights based on the responses of 30,660 people from four European countries. Popul Health Metr 2015; 13: 10.
28. Salomon JA, Haagsma JA, Davis A, et al.: Disability weights for the Global Burden of Disease 2013 study. Lancet Glob Health 2015; 3: e712–23.
29. Devleesschauwer B, McDonald SA, Speybroeck N, Wyper GMA: Valuing the years of life lost due to COVID-19: the differences and pitfalls. Int J Public Health 2020; 65: 719–20.
30. Mesalles-Naranjo O, Grant I, Wyper GMA, et al.: Trends and inequalities in the burden of mortality in Scotland 2000–2015. PLoS One 2018; 13: e0196906.
31. Oh IH, Ock M, Jang SY, et al.: Years of life lost attributable to COVID-19 in high-incidence countries. J Korean Med Sci 2020; 35: e300.
32. Lenzen-Schulte M: Long COVID: Der lange Schatten von COVID-19. Dtsch Arztebl 2020; 117: A-2416.
33. Destatis: Sterbefälle und Lebenserwartung Sonderauswertung zu Sterbefallzahlen der Jahre 2020/2021. www.destatis.de/DE/Themen/Gesellschaft-Umwelt/Bevoelkerung/Sterbefaelle-Lebenserwartung/sterbefallzahlen.html (last accessed on 9 February 2021).
34. Kanieff M, Rago G, Minelli G, et al.: The potential for a concerted system for the rapid monitoring of excess mortality throughout Europe. Euro Surveill 2010; 15: 19697.
35. Mazick A, Gergonne B, Nielsen J, et al.: Excess mortality among the elderly in 12 European countries, February and March 2012. Euro Surveill 2012; 17: 20138.
36. an der Heiden M, Muthers S, Niemann H, Buchholz U, Grabenhenrich L, Matzarakis A: Heat-related mortality—an analysis of the impact of heatwaves in Germany between 1992 and 2017. Dtsch Arztebl Int 2020; 117: 603–9.
37. an der Heiden M, Muthers S, Niemann H, Buchholz U, Grabenhenrich L, Matzarakis A: Schätzung hitzebedingter Todesfälle in Deutschland zwischen 2001 und 2015. Bundesgesundheitsbl – Gesundheitsforschung – Gesundheitsschutz 2019; 62: 571–9.

Corresponding author
Dr. rer. med. Alexander Rommel
Robert Koch Institute
Abteilung 2, Epidemiologie und Gesundheitsmonitoring
Nordufer 20, 13353 Berlin, Germany
RommelA@rki.de

Cite this as:
Rommel A, von der Lippe E, Plass D, Ziese T, Diercke M, an der Heiden M, Haller S, Wengler A, on behalf of the BURDEN 2020 Study Group: The COVID-19 disease burden in Germany in 2020—years of life lost to death and disease over the course of the pandemic. Dtsch Arztebl Int 2021; 118. DOI: 10.3238/arztebl.m2021.0147

► **Supplementary material**

eMethods, eTables, eFigures, eBox:
www.aerzteblatt-international.de/m2021.0147

Supplementary material to:

The COVID-19 Disease Burden in Germany in 2020

Years of Life Lost to Death and Disease over the Course of the Pandemic

by Alexander Rommel, Elena von der Lippe, Dietrich Plass, Thomas Ziese, Michaela Diercke, Matthias an der Heiden, Sebastian Haller, and Annelene Wengler on behalf of the BURDEN 2020 Study Group

Dtsch Arztebl Int 2021; 118: 145–51. DOI: 10.3238/arztebl.m2021.0147

eMETHODS 1

Underlying data and principles of calculation

According to the German Infection Protection Act, the following are notifiable: any suspected or confirmed case of COVID-19 or death resulting from it, as well as any confirmation of the SARS-CoV-2 pathogen, indicating the presence of an acute infection. COVID-19 cases meeting the definition of the Robert Koch Institute (RKI) must be electronically reported by the responsible local health authority to the responsible federal state authority on the next working day at latest, and by the federal state authority to the RKI on the next working day at latest. The information to be reported includes the confirmation of the pathogen, clinical manifestations (symptoms), risk factors (pre-existing conditions), hospitalization, and death. Medical personnel and health authorities are also required to report any pertinent new information that becomes known in any particular case after the initial report. Delays can arise in the reporting of cases by medical personnel to the local health authority and in the reporting of the information to the federal state authority and the RKI. The validity of the reported data is characterized by the features of notification and surveillance systems in general (3): they rapidly and continuously provide comprehensive information about the pandemic, but this information is derived solely from infected persons who have been in contact with the health care system. Notification systems thus tend to underreport mild cases while counting more severe cases almost completely. This is a negligible problem, in the sense that milder cases hardly enter into the calculation of the burden of disease. It should be borne in mind, however, that treatment in intensive care may be less than fully reported (3). Missing information on clinical manifestations also makes it uncertain whether the available information accurately characterizes the group of reported cases as a whole.

When a person dies related to COVID-19, the reported information must include the dates of reporting and of death, the age and sex of the deceased, and whether COVID-19 or mainly other diseases were the underlying causes of death (4). Only deaths due to COVID-19 were considered in the analyses presented in this article. According to the guidelines for submission of notifiable data, a death due to COVID-19 is one in which COVID-19 is listed as an element of the causal chain in Section I a–c of the death certificate (1). Figures on the reference diseases that were used for comparisons were derived from the cause-of-death statistics for Germany in 2017. Non-informative causes of death were redistributed for the purpose of calculating the burden of disease (13, 14).

As of 18 January 2021, 1 782 798 laboratory-confirmed SARS-CoV-2 cases (uncorrected figure) for the year 2020 had been reported to the Robert Koch Institute. In 13 293 cases (0.7%), the patient's sex was either not given or else stated as "diverse." Information about age was missing in 3874 cases (0.2%), and information about vital status (alive or dead) was missing in 11 285 cases (0.6%). Thus, a total of 34 154 cases with

missing data (1.9%) were excluded from further analysis, yielding a corrected figure of 1 748 644 cases. The numbers of reported cases and reported deaths rose steadily at first, fell in the summer months, and rose again from September onward *(eFigure 1)*. Among all the reported cases, there were 38 641 deaths, 81.9% of which were reported as having been mainly due to COVID-19. 52.6% of these deaths from COVID-19 were in men, and 89.0% of the persons who died were over age 70. In absolute numbers, a COVID-19 infection (not resulting in death) was most common in persons aged 50 to 59, while a large percentage of deaths from COVID-19 were in persons aged 80 to 89 *(eFigure 2)*. 9.1% of those who died had no pre-existing condition; the mean number of pre-existing conditions among those affected was 1.6. Information on pre-existing conditions is highly uncertain, however, as data are lacking up to the present in 49.2% of cases. The distribution of disease severity grades in persons who had COVID-19 but did not die is highly dependent on age: older persons had a worse disease course more commonly than younger ones *(eTable 2)*. The percentage of moderate and severe disease courses tended to decline over time, while that of asymptomatic infections increased *(eFigure 3)*.

eMETHODS 2

Methods of calculation

Years of life lost (YLL)

From the statistical point of view, any person who dies has a mean residual life expectancy at the time of death. In the present study, the residual life expectancy was taken to be the maximum figure for residual life expectancy by age of death in any of the 16 federal states of Germany, according to the life tables of the Federal Statistical Office for 2016/2018 (25). The same residual life expectancy was assumed for men and women. The disease-specific YLL in any particular age group is a function of the number of deaths and the residual life expectancy in that age group:

$$YLL = \sum_{i=0}^{n} d_{i,g} * l_i$$

where i is age in years, $d_{i,g}$ the number of deaths at age i among persons with sex g, and l_i the residual life expectancy at age i.

Years lived with disability (YLD) and overall disease burden (disability-adjusted life years, DALY)

The four severity grades, from asymptomatic to severe, are derived from the reported cases according to the symptom descriptions used in the Global Burden of Disease study for upper and lower respiratory infections and according to the hospitalization status (7, 26) *(eTable 1)*. Approximately half of all the affected persons were characterized as asymptomatic, as they had neither upper nor lower respiratory symptoms. Patients with a mild disease course were those who had, e.g., a sore throat or runny nose; those who also had fever, cough, or pneumonia had a moderate course. The patients who had a severe course were those who had to be hospitalized. Relatively few patients required intensive care; as in the European Disability Weights study, these patients constituted the group with a very severe or critical course, which was specifically additionally defined for COVID-19 (26, 27). The age- and sex-specific distributions of grades of severity entered into the further analysis *(eTable 2)*. The Robert Koch Institute sometimes uses a classification of grades of severity that differs from the above, mainly in the definition of mild cases (3); this different severity scale cannot be linked as easily to the existing disability weights and is therefore not used in the present study.

In order to scale the YLD to the unit of lost years of life, asymptomatic, mild, moderate and severe cases were weighted with the disability weights for upper and lower respiratory infections fom the Global Burden of Disease study, while very severe cases were weighted with the weighting for intensive care from the European Disability Weights study (26, 27) *(eTable 1)*. Deaths generally result in a loss of several years or even decades of life, depending on the residual life expectancy, while disability weights range from a minimum of 0, corresponding to intact health, to values close to 1 (where 1 corresponds to death) *(eTable 1)* (28). In addition, an average duration of illness is assigned to each severity grade, because infectious diseases generally take a temporally limited course. The specific duration of illness reflects the time from the onset of symptoms to the improvement of the patient's overall condition (26). In general, COVID-19 is assumed to be infectious for 8–9 days, or up to 20 days in severe cases (21). The legal duration of quarantine in Germany has therefore been set at 14 days. This value is used in the present analyses for asymptomatic, mild, and moderate cases. For severe cases, a median seven-day duration of hospitalization is added, yielding a duration of illness of 21 days overall. Finally, very severe cases lasted a

median of 18 days longer (21) and were therefore assigned a toal duration of 32 days *(eTable 1)*. The formula for YLD is as follows:

$$YLD = \sum_{i=1}^{10} \sum_{g=1}^{2} \sum_{j=1}^{5} \delta_j * I_{i,g,j} * DW_j$$

where i is the age group, g the sex, j the grade of severity, $I_{i,g,j}$ the number of reported cases, and DW_j the specific disability weight for grade of severity j. An additional multiplicative factor was used to reflect the duration of illness: $\delta_j = \frac{duration_j}{365.25}$.

The YLD resulting from the above calculation can be interpreted as a number of lost years of life, even for temporally limited disease courses. YLL and YLD are thus measured in the same units (lost years of life) and can be added together to give the overall burden of disease, i.e., disability-adjusted life years (DALY):

$$DALY = YLL + YLD$$

eMETHODS 3

Additional information on method

Years of life lost, YLL

The YLL figures react sensitively to two methodological aspects of the calculation of the residual life expectancy of deceased persons, which must therefore be kept in mind in the interpretation of the findings, namely, the selection of life tables and the consideration (or not) of pre-existing conditions. These are, primarily, normative decisions, as they define a counterfactual state in positing the number of lost years of life that could have been prevented if the affected persons had not died (29). It is centrally important whether an internationally uniform or a country-specific residual life expectancy is chosen for use in the analysis. The present study employed the maximal age-specific life expectancies for Germany based on the 2016/2018 life tables. The YLL figures thus express an empirically measured prevention potential in the German population. The highest empirically derived age-specific residual life expectancy among all the German federal states is used as the measure of lost years of life due to death. This method is often used in country-specific disease burden calculations (7, 30). In contrast, for international comparisons, global life tables are used (19, 31); the resulting YLL figures are more abstract, as they do not reflect mortality as it actually exists in individual countries.

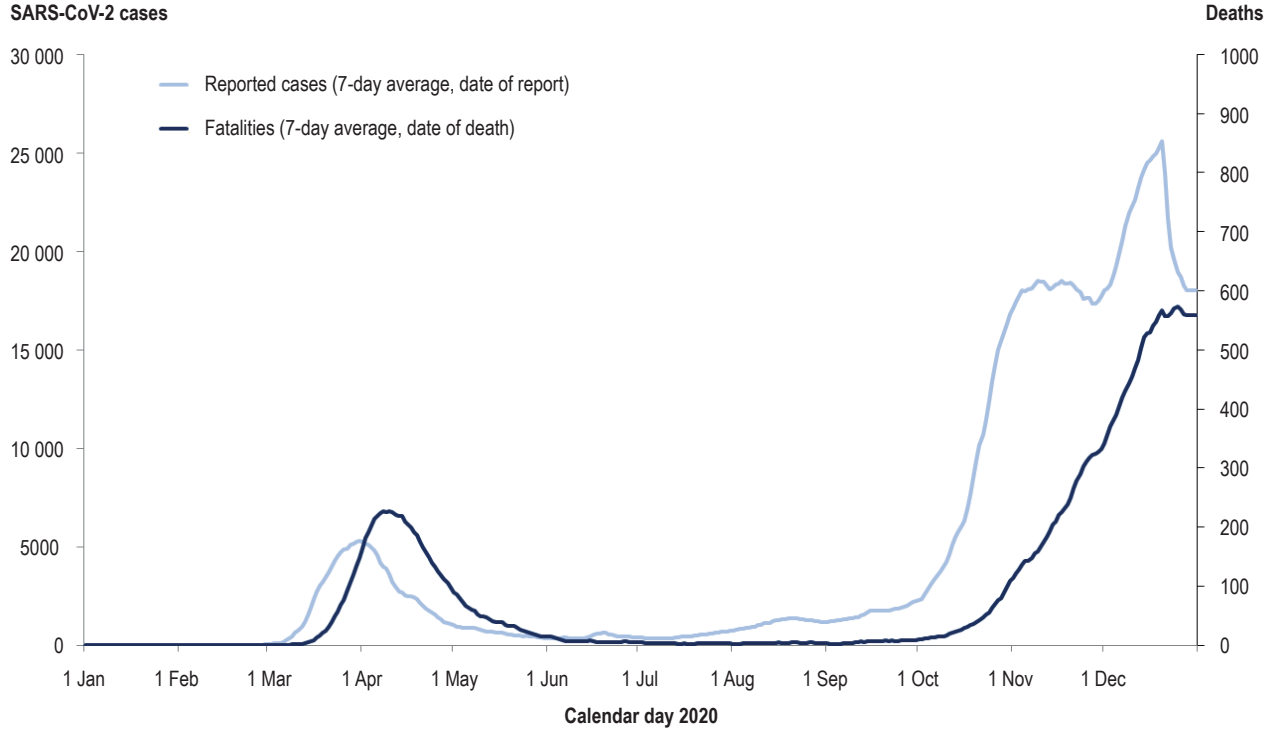
Some studies on the COVID-19 burden of disease also adjust the residual life expectancy—and thus the YLL—for pre-existing conditions (18). This is done on the assumption that a person who died of COVID-19, if he or she had survived, would have gone on to live for a shorter time if he or she had one or more pre-existing conditions (the more such diseases, the shorter the life expectancy). In the present study, in contrast, all persons who died at any particular age were assigned the same residual life expectancy. The first approach is an attempt to correct the counterfactual state (see above) with additional information on the state of health of the affected persons; in the second approach, which is used in the Global Burden of Disease study (7, 19), the same residual life expectancy is deliberately used for all persons of the same age. The goal is to define, as it were, a normative prevention potential that applies equally to all of the persons who died. This is because it makes the empirically determined maximal achievable life expectancy, independent of individual pre-existing conditions, the benchmark for the loss of life years.

Years lived with disability (YLD)

The methods of this study differ from those of a study from South Korea (7) in three major ways. First, different distributions of severity grades are used. The present study, being based on cases that were notified to the health authorities, had a higher percentage of asymptomatic cases and a lower percentage of mild cases, while having, at the same time, a larger number of moderate and severe cases. Because of the use of data reported to the national notification system, the percentage of mild and asymptomatic cases was underestimated at the beginning of the pandemic to a greater extent than at later times, because many infected persons did not consult a physician and were not tested. Over the course of the pandemic, the number of tests increased, leading to an increase in the percentage of asymptomatic cases over time. Accordingly, the percentage of moderate cases (mainly those with pneumonia) and severe cases (hospitalizations) fell as the pandemic progressed *(eFigure 3)*. Second, different weights were used, and this had a large effect on the size of YLD. In the South Korean study, some of the COVID-19 cases received markedly higher weights for pneumonia or sepsis. Third, the global duration of illness of 28.4 days that was used in the South Korean study is higher than the average of the

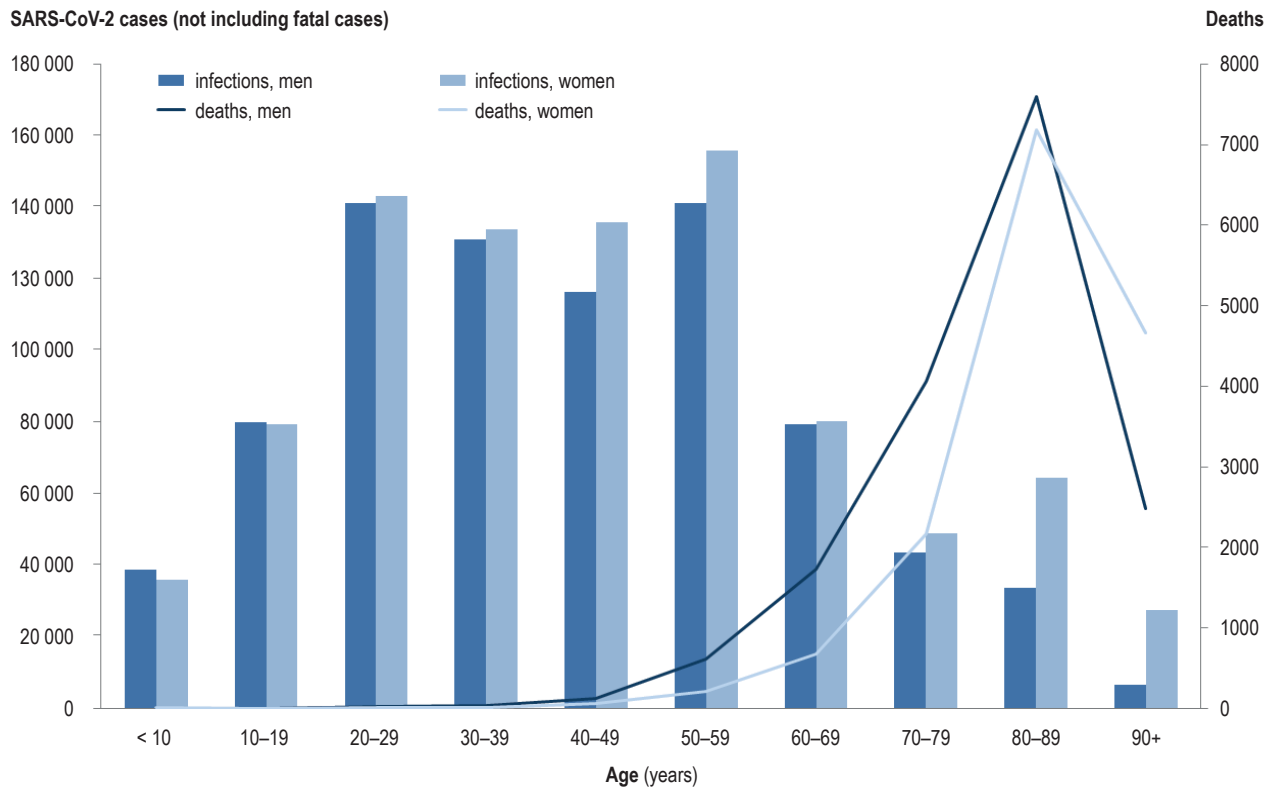
gradated durations of illness, depending on severity, that were used in the present study. The overall effect of this was an increased contribution of YLD to DALY of 10.3%. An important role might also be played by long-term sequelae of COVID-19 that have not yet been adequately taken into account. The Robert Koch Institute assumes that only a relatively small percentage of persons who survive COVID-19 go on to suffer from long-term sequelae: 40% of the hospitalized patients and 10% of those who were not hospitalized. There is as yet no uniform, medically validated definition of long-term sequelae, and their definitive causal attribution to COVID-19 remains unclear, as does their frequency after a mild course of the disease (21, 32). A further factor complicating the calculation of disease burden is that, for all types of long-term sequelae, well-founded assumptions about their average duration must be made, and disability weights must be assigned for which there are, in general, no established standards. Taking the long-term sequelae of COVID-19 into account in the calculation of disease burden will thus remain a task for future research on the basis of a more secure knowledge base. As the current evidence yields no definite answers, the fact that long-term sequelae do not enter into the present analysis must be made transparent and must be borne in mind in the interpretation of the findings.

eFIGURE 1



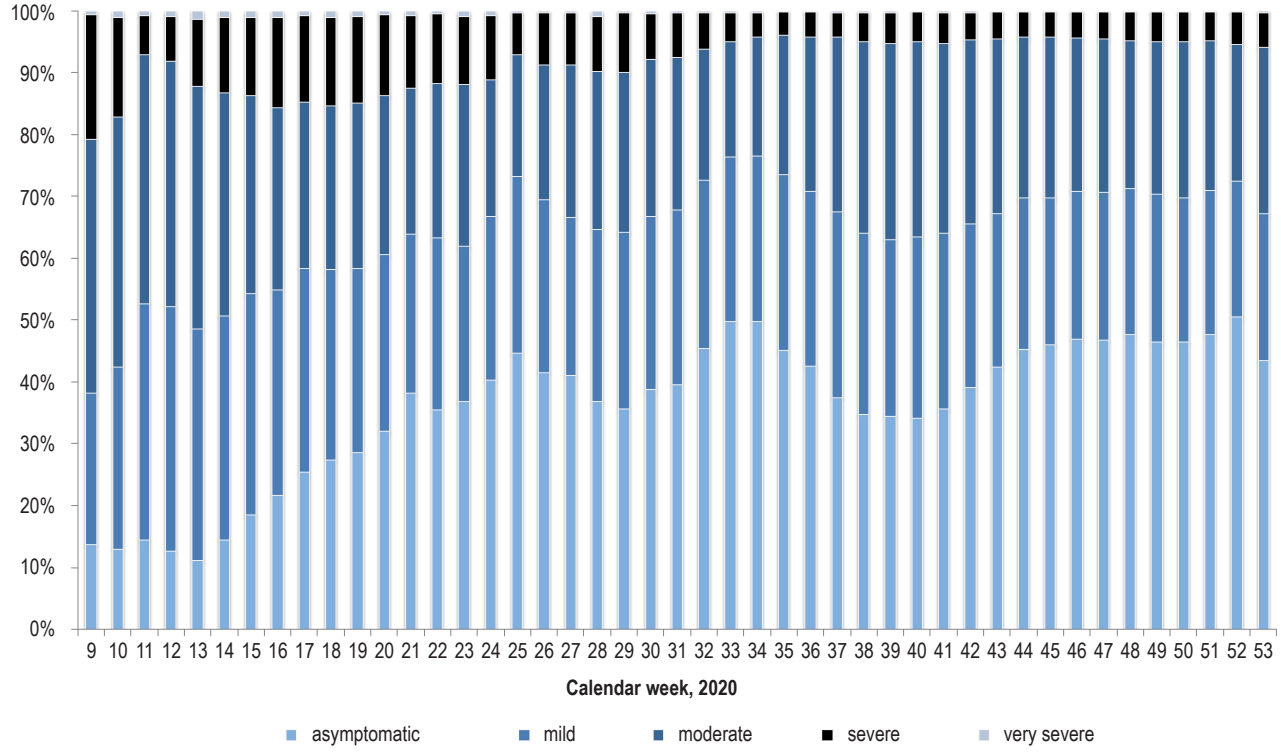
Reported cases of SARS-CoV-2 and reported deaths from COVID-19 in Germany in 2020 over the course of the year
Source: data reported in 2020 as required by the Infection Protection Act (data as of 18 January 2021)

eFIGURE 2



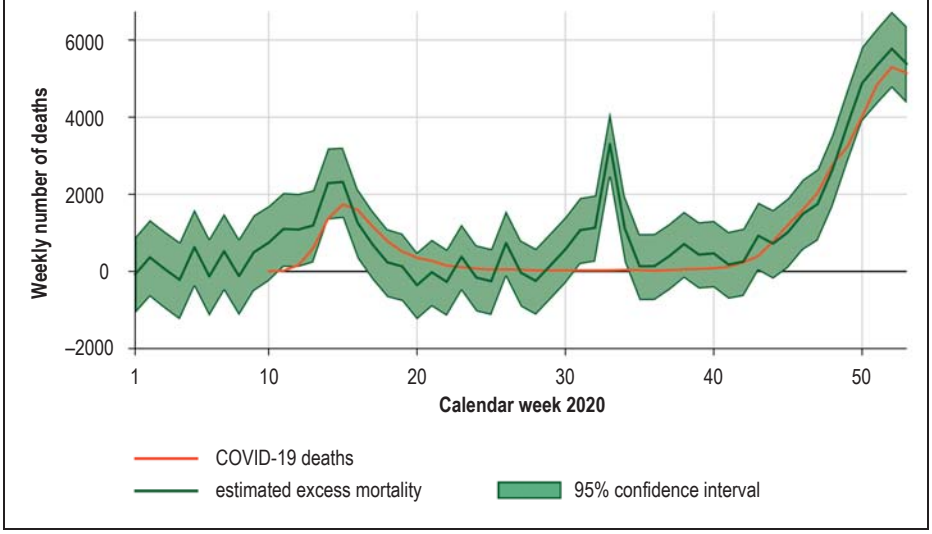
Reported SARS-CoV-2 cases (not including fatal cases) and deaths from COVID-19 in Germany in 2020 by age and sex
Source: data reported in 2020 as required by the Infection Protection Act (data as of 18 January 2021)

eFIGURE 3



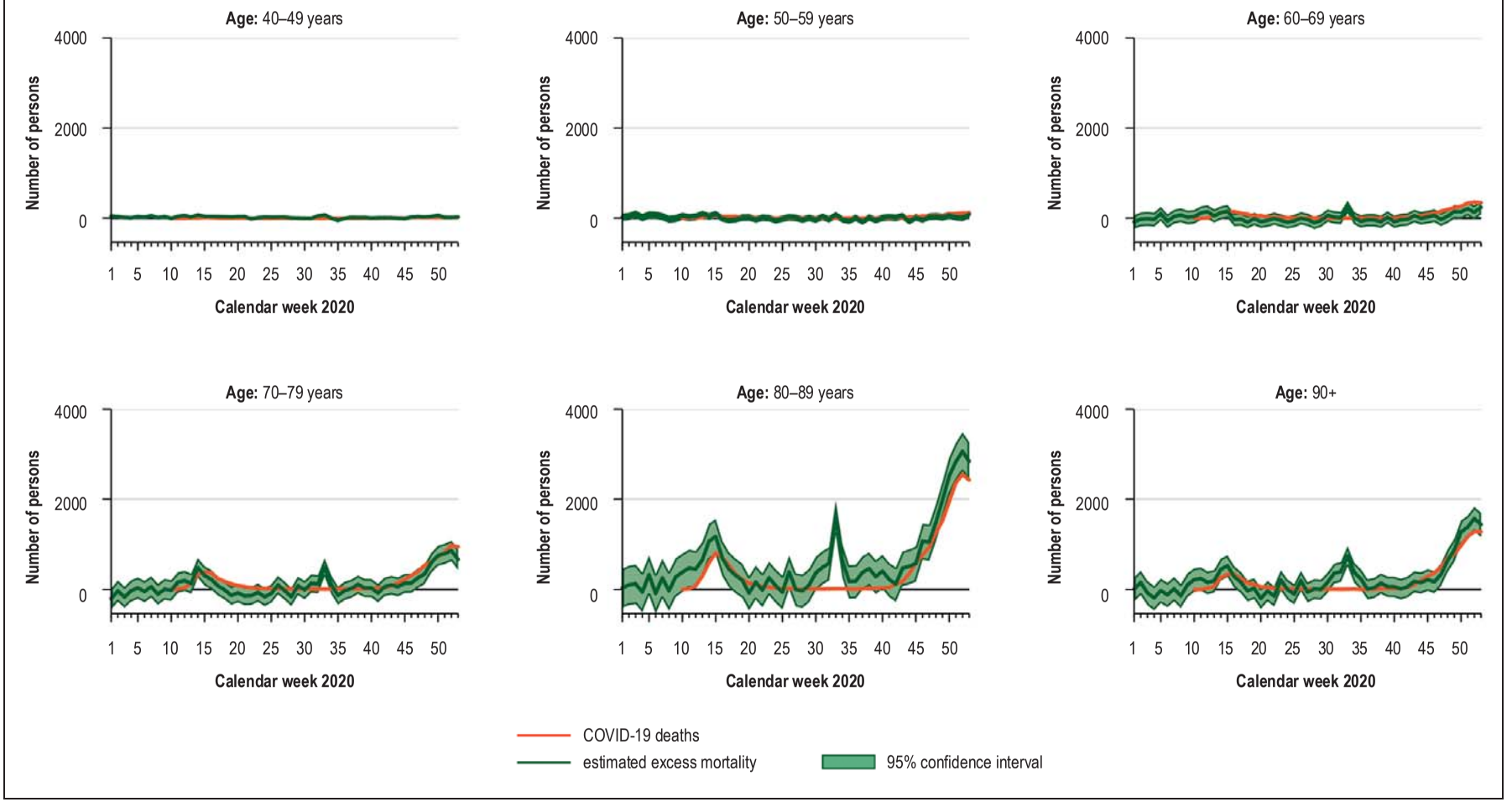
Distribution of severity grades of SARS-CoV-2 cases in Germany in 2020 (not including fatal cases) by calendar week
Source: data reported in 2020 as required by the Infection Protection Act (data as of 18 January 2021); authors' own calculations

eFIGURE 4



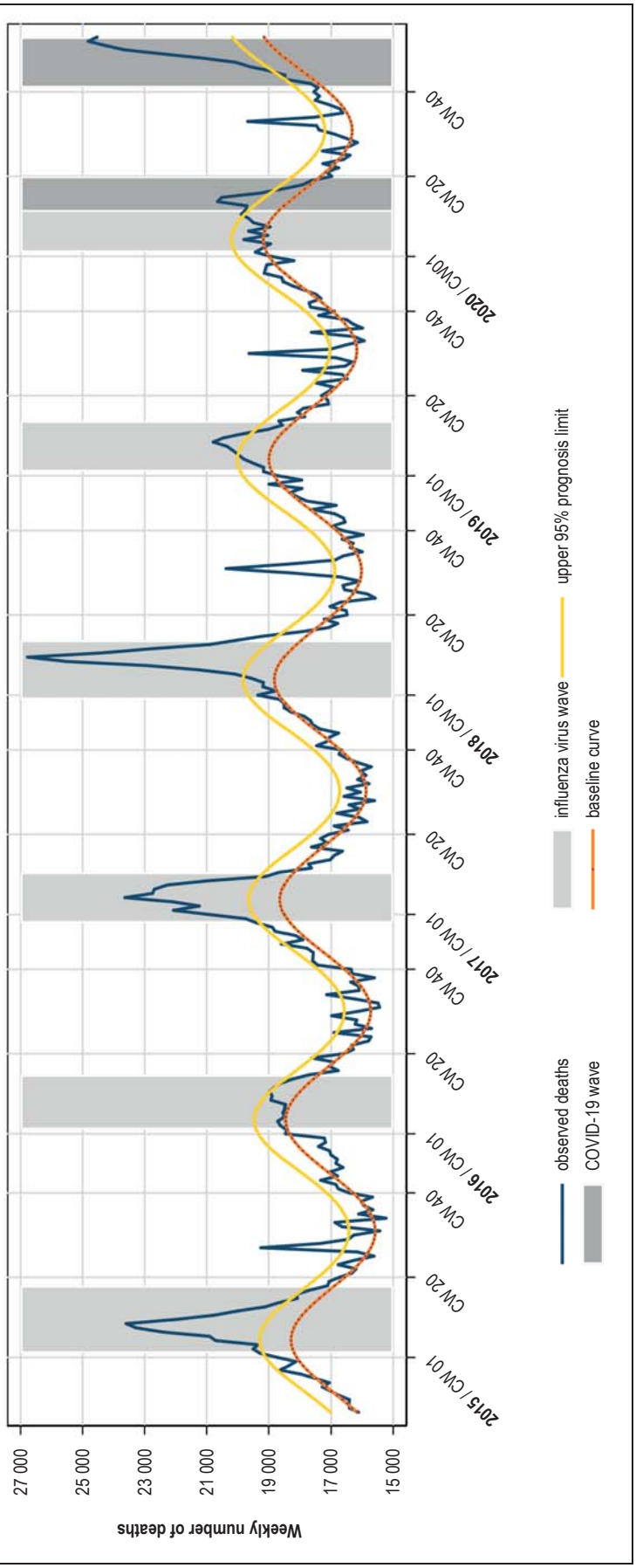
Estimated excess mortality in Germany in 2020 compared to the number of reported deaths from COVID-19
Source: Destatis, special analysis of fatality figures (33); authors' own calculations

eFIGURE 5



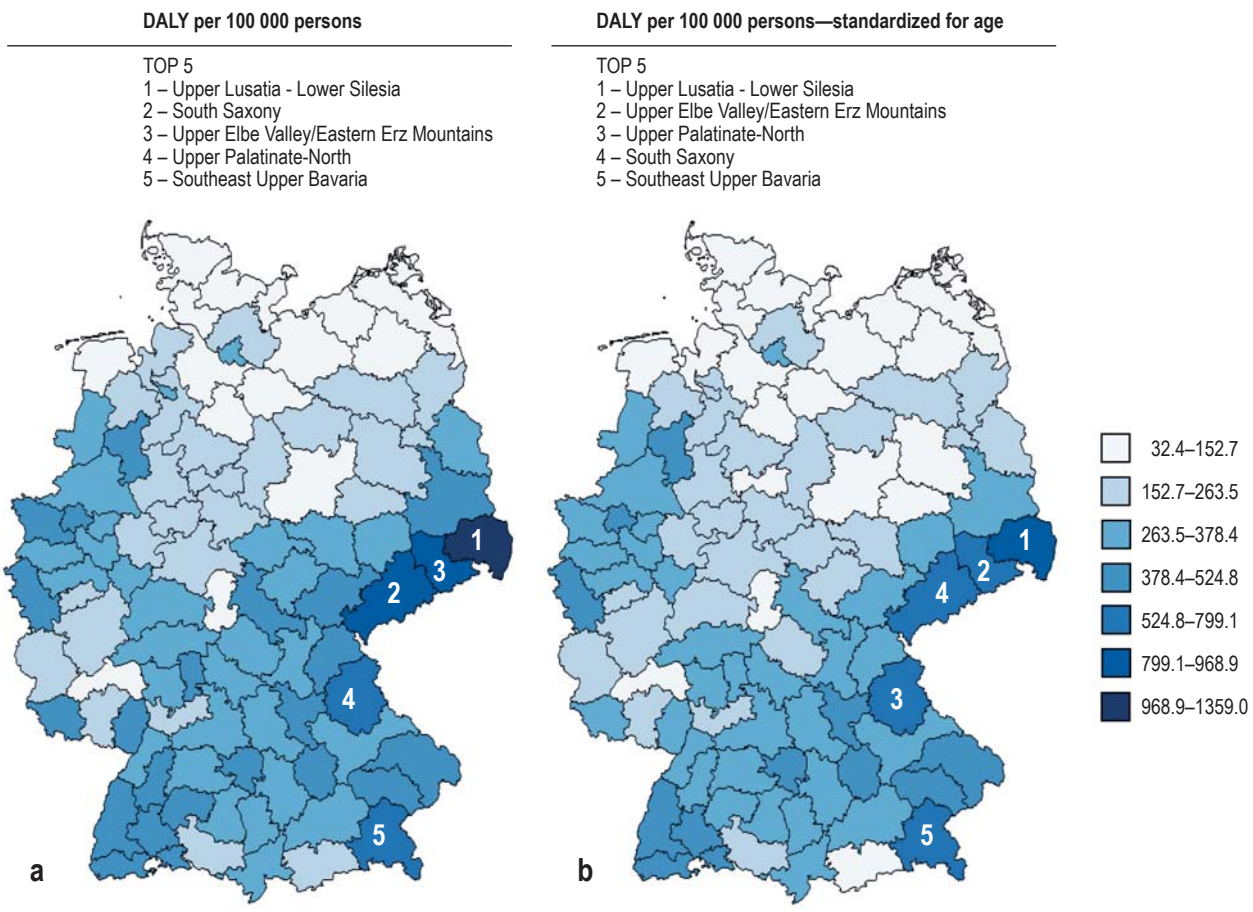
Estimated excess mortality in Germany in 2020 compared to the number of reported deaths from COVID-19, by age group
Source: Destatis, special analysis of fatality figures (33); authors' own calculations

eFIGURE 6



Modeling of background mortality in Germany, 2015–2020
Source: Destatis, special analysis of fatality figures (33); authors' own calculations

eFIGURE 7



Overall COVID-19 disease burden (DALY) in Germany in 2020 at the level of the spatial planning regions *(Raumordnungsregionen)*, per 100 000 population
Sources: data reported in 2020 as required by the Infection Protection Act (data as of 18 January 2021), life tables 2016/2018, European standard population 2013; authors' own calculations
DALY, disability-adjusted life years

eBOX

Excess mortality

The purpose of these analyses was to test whether the overall mortality differed from that of previous years. To determine the excess mortality, the time series of weekly overall numbers of deaths in 2016 and in 2020 were analyzed and compared (33). The EuroMoMo algorithm (34, 35) was used to characterize the course of the mortality figures, overall and in each age group, with a sinusoidal pattern of seasonal variation and a linear trend. The linear trend enabled the model to take account of demographic aging, i.e., the increased percentage of elderly persons in the population over time, as well as of changes in life expectancy in Germany. Mortality was considered unexpectedly high or low in any particular week if the observed mortality figures for that week lay outside the interval predicted by the model. Thus, the expected values derived from the model were used to determine excess mortality or reduced mortality. In some years, excess mortality appears in the winter months, during the influenza wave; heat waves in the summer months are regularly associated with elevated mortality figures (36, 37).
(eFigures 4–6)

eTABLE 1

Calculation of years lived with disability (YLD) due to COVID-19 in Germany in 2020 [*1]

Definition of severity grade		Parameter		
Grade	**Case definition**	**Distribution** [*2]	**Duration of illness**	**Disability weights**
Asymptomatic	no reported symptoms corresponding to COVID-19, or else no information on clinical manifestations	42%	14 days	0.000
Mild	general signs of illness, sore throat, runny nose, disturbance of smell or taste, diarrhea, or clinical manifestations are present	25%	14 days	0.006
Moderate	the above and, in addition: fever, cough, or pneumonia	27%	14 days	0.051
Severe	hospitalization (but not in an intensive care unit)	5%	21 days	0.133
Very severe/critical	intensive care	< 1%	32 days	0.655
Total		100%		

[*1] Source: the authors' own definition,based on those of the Global Burden of Disease study (26) and the European Disability Weights study (27)
[*2] Distribution based on 1 717 006 cases (not including fatal cases) reported as of 18 January 2021

eTABLE 2

Severity distribution of nonfatal cases of SARS-CoV-2 in Germany in 2020, by age and sex*

Age (years)	Sex	Severity grade				
		asymptomatic	mild	moderate	severe	very severe
<10	male	61%	23%	14%	2%	0%
	female	60%	23%	15%	2%	0%
10–19	male	51%	27%	21%	1%	0%
	female	47%	29%	23%	1%	0%
20–29	male	43%	27%	28%	1%	0%
	female	38%	28%	31%	2%	0%
30–39	male	41%	27%	30%	2%	0%
	female	38%	29%	31%	2%	0%
40–49	male	41%	26%	29%	4%	0%
	female	37%	28%	32%	3%	0%
50–59	male	38%	25%	30%	5%	1%
	female	36%	27%	33%	4%	0%
60–69	male	39%	23%	26%	10%	1%
	female	38%	25%	30%	8%	1%
70–79	male	41%	18%	16%	22%	2%
	female	44%	20%	18%	17%	1%
80–89	male	47%	15%	10%	26%	1%
	female	55%	16%	10%	19%	1%
90 +	male	58%	14%	7%	20%	0%
	female	67%	15%	6%	12%	0%

*Sources: data reported in 2020 as required by the Infection Protection Act (data as of 18 January 2021), authors' own calculations