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Uncovering the toll of the first three COVID-19 waves: excess mortality and social patterns in Belgium

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Abstract

Background This study aims to assess which population groups experienced the heaviest mortality burden during the first three COVID-19 waves in Belgium; and investigate potential changes in social differences in all-cause mortality during the epidemic and compared to the pre-COVID period.

Methods Exhaustive all-cause mortality information (2015–2021) from the Belgian population register was linked to demographic and socioeconomic census and register data. Annual cohorts consisting of 6.5 million to 6.8 million persons were created selecting persons aged 35 and older. Excess mortality was investigated comparing the 137,354 deaths observed during the first three COVID-19 waves with mortality in the reference period 2015–2019. Methods of analysis include direct standardization and Poisson regression analyses.

Results Elderly men experienced the highest absolute mortality burden during all three COVID-waves, followed by elderly women, middle-aged men, and middle-aged women. Care home residents consistently experienced higher mortality rates during the first and second wave compared to peers living in other living arrangements. In wave 3, care home residents showed significant absolute mortality deficits compared to the reference period. When adjusting for all demographic and socioeconomic factors, the traditional pattern of educational and income mortality inequalities was found among the elderly population during the COVID-waves. In contrast, the educational mortality gap among middle-aged persons deepened during COVID-waves 2 and 3 with excess mortality between 19 and 30% observed among mainly lower-educated persons. Income mortality inequalities among middle-aged women and men remained stable or even diminished for some specific groups in some waves.

Conclusion The widening educational mortality gap among middle-aged persons in successive waves suggest an important role of knowledge and associated educational resources during the COVID-19 epidemic. Belgium's broad implementation of public health control and prevention measures may have successfully averted a further widening of social mortality inequality between income groups and among the elderly population.

Keywords COVID-19, All-cause mortality, Excess mortality, Social inequalities

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Text box 1. Contributions to the literature

•Few studies investigate changes in social mortality patterns throughout the course of the COVID-crisis.

• Elderly men had the highest absolute mortality burden in all three COVID-waves. Care home residents showed a particular mortality pattern.

• Traditional educational and income mortality inequalities persisted among the elderly, suggesting effective COVID-19 support and preventative measures in Belgium.

• The widening educational mortality gap among middle-aged persons in successive waves indicate an important role of knowledge-related resources during the COVID-19 crisis in Belgium.

Background

Syndemic nature of the crisis

The COVID-19 pandemic has been described as a syndemic characterized by social, economic, and health factors interacting and exacerbating the disease burden [1]. Previous studies have established that COVID-19 has a socially patterned distribution, with higher risks for exposure, infection, severe illness, and death among socially disadvantaged groups [2–5]. Of course, the crisis has a broader health impact beyond COVID-19 itself. Protective measures were implemented to safeguard the healthcare system, and some -already vulnerable- groups of people refrained from seeking healthcare out of fear or hesitation [6]. Reorganizations of healthcare systems have been associated with unintended but significant consequences on access to care, diagnosis and treatment of multiple diseases [7, 8].

Excess mortality measures have been widely used to investigate the overall impact of the crisis on population health. When comparing the all-cause mortality pattern during the epidemic with the situation before the outbreak, elevated mortality risks have been found for several sociodemographic factors (e.g., old age, male sex, living in a care home facility, migrant background), socioeconomic factors (e.g., low income, low educational level), and comorbidities (e.g., obesity) [3, 4, 9–11]. Much of the available literature covers the first wave of the epidemic. Few studies focus on changes in the observed excess mortality patterns over time and these are often limited by the unavailability of socioeconomic indicators [5, 12, 13]. Deeper insights in the evolution of social health inequalities over time, through the consecutive waves, can help us understand the dynamic nature of the epidemic and the role of pre-existing drivers of social differences in population health.

Insights from the stages of diseases theory

Building on the Stages of Diseases Theory (SDTh), social health inequalities are expected to change considerably throughout the course of the epidemic [14, 15]. SDTh incorporates principles from the Fundamental Cause Theory and explains social health inequalities by the unequal access to flexible resources (e.g., knowledge, money and social connections) [16]. Social health inequalities can arise when the occurrence of a new disease is associated with the societal structure and/or because of an unequal distribution of these fundamental resources in society. The SDTh presents four distinct consecutive stages of disease occurring over time. At the outbreak of a disease, the first stage of "natural mortality" is characterized by a lack of knowledge on the disease prevention and treatment in society. Social health inequalities are believed to be relatively small during this period, as any effective protective behaviour by a societal group will be based on coincidence. In the second stage of "producing inequalities", health knowledge increases in society with an unequal advantage for some groups. As a result, social health inequalities will widen during this stage. The third stage of "reducing inequalities" is characterized by a dissemination of the innovative health knowledge in society. In the fourth and final stage, mortality is reduced by widely available preventative resources and effective treatment opportunities for all social groups, and the disease can even be eliminated. For the United States, Clouston and colleagues have found evidence that areas with more resources experienced lower COVID-19 disease burdens during the early stages of the crisis [15]. An ecological study from Barcelona corroborates these findings and shows a widening of area-level socioeconomic inequalities in COVID-19 infections [17]. To our knowledge, no previous study has investigated the evolution of the social patterning of all-cause mortality during the different waves of the COVID-19 crisis using individual-level information on socioeconomic background. Earlier findings indicate that the SDTh could be applicable for Belgium, as considerable area-level social differences in COVID-19 incidence were observed during periods of intense virus circulation in COVID-waves 2 and 3, while the first wave and interwave periods showed less pronounced differences, potentially due to limited testing and evolving social measures [18]. An individual-level study on all-cause mortality during the first COVID-waves suggest atypical excess mortality patterns by education and income [3], but it remains unclear in what way social health inequalities changed throughout the course of the crisis (Fig. 1).

Objectives

The current study has two main objectives. First, it aims to assess which population groups experienced the heaviest mortality burden during the first three COVID-19 waves in Belgium. Second, it investigates potential changes in social differences in all-cause mortality throughout the epidemic and compared to the pre-COVID period.

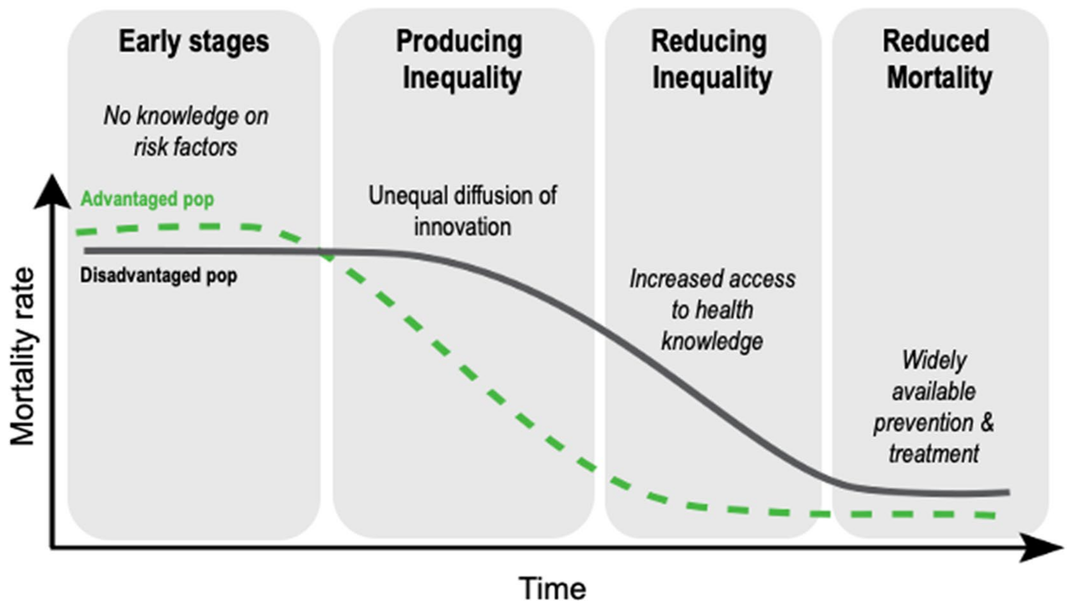

Fig. 1 Stage of Disease theory - Scheme for a hypothetical cause of death. Adapted from Clouston, Rubin, Phelan & Link (14)

Materials and methods

Study design and population

Statistics Belgium provides individual-level linked data from three administrative sources which cover the population legally residing in Belgium. These sources include the Belgian National Register, which provides yearly stock files of the total official population in Belgium from 2015 to 2020, containing sociodemographic information and data on all-cause mortality. The second source is the 2011 administrative census, which provides information on educational attainment from various administrative data sources. The available educational information is highly accurate, but also entails a considerable proportion of missing values due to incomplete data collection (e.g., degrees obtained abroad) [19]. The third source is the IPCAL database, which contains official tax information, including yearly personal income (2014–2017). The study population was selected in two stages: First, we selected all 7,413,146 persons aged 25 and older at the time of the 2011 census, which is the age when most persons have traditionally completed their educational attainment. Second, annual cohorts for the period 2015–2020 were created selecting persons aged 35 and older on January 1st of each study year. Annual cohorts ranged between 6.5 million persons in 2015 to 6.8 million persons in 2020.

Mortality indicators

To identify the population groups that experienced the heaviest mortality burden during the epidemic, we compared mortality rates during the COVID waves and a during a reference pre-COVID period (2015–2019) and calculated mortality excesses. Excess mortality was defined as the increase in mortality measures during a COVID wave compared to the mortality measures during the pre-COVID reference period 2015–2019. We present excess mortality as the proportional change observed in the COVID-19 wave compared to the reference period. To investigate absolute mortality inequalities, Directly Standardised Mortality Rates (DSMRs) and their 95% confidence intervals (CI) were calculated for the three COVID-19 waves and the standard period using STATA (SE 17.0). The rates were standardized using the total Belgian population distribution on January 1st, 2020. The DSMRs for each year in 2015–2019 were pooled using random-effects meta-analysis models to provide robust and stable estimates for the reference period. Statistical significance of the change in mortality measures between the COVID-19 waves and the reference period was tested as outlined by Altman and Bland [20].

To gauge relative mortality inequalities, Mortality Rate Ratios (MRRs) and 95% CI were calculated using multivariable Poisson regression analyses in STATA (SE 17.0). The natural logarithm of the person time was employed as the offset variable to accurately estimate mortality rates while accounting for differences in follow-up time [21]. Preliminary analyses were carried out to check for overdispersion and multicollinearity (results not shown). Rather than using data-driven (variable) selection techniques, the models were constructed in four main steps based on the literature. The first model included age as a continuous variable to obtain age-adjusted MRRs. The second model extended model 1 by also including education and income to measure socioeconomic differences in mortality. Building on the previous model, the third model adjusted for sociodemographic background by including migrant background, household living arrangement and region of residence. Finally, the fourth model also considered approximate indicators of pre-existing health issues, specifically whether individuals in the middle-aged population received health benefits and whether individuals in the elderly population resided in a care home facility. Interaction terms were not included in any of these models. To obtain robust estimates for the reference period, the yearly MRRs in 2015–2019 were pooled using random-effects meta-analysis models.

Socioeconomic measures

In line with Kunst & Mackenbach, we used both educational attainment and personal income as indicators of socioeconomic position [22]. Education was chosen to capture knowledge-related resources (e.g., ability to understand health prevention messages and to communicate with health services), while income was chosen as an indicator for material resources (e.g., ability to afford higher-quality protective materials and innovative treatments).

Educational attainment refers to the highest achieved educational degree on January 1st, 2011 (the date of the Belgian census). The data was originally coded using the International Standard Classification of Education (ISCED) but was recategorized into five categories: (a) Primary education or less (ISCED 0–1); (b) Lower secondary education (ISCED 2); (c) Upper secondary education (ISCED 3–4); (d) Higher education (ISCED 5–8); (e) Missing information. The group with missing educational information is most likely very diverse with persons who obtained their educational degree abroad (e.g., expats or first-generation migrants), from non-traditional education (e.g., self-directed learning), or are faced with administrative challenges (e.g., interrupted education). Since the missing data is not considered to be random (Supplementary Figure A1), it was included as a separate category to ensure a comprehensive analysis. However, because this category doesn't directly align with the SDTh framework, our interpretations primarily focus on the categories with complete educational information.

Personal income was derived from the net taxable income and divided into five groups based on deciles (D): zero declared income; low income (D1-D4); middle income (D5-D7); high income (D8-D10); and missing information. The group with missing income information is most likely composed of persons who work in the informal economy, are exempt from taxes (e.g., income from property rent) or pay taxes abroad. Similar to our approach for missing educational information, missing income was assumed not to be missing at random (Supplementary Figure A2) and was therefore included in our analyses as a separate category. However, for interpretative purposes we primarily focused on the non-missing income groups.

To capture the relationship with pre-existing income, we used income information from the year prior to the wave under investigation (e.g., 2014 income situation in mortality analyses for wave 1 in 2015). For the mortality analyses in 2019, 2020 and 2021, we used the 2017 income information as more recent income data was unavailable.

Sociodemographic measures

Migrant background was assessed by considering information on the individual's nationality at birth, current nationality, and nationality of parents, which allowed for the classification into three distinct groups: Belgian natives, first-generation (FG) migrants, and second-generation (SG) migrants.

Household living arrangement was defined as the officially declared living situation in the National Register on January 1st of the year of the wave under investigation, except for wave 3 in 2021 where the 2020 living arrangement was used due to data unavailability. Four categories were constructed based on this information: living with a partner; living alone; living in other housing situations (e.g., adult child with parents); and collective households (e.g., prisons, residential care facilities, religious communities).

Region of residence refers to the Belgian Region where the person was officially domiciled on January 1st of the year of the wave under investigation. Prior research has identified consistent variations in mortality across the three different Belgian Regions, with Flanders having the lowest mortality rates, Wallonia displaying the highest rates and the Brussels Capital Region (BCR) falling in between [23]. In addition, regional differences in mortality are likely to occur during the crisis because each Region was responsible for some important tasks in the governmental COVID-19 management strategy (e.g., health prevention).

Pre-existing health situation

To approximate pre-existing health problems among middle-aged individuals, we consider *high health benefits*. Specifically, we deemed a person to suffer from important health concerns when 60% or more of their yearly net taxable income comes from health benefits. This indicator is a proxy for the more severely ill employed persons and disabled persons. Because eligibility for health benefits is determined by criteria such as labour performance, this indicator was only considered for the middle-aged population. Like the income variable, we used the information from the year preceding the wave under investigation, except for the waves in 2019–2021 for which we used the latest available information from

2017. For an overview of the characteristics of the Belgian sick pay system, we refer to an international comparison made by Ose et al. [24].

Care home residency refers to whether an elderly person lived in a residential care home facility on January 1st of the year of the wave under investigation.

Data analysis

To account for potential confounding effects associated with advanced age and male sex in the COVID-19 disease burden [25], the analyses were stratified by sex and major age group. A binary sex categorisation (men/women) was derived from the official population statistics. The "middle-aged" group consists of persons between the ages of 35 and 64 on January 1st of the year being investigated, while the "elderly" group comprised persons aged 65 years or over on the same date. Supplementary Table A1 provides an overview of the four subpopulations. Given the previously reported vulnerability of care home residents in Belgium [26], we provided additional analyses for elderly men and women stratifying for care home residency.

Analyses were performed separately for each wave of the epidemic, as defined by Sciensano, the national institute for health [27]. Wave 1 took place between March 1st, 2020 and June 22nd, 2020. Wave 2 occurred from August 31st, 2020 and February 14th, 2021. Wave 3 lasted from February 15th, 2021 to June 27th, 2021. The reference period was constructed using the same dates in the years between 2015 and 2019.

Results

Changes over time: absolute mortality inequalities

Figure 2 presents the DSMRs and their corresponding 95% CIs by educational attainment and wave. Overall, the results indicate that elderly men experienced the highest absolute mortality burden during all three COVID waves, followed by elderly women, middle-aged men, and middle-aged women. The largest excesses in mortality were found among elderly men and women during the first COVID-wave. For elderly women, the investigated educational groups showed significant excesses between 19% and 29% in wave 1 compared to the reference period 2015–2019. For elderly men, excess mortality by educational group in wave 1 fluctuated between 17% and 25%. Excess mortality waned slightly in wave 2 with 8-18% significantly higher mortality among elderly women and 12-22% among elderly men compared to the reference period. In wave 3, only specific groups of elderly experienced significant excesses: elderly women with missing educational information (5%) and elderly men with a primary educational degree or less (9%) or lower secondary

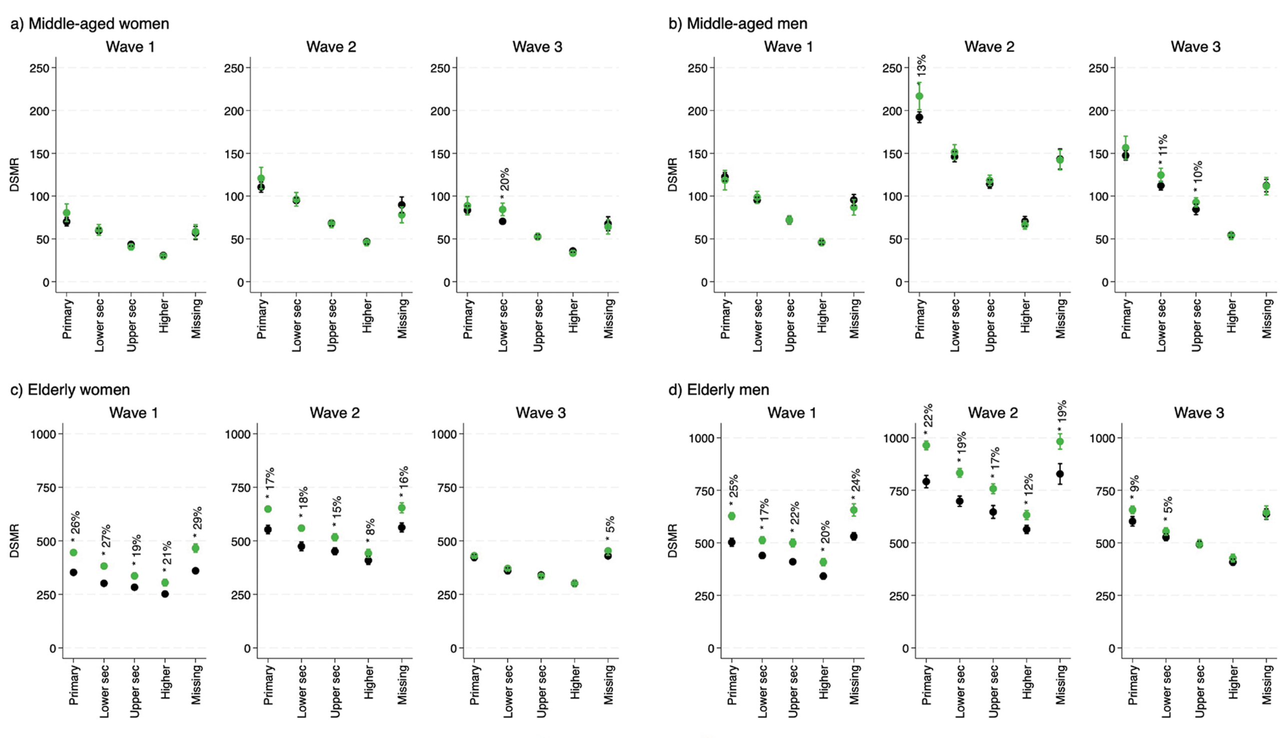

Fig. 2 Directly Standardized Mortality Rates (DSMR) and 95% confidence intervals by educational attainment, subpopulation and wave. Reference: Total Belgian population on January 1st, 2020; (*) marks significant excess mortality between the COVID-wave and the reference period ($p < 0.05$); (%) indicates the proportional change in DSMR compared to the reference period. Note: Y-axis **a**) and **b**) differs from **c**) and **d**)

degree (5%). Among the middle-aged, excesses were generally not significant except, in wave 2, for the primary-educated men (13%), and, in wave 3, the lower secondary educated women (20%), lower secondary educated men (11%) and upper secondary educated men (10%).

The analyses by income group (Supplementary Figure A3) showed similar findings for elderly women and men. For the middle-aged, men with high incomes showed significant excess mortality during wave 1 (13%) and 3 (17%), unlike any peers in the low to middle income groups. Middle-aged women and men with no declared income showed 20% excess mortality in wave 1 and 16% excess mortality in wave 2, respectively.

In order to further investigate the mortality burden in the elderly population, Fig. 3 displays the DSMRs and their 95% confidence intervals by care home residency status and educational attainment. The findings suggest that living in a care home was associated with considerably higher absolute mortality levels, distinct social patterns in mortality, and a larger excess mortality compared to other living arrangements.

Excess mortality among care home residents was most pronounced during the first and second wave. Female care home residents had 47–81% higher mortality during wave 1 compared with pre-COVID, while male care home residents had 69–83% higher DSMRs. In wave 2, excesses were lower but still significant with 20-35% higher mortality among women and 29-36% higher among men residing in care homes. Notably, high-educated women in care homes did not experience excess mortality. In wave 3, in contrast, care home residents showed significant mortality reductions (deficits) compared to the reference period, which was not observed among non-care home residents. Among female care home residents, mortality dropped with 16-25%. Male care home residents had 14-28% lower mortality rates, except for the upper secondary educated groups who did not show a significant deficit.

Although much less outspoken than with care home residents, non-care home residents also experienced excess mortality (9-20%) and did so in all 3 waves (except for upper secondary educated men in wave 3). Strikingly, non-residents revealed clear educational mortality gradients during all COVID-waves (and the reference period), which was not observed for care home residents. There was, however, one exception to that conclusion with higher-educated care home residents experiencing significantly lower mortality rates in all waves during the reference period. The findings on income group largely support these findings (Supplementary Figure A4).

Changes over time: relative mortality inequalities

Table 1 displays the MRRs from the fourth model and their corresponding 95% confidence intervals for various subpopulations and COVID-19 waves. With adjustment for demographic and pre-existing health situation, the results demonstrate that distinct socioeconomic mortality differences were evident across all subpopulations in all three COVID-19 waves. Differences did not significantly change across waves. Mortality rates were consistently higher among lower-educated individuals compared to their high-educated peers. For middle-aged women and men with a primary degree or less, mortality rates were 48–66% higher for women and 45–72% higher for men compared to those with a higher educational degree. Among the elderly population, these differences were 31–37% and 34–38% for women and men, respectively.

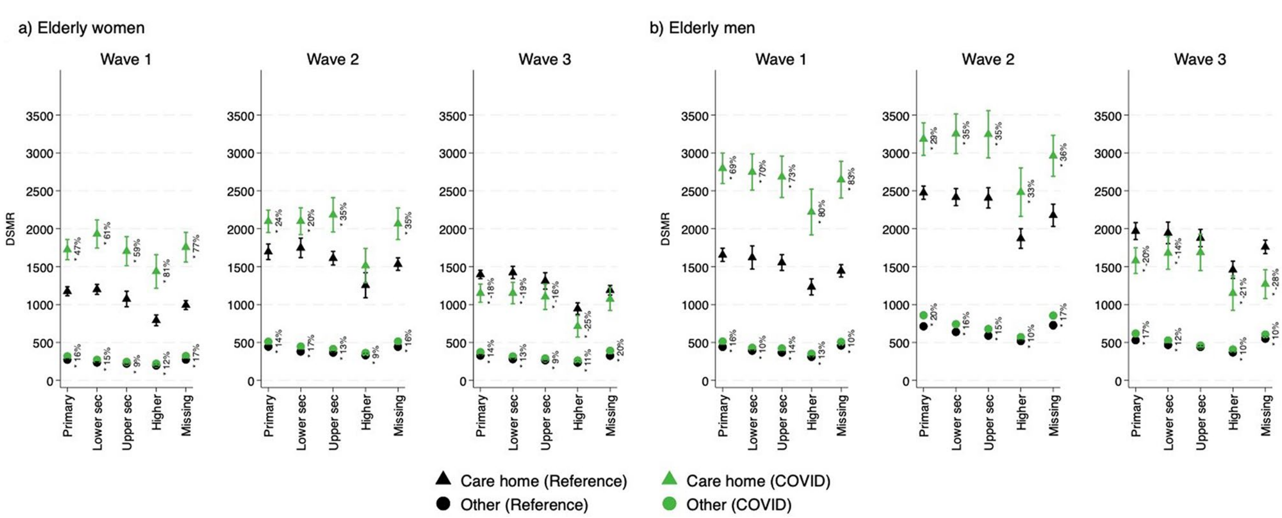

Fig. 3 Directly Standardized Mortality Rates (DSMR) and 95% confidence intervals for elderly women (**a**) and elderly men (**b**) by care home residency, educational attainment, and wave. Reference: Total Belgian population on January 1st, 2020; (*) marks significant excess mortality between the COVID-wave and the reference period ($p < 0.05$); (%) indicates the proportional change in DSMR compared to the reference period

Table 1 Mortality rate ratios (MRR) and 95% confidence intervals (CI) by subpopulation and COVID-19 wave

	Middle-aged women						Middle-aged men					
	Wave 1		Wave 2		Wave 3		Wave 1		Wave 2		Wave 3	
	MRR	CI	MRR	CI	MRR	CI	MRR	CI	MRR	CI	MRR	CI
Age (years)	1.09***	1.08;1.10	1.08***	1.08;1.09	1.08***	1.08;1.09	1.10***	1.09;1.10	1.09***	1.09;1.10	1.09***	1.09;1.10
Education												
Higher education	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)
Upper secondary	1.02	0.88;1.18	1.13*	1.01;1.27	1.19*	1.04;1.37	1.26***	1.12;1.41	1.40***	1.27;1.53	1.41***	1.26;1.57
Lower secondary	1.19*	1.02;1.40	1.29***	1.13;1.46	1.53***	1.31;1.77	1.40***	1.24;1.59	1.45***	1.32;1.61	1.60***	1.42;1.80
Primary or less	1.48***	1.24;1.77	1.58***	1.37;1.83	1.66***	1.39;1.97	1.45***	1.26;1.67	1.72***	1.54;1.92	1.71***	1.49;1.95
Missing	1.43***	1.16;1.77	1.32**	1.11;1.58	1.47***	1.19;1.80	1.29**	1.10;1.52	1.48***	1.31;1.67	1.54***	1.32;1.79
Income												
High	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)
Middle	1.39***	1.16;1.65	1.24**	1.07;1.43	1.23*	1.04;1.46	1.27***	1.13;1.42	1.45***	1.32;1.58	1.40***	1.26;1.55
Low	1.57***	1.32;1.86	1.54***	1.35;1.76	1.64***	1.40;1.92	1.73***	1.54;1.93	1.91***	1.75;2.09	1.73***	1.56;1.92
Zero	4.28***	3.41;5.37	3.53***	2.95;4.24	3.80***	3.07;4.72	3.27***	2.77;3.85	3.72***	3.27;4.24	3.62***	3.11;4.22
Missing	2.97***	1.90;4.64	2.13***	1.45;3.13	3.19***	2.18;4.68	2.64***	1.94;3.59	2.25***	1.72;2.93	2.62***	1.98;3.48
Migrant background												
Be	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)
Non-Be FG	0.56***	0.47;0.66	0.60***	0.53;0.69	0.61***	0.52;0.71	0.61***	0.54;0.70	0.67***	0.61;0.73	0.67***	0.59;0.75
Non-Be SG	0.83*	0.69;1.00	0.78**	0.67;0.91	0.89	0.76;1.05	0.74***	0.64;0.85	0.81***	0.73;0.91	0.86*	0.76;0.97
Household living arr.												
With partner	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)
One-person	1.74***	1.57;1.93	1.61***	1.48;1.75	1.50***	1.36;1.65	2.02***	1.86;2.19	1.89***	1.78;2.02	1.78***	1.65;1.92
Other	1.83***	1.50;2.24	1.89***	1.62;2.21	1.44***	1.18;1.76	1.80***	1.57;2.07	1.58***	1.42;1.76	1.60***	1.41;1.81
Collective household	7.19***	5.57;9.29	5.28***	4.20;6.63	4.08***	3.04;5.47	4.60***	3.80;5.56	3.80***	3.24;4.45	2.97***	2.43;3.64
Region												
Flanders	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)
BCR	1.16	0.96;1.40	1.19*	1.03;1.38	1.23*	1.03;1.46	1.33***	1.16;1.53	1.33***	1.20;1.49	1.30***	1.14;1.48
Wallonia	1.29***	1.16;1.43	1.35***	1.24;1.46	1.29***	1.17;1.42	1.43***	1.32;1.54	1.46***	1.37;1.56	1.37***	1.27;1.47
High health benefits												
No	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)
Yes	3.00***	2.66;3.39	2.66***	2.41;2.92	2.73***	2.45;3.05	2.52***	2.28;2.79	2.45***	2.26;2.65	2.52***	2.29;2.77
Pseudo R-squared	0.0096		0.0057		0.0665		0.0096		0.0069		0.0757	
Df	17		17		17		17		17		17	
BIC	229,804		505,382		30,175		385,384		845,774		46,655	
N	2.275.371		2.272.507		2.269.679		2.289.936		2.285.059		2.280.184	
	Elderly women						**Elderly men**					
	Wave 1		**Wave 2**		**Wave 3**		**Wave 1**		**Wave 2**		**Wave 3**	
	MRR	**CI**	**MRR**	**CI**	**MRR**	**CI**	**MRR**	**CI**	**MRR**	**CI**	**MRR**	**CI**
Age (years)	1.10***	1.10;1.10	1.11***	1.10;1.11	1.09***	1.09;1.09	1.10***	1.09;1.10	1.10***	1.10;1.11	1.08***	1.08;1.09

Table 1 (continued)

Education												
Higher education	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)
Upper secondary	1.11**	1.04;1.19	1.19***	1.12;1.26	1.12**	1.04;1.19	1.17***	1.10;1.24	1.18***	1.13;1.24	1.13***	1.07;1.20
Lower secondary	1.24***	1.17;1.32	1.25***	1.18;1.31	1.22***	1.14;1.30	1.18***	1.11;1.25	1.27***	1.21;1.33	1.24***	1.17;1.31
Primary or less	1.37***	1.29;1.45	1.36***	1.29;1.43	1.31***	1.23;1.39	1.34***	1.26;1.41	1.38***	1.31;1.44	1.37***	1.30;1.45
Missing	1.31***	1.22;1.41	1.29***	1.21;1.37	1.32***	1.22;1.42	1.32***	1.23;1.42	1.34***	1.26;1.42	1.33***	1.24;1.43
Income												
High	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)
Middle	1.08*	1.01;1.16	1.07*	1.01;1.13	1.06	0.99;1.14	1.16***	1.09;1.22	1.14***	1.09;1.20	1.16***	1.10;1.23
Low	1.16***	1.08;1.23	1.18***	1.11;1.24	1.15***	1.08;1.23	1.36***	1.28;1.44	1.33***	1.27;1.39	1.32***	1.25;1.40
Zero	0.91	0.76;1.09	1.03	0.89;1.19	1.03	0.87;1.22	1.13	0.92;1.37	1.15+	0.98;1.35	1.19	0.98;1.45
Missing	1.56***	1.23;1.99	1.47***	1.18;1.81	1.27	0.98;1.65	1.77***	1.35;2.31	1.60***	1.26;2.04	1.60***	1.22;2.12
Migrant background												
Be	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)
Non-Be FG	0.93*	0.88;0.99	0.97	0.92;1.02	0.99	0.93;1.05	0.88***	0.83;0.93	1.00	0.95;1.04	0.95	0.89;1.00
Non-Be SG	0.98	0.86;1.12	0.95	0.85;1.06	0.88	0.77;1.01	1.10	0.98;1.24	0.99	0.90;1.09	0.98	0.87;1.10
Household living arr.												
With partner	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)
One-person	1.31***	1.26;1.37	1.31***	1.27;1.36	1.24***	1.19;1.29	1.34***	1.29;1.39	1.27***	1.23;1.31	1.27***	1.22;1.31
Other	1.96***	1.82;2.11	1.77***	1.66;1.88	1.59***	1.48;1.71	1.42***	1.30;1.56	1.36***	1.26;1.47	1.26***	1.16;1.38
Collective	3.16***	2.87;3.49	2.65***	2.45;2.87	1.74***	1.57;1.91	3.06***	2.72;3.43	2.61***	2.36;2.89	1.53***	1.34;1.74
Region												
Flanders	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)
BCR	1.35***	1.28;1.43	1.12***	1.06;1.17	1.08*	1.02;1.14	1.51***	1.42;1.60	1.20***	1.14;1.27	1.15***	1.08;1.23
Wallonia	1.20***	1.16;1.23	1.28***	1.24;1.31	1.15***	1.12;1.19	1.26***	1.22;1.31	1.42***	1.38;1.46	1.23***	1.19;1.28
Care home residency												
No	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)	1	(Ref.)
Yes	1.69***	1.54;1.85	1.56***	1.45;1.68	1.27***	1.16;1.39	1.90***	1.69;2.14	1.64***	1.48;1.82	1.18*	1.04;1.35
Pseudo R-squared	0.0124		0.0084		0.0842		0.0091		0.0062		0.0589	
Df	17		17		17		17		17		17	
BIC	2,528,214		4,537,165		163,677		2,183,214		4,144,310		152,407	
N	1.222.026		1.193.104		1.165.960		965.678		941.160		916.455	

Note MRRs are adjusted for all variables presented; p≤0.05(*); p≤0.01(**); p≤0.001(***) marks significant difference with the reference group

Results also showed considerable mortality differences by income among middle-aged women and men. Compared to the high-income groups, women with no declared income had mortality rates more than 4 times higher in wave 1, and over 3.5 times higher in wave 2 and 3. Similarly, men with no declared income had 3 to almost 4 times higher rates in all three waves. Those in the low-income group also had higher mortality, 54–64% higher among women and 73–91% higher among men across waves. In contrast, elderly individuals with zero declared income did not experience significantly higher mortality compared to those with high incomes. Elderly with low incomes experienced 15–18% and 32–36% higher mortality compared to their peers in high-income groups.

Table 1 provides additional evidence of important sociodemographic differences in mortality during the three COVID-19 waves. The data revealed that middle-aged subpopulations with a migration background had lower mortality rates, even after adjustment for socio-economic background and pre-existing health situation. First-generation migrant women and men experienced a significant mortality advantage in all three waves, with 39–44% and 33–39% lower rates compared to Belgian natives. Second-generation migrant men had 14–26% lower rates; while second-generation migrant women only had a significant mortality advantage of 17% and 22% in wave 1 and 2, respectively. In the elderly population, significant mortality advantages were found for first-generation migrant women in wave 1 and for first-generation migrant men in wave 1 and 3.

As expected, large mortality differences were found by household living arrangements in all subpopulations and all three waves. Persons living in collective households (e.g., prisons, religious communities) experienced the highest MRRs compared to those living with a partner (even after adjustment for care home residency among the elderly). The gap between persons in collective households and those living with a partner appeared to decrease throughout the course of the epidemic. For example, MRRs for middle-aged women living in collective homes decreased from 7.19 (CI 5.57–9.29) in wave 1 to 5.28 (CI 4.20–6.63) in wave 2 and to 4.08 (CI 3.04–5.47) in wave 3. Living alone also was related to higher MRRs compared to living with a partner. For middle-aged women and men in one-person households, mortality was 74% and 102% higher in wave 1 compared to peers living with a partner. Again, the difference declined over the course of the epidemic with MRRs in wave 3 being 50% and 78% higher among middle-aged women and men living alone. For elderly women and men in one-person households, mortality was approximately 30% higher in all three waves compared to peers living with a partner. For elderly in a care home, mortality was significantly higher than their peers. Their MRRs also decreased throughout the course of the epidemic, both for women (MRR_{W1} 1.69 CI_{W1} 1.54–1.85 to MRR_{W3} 1.27 CI_{W3} 1.16–1.39) and men (MRR_{W1} 1.90 CI_{W1} 1.69–2.14 to MRR_{W3} 1.18 CI_{W3} 1.04–1.35).

The results also showed evidence of significant mortality differences by Region of residence (except for middle-aged women living in the BCR in wave 1). MRRs were highest for persons living in Wallonia and lowest for those living in Flanders, with the BCR in between. However, there was a different pattern in wave 1, with elderly women and men living in the BCR having the highest rates with MRRs of 1.35 (CI 1.28–1.43) and of 1.51 (CI 1.42–1.60), respectively.

Pre-existing health situations were significantly related to elevated mortality as well. Middle-aged women and men who received high shares of health benefits experienced over 2.5 times higher rates in all three waves compared to those who did not receive high health benefits.

To understand whether the size of relative inequalities changed during the epidemic, the adjusted MRRs for the COVID-period and the reference period were gauged by educational attainment and wave. Figure 4 shows the results for middle-aged women and men. Clear educational mortality differences were present in all waves, both during COVID as during the reference period. However, the strong gap between high-educated persons and the rest seems to have widened from COVID-wave 1 to 3. In wave 1, no excess mortality was observed. In wave 2, women and men with a primary degree or less experienced approximately 20% higher mortality compared to the reference period. In wave 3, excess mortality had risen to approximately 25% for these groups. An even more pronounced widening was observed for middle-aged men with an upper secondary degree with 13% excess mortality in wave 2 and 23% in wave 3. In contrast, the results by income group for middle-aged women and men (Supplementary figure A5) suggest that the pattern in income mortality differences is more robust than the pattern in educational mortality differences. The strong gap between high-income persons and persons in lower income groups remained consistent, except for a mortality deficit of 20% and more among middle-aged women (wave 2) and men (wave 1 and 3) who declared no income; and middle-aged men in the middle-income group (wave 1).

For elderly women and women, mortality differences by educational attainment or income group did not seem to vary during the COVID-waves (Supplementary figures A6 and A7).

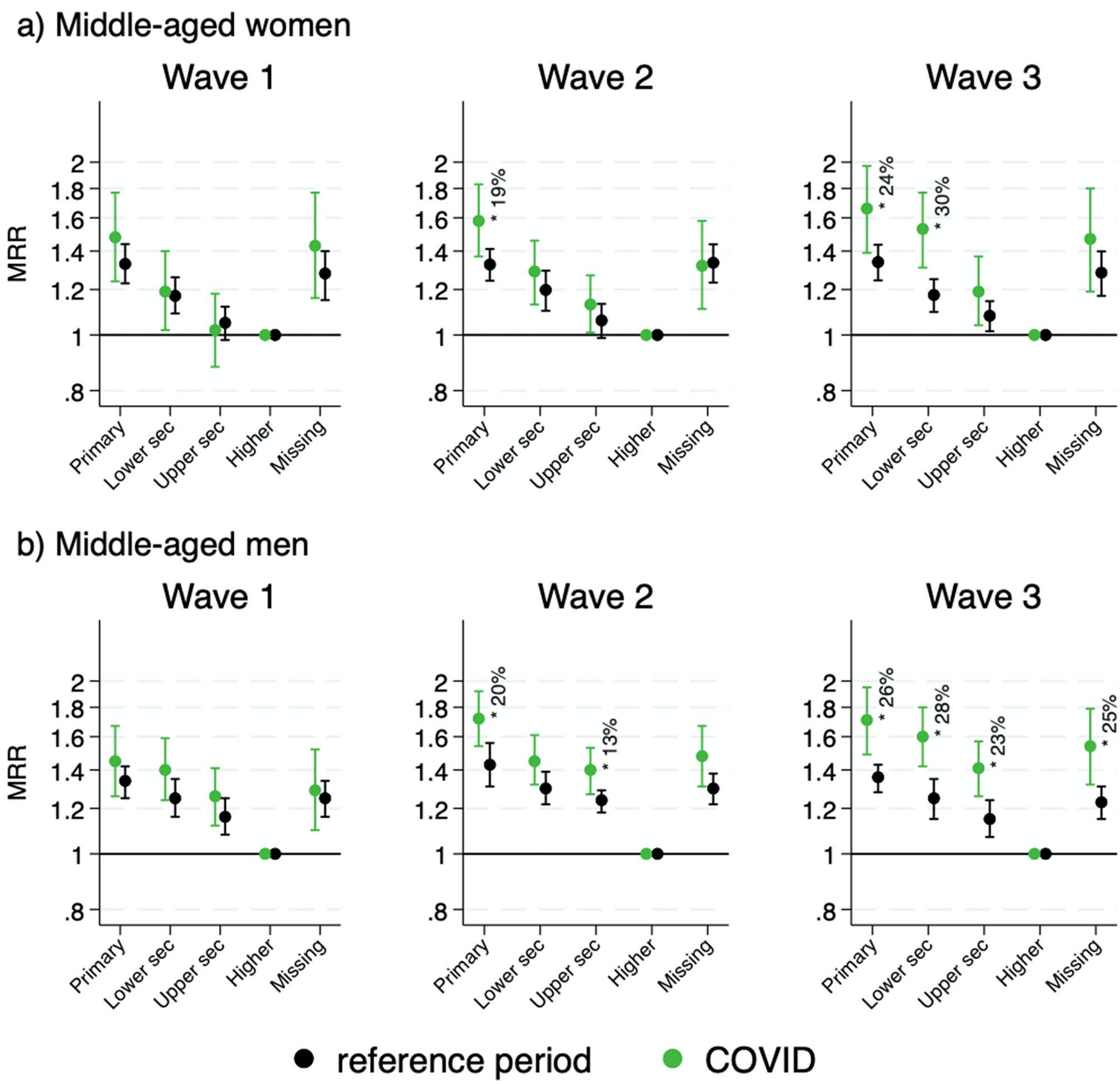

Fig. 4 Mortality Rate Ratios (MRRs) for the middle-aged population by educational attainment and wave. Note: MRRs are adjusted for age (years), personal income, migrant background, household living arrangement, region of residence, and having received a high share of health benefits; (*) marks significant excess mortality between the COVID-wave and the reference period ($p < 0.05$); (%) indicates the proportional change in MRR compared to the reference period

Discussion

The COVID-19 pandemic has had a significant impact on the mortality rates of the elderly population. During the first and second wave of the epidemic, their DSMRs were notably higher compared to the reference period, across all educational and income groups. During wave 3 there was some respite, as excess mortality was generally no longer significant. The most significant mortality increase was observed among care home residents, particularly during the first wave of the epidemic, with a gradual decrease in the second wave and even a mortality deficit in the third wave. According to a previous decomposition of excess mortality in Walloon care homes during the Spring of 2020, these significant increases in care homes were most likely the result of a combination of factors: the age composition of care home residents, their pre-COVID frail health condition, the high contamination rate in care homes, and the organization of care home resources and staff [26]. The COVID-19 virus was already present in care homes in Belgium at the early start of the epidemic [28, 29] and its spread in Belgian care homes was intensified due to the government's delayed response [3, 30, 31]. The evolution through consecutive waves might be attributed in part to the successful implementation of prevention and vaccinations campaigns in Belgium, especially among the elderly [32, 33]. The mortality deficit among care home residents observed in the third wave can be explained by several factors. First, care home residents and staff were prioritised in the vaccination campaign meaning they could receive their first dose of the COVID-19 vaccine from January 5th, 2021 onward. Approximately 6% of persons older than 65 years completed their full primary vaccination before the start of wave 3 [34]. All other elderly persons without prespecified health risks were invited to get vaccinated from March 1st, 2021 onward and that was widely embraced in Belgium with complete primary vaccination rates of 93% among the 65+population on October 31st, 2021 [32]. Second, Vandael and colleagues [29] report that care homes increasingly implemented infection prevention and control measures and gained additional support by the Regional health authorities during the second wave. It is highly likely that these good practices also contributed to reduced mortality among care home residents during wave 3. Third, the observed mortality during wave 3 may be influenced by difficulties in identifying care home residents in 2021. The most recently available information on care home residency dates from January 1st, 2020, in contrast to the reference years 2015–2019 for which annual information is available. From this group of identified care home residents, the frailest individuals died early in the epidemic, resulting in a relatively healthier population in care homes during wave 3. In addition, the epidemic had an influence on the composition of the care home population, as an unknown proportion of residents left their care home to be with their family and the influx of new residents was restricted by COVID-19 control measures or fear of contagion [26].

Regarding temporal patterns in *mortality excess by socioeconomic variables*, DSMRs for the elderly population showed that all educational groups experienced significantly higher absolute mortality during the first and second COVID-wave. In wave 3, only elderly men with a primary or lower secondary degree experienced excess mortality. Results by income group showed similar findings. Among the middle-aged, excesses were generally not significant, except for the primary-educated men in wave 2, the (lower) secondary educated men and women in wave 3 and the high-income men during wave 1 and 3. When considering relative mortality inequalities by socioeconomic group over time, results for the elderly population demonstrate that COVID-19 did not fundamentally alter the traditional pattern of higher mortality rates among lower socioeconomic groups. In contrast, for the middle-aged population, educational inequalities intensified during COVID-waves 2 and 3 compared to the reference periods. While controlling for age, income, sociodemographic background and the pre-existing health situation, middle-aged women and men with a primary degree or less experienced significantly higher mortality in COVID-wave 2, expanding the education mortality gap with their high-educated peers. In wave 3, the educational mortality gradients became even steeper for middle-aged women and men with a primary education or less, and for those with a lower secondary education. Notably, middle-aged men with an upper secondary degree also experienced a significant mortality excess during wave 3. Given that COVID-19 is a syndemic pandemic, there are numerous underlying mechanisms that contribute to this vulnerability [1]. Lower educational levels may be associated with a lower accessibility to sound coping mechanisms, a more limited knowledge about how to implement COVID-19 lockdown and hygiene measures, and with poorer healthcare [9, 10, 35]. Clear educational differences have been observed in COVID-19 vaccination [33]. However, this may only partly explain this finding because of the timing late in the third wave for the population 18 to 64 years old [32]. Lower educated socioeconomic classes typically work in occupations that increase exposure to the virus, especially in sectors characterised by constant human contact (bus drivers, retail staff, cleaners, etc.) compared to those working in sectors that allow working from home or in a more protected environment [36]. Overall, these findings for education are consistent with previous findings that pre-existing socioeconomic inequalities in all-cause and COVID-19 specific mortality have deepened due to the outbreak itself, lockdown measures and the disruption of daily life during the epidemic [15, 37].

Whereas relative educational mortality inequalities seem to have widened during the COVID-epidemic for the middle-aged population, the results regarding income mortality inequalities differ. MRRs for middle-aged women and men show a stable or even decreasing pattern of income inequalities over time, when controlling for age, educational attainment, sociodemographic background and the pre-existing health situation. Notably, mortality deficits were observed for the vulnerable group of women (wave 2) and men (wave 1 and 3) with no declared income, as well as for middle-income men in wave 1. However, it is important to acknowledge that the most recently available income data dates from 2017. In an evaluation of the effectiveness of Federal and Regional social policy measures in Belgium during 2020, Wizan, Neelen and Marchal found that –especially federal-income support measures were successful in mitigating a significant proportion of income volatility induced by the pandemic [38]. It is possible that COVID-19 emergency government support measures may have contributed to lower mortality rates for these vulnerable groups than expected from the reference period.

The increasing relative risks of the lower educated in successive waves align with the Fundamental Cause Theory [16, 39] and the SDTh [14, 15]. As COVID-19 was a new infectious disease, insights in risk factors and prevention initially lacked. These gradually came to development when public health control and prevention measures were put in place. One could thus expect that mortality inequalities were generally smallest during the first wave and highest during the second and third wave. This trend was observable in middle-aged people for educational inequalities. For income, however, no such changes could be observed, nor for the elderly population. These findings clearly demonstrate the need for further research into the underlying mechanisms and interplays between education, income, age and health status. In our view, educational attainment and the effective use of the associated resources play a powerful role in understanding Belgian excess mortality during COVID-19. We hypothesise that the implemented COVID emergency government measures may have been effective in controlling income mortality inequalities (and even decreasing them for some groups in some waves). Specifically for elderly persons, the timing and broad roll-out of the vaccination campaign seem powerful explanations for the presented findings. Regarding the elderly population, there was a noticeable contrast between those residing in care homes and those living independently.

Our study has several limitations. First, during the time of our analysis, it was not feasible to distinguish deaths specifically caused by COVID-19. Therefore, we were unable to investigate the underlying factors contributing to the excess mortality observed during the different waves of the epidemic. Excess mortality can result from a variety of factors, including a reduction in mortality for specific causes, such as traffic accidents, and an increase in mortality due to other causes. Hence, excess mortality should be interpreted as mortality related to the COVID-19 epidemic rather than people dying from COVID-19. Excess mortality is however a useful indicator to estimate the total impact of the COVID-19 epidemic, as it considers not only deaths directly caused by COVID-19, but also deaths that may have been indirectly caused by the pandemic due to factors such as delayed medical care and disrupted healthcare systems [40].

Second, it is also important to note that we did not dispose of data on occupation, health seeking behaviour, uptake of government guidelines, and other determinants of mortality differences, which could influence this study's findings. In addition, information on educational attainment was based on data of the 2011 census, and personal income for the years 2019–2021 was based on 2017 income information. Yet, the age groups involved are not the most mobile in terms of educational attainment. Income information was grouped into three categories based on income deciles, which may limit the variability over time. The available income information may not capture extent of income differences fully, especially among care home residents. Differences in mortality rates by income were generally not significant among the elderly in care homes, possibly due to a selection effect, as entering a care home is relatively expensive in Belgium, and only people with higher incomes can afford it. The variable used in the study only measures taxable income and not wealth, which includes assets such as property, investments, and savings.

Third, the absence of data on incidence and survival also restricts the ability to fully examine the socioeconomic inequalities related to COVID-19. The study by Angelici and colleagues on educational patterns in COVID incidence in Rome followed a clear pattern through successive waves, with higher incidence initially seen among the higher-educated, which later shifted to being higher among the less-educated [9]. This finding is consistent with the extended Fundamental Cause Theory. In order to better understand the direct effects of the spread of COVID-19 and its implication on excess mortality in the Belgian situation, further analyses using incidence data and/or cause-specific data to disentangle COVID-19 as a cause of excess mortality [40]. Future studies should explore how different causes of death interact with COVID-19 mortality to generate excess mortality and how this is patterned by socioeconomic and – demographic characteristics.

Our study's main strength is the comprehensive dataset that allowed for a detailed analysis of subgroups. We were able to include all deaths in the country, and a wide range of sociodemographic and socioeconomic determinants. Our study is also among the first to assess trends across different waves in socioeconomic inequalities in COVID-19 excess mortality using individual-level data.

Conclusion

Elderly men experienced the highest absolute mortality burden during all three COVID-waves, followed by elderly women, middle-aged men, and middle-aged women. More specifically, care home residents consistently experienced higher mortality rates during the first and second wave compared to peers living in other living arrangements. In wave 3, care home residents showed significant absolute mortality deficits compared to the reference period. Compared to the reference period, the largest increases in mortality, in absolute terms, are found among the elderly population during the first and second COVID-wave. Only some specific groups of elderly persons experienced excess mortality during wave 3. In relative terms, the COVID-19 epidemic did not fundamentally alter the traditional pattern of educational and income mortality inequalities among the elderly population. In contrast, the middle-aged population experienced an increase in relative educational mortality inequalities compared to the reference period. Meanwhile, the income mortality gap for middle-aged women and men remained stable or even diminished for some specific groups in some waves. The increase in relative educational mortality inequalities among the middle-aged provide support for the Fundamental Cause Theory, as well as for the SDTh. It is likely that the broad roll-out of COVID-19 government support measures and successful vaccination campaign in Belgium mitigated the relative income mortality inequalities in the middle-aged population and socioeconomic mortality inequalities among the elderly population.

Abbreviations

BCR	Brussels Capital Region
DSMR	Directly Standardised Mortality Rates
ISCED	International Standard Classification of Education
MRR	Mortality Rate Ratios
SDTh	Stages of Diseases Theory

Supplementary Information

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Supplementary Material 1

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Author contributions

LVdB: Conceptualization, Methodology, Validation, Formal analysis, Writing of the original draft, Writing - Review & Editing, Visualization. SG: Conceptualization, Methodology, Validation, Writing of the original draft, Writing - Review & Editing. BD: Conceptualization, Methodology, Writing - Review & Editing. KV: Conceptualization, Methodology, Validation, Formal analysis, Writing of the original draft, Writing - Review & Editing.

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Data availability

The analyses are based on data from a census-linked mortality follow-up study and cannot be made available due to privacy issues. Researchers can gain full access to the data by submitting an application to the Privacy Commission Belgium. In order to get permission to use data from the Belgian population register linked to census data an authorization request (in Dutch or French) needs to be submitted to the Belgian Data Protection Authority. The authorization request includes an application form and additional forms regarding data security. The necessary forms for the authorization request can be downloaded from the Data Protection Authority website (https://www.dataprotectionauthority.be). Next to information on the applicant and a list of requested data, the authorization request should specify why the data from the population register are necessary, for which time span data will be stored, and who will have access to the data.This research as well as the data adhere to the ethical code of scientific research in Belgium, see: http://www.belspo.be/belspo/organisation/publ/pub_ostc/Eth_code/ethcode_nl.pdf. All authors have signed the ethical code.

Declarations

Ethics approval and consent to participate

This research as well as the data adhere to the ethical code of scientific research in Belgium, see: http://www.belspo.be/belspo/organisation/publ/pub_ostc/Eth_code/ethcode_nl.pdf. All authors have signed the ethical code.

Consent for publication

Not applicable.

Competing interests

BD is Co-Editor-in-Chief at Archives of Public Health. The other authors declare that they have no competing interests.

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