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# Decomposing life expectancy changes in Spain in the COVID-19 pandemic and post-pandemic periods

Javier Llorca[1], Inés Gómez-Acebo[1,2,3*], Jéssica Alonso-Molero[1,2,3] and Trinidad Dierssen-Sotos[1,2,3]

**Abstract**

**Background** COVID-19 pandemic produced an important decrease in life expectancy at birth (LE) in 2020 in Western European countries, which has only been recovered in 2023. Spain has the highest LE in the European Union in spite of being one of the European countries more affected by the pandemic. The main goal in this study is to decompose the LE changes in Spain over the 2019–2023 period into age-specific and cause-of-death-specific contributions, and to compare them with those occurred in the pre-pandemic period 2010–2019.

**Methods** Data on LE and mortality rates by age and for each main group of causes was obtained from the Spanish National Institute for Statistics (INE) for years 2010, 2019, 2020, 2021, 2022 and 2023. We estimated age-specific contribution to changes in LE using the Arriaga decomposition method. Age-specific contributions were proportionally attributed to each main cause of death.

**Results** Age groups higher than 20 years old had negative contribution to LE in 2020 and, most of them, positive contribution in each year from then. Paradoxically, the most affected groups in 2020 have positive contribution to LE changes in the whole 2019/2023 period, while age groups under 45 years old have still negative contributions to LE. Infectious diseases were the main contributor to the sharp drop in life expectancy in 2020, accounting for – 1.33 years in the total population, with a more severe impact in men (– 1.43 years) than in women (– 1.16 years). From 2021 onwards, their contribution became positive, with a net effect close to zero by 2023 (– 0.11 in men; –0.20 in women). Neoplasms showed no signs of pandemic-related excess mortality. On the contrary, they maintained a positive contribution throughout the period, particularly in men (+ 0.25 years, compared to + 0.05 in women). Circulatory diseases also made a positive contribution to LE in the whole period (+ 0.09 years in men, + 0.16 years in women), although almost of it happened in 2023.

**Conclusion** Four years after the beginning of the pandemic, age groups under 45 years old have still negative contributions to LE. Tumours and cardiovascular diseases have the more positive contribution to LE changes in 2019/2023. Nevertheless, while tumours contributed positively each single year, cardiovascular diseases only made a relevant positive contribution in the post-pandemic 2023.

*Correspondence:
Inés Gómez-Acebo
ines.gomez@unican.es

Full list of author information is available at the end of the article

**Keywords** Life expectancy, COVID-19, Excess mortality, Age-specific mortality, Cause-of-death decomposition, Infectious diseases, Chronic diseases, Cardiovascular diseases, Spain

## Introduction

The World Health Organization (WHO) considered COVID-19 a public health emergency of international concern from 30th January 2020 to 5th May 2023 [1]. As for 12 March 2025, WHO reported 7.1 million cumulative deaths worldwide due to COVID-19 [2]. The number of deaths conceals unequal repercussion across different countries and demographic characteristics like age and sex [3]. Moreover, population health has been affected in different ways, including changes in health care functioning, leading to increased mortality due to other causes of death [4].

Life expectancy at birth (LE) is an extensively used measure on population health. It summarizes age-specific mortality rates in a determined period (usually a year) by estimating the average number of years a synthetic cohort of newborns would live if they were subjected to the age-specific mortality rates in the specified year. Changes in life expectancy are, thus, consequence of changes in age-specific mortality rates. Changes in LE summarize changes in mortality due to all causes of death; therefore, changes in LE in the pandemic or post-pandemic period cannot be exclusively attributed to the COVID-19 pandemic.

COVID-19 pandemic produced an important decrease in life expectancy at birth (LE) in 2020 in Western European countries, which has only been recovered in 2023 [5]. In these countries, it has been shown that worsening in mortality rates in people being 60 years old or more contributed to most of the 2020 losses in LE [3]. Spain has the highest LE in the European Union [5] in spite of being one of the European countries more affected by the pandemic [6]. According to the Spanish National Institute for Statistics [7], LE in Spain improved 1.46 years from 2010 to 2019 (both sexes), fell 1.25 years in 2020 and then increased to 83.77 years in 2023. By the way, 2023 was the first year with LE higher than that of the pre-pandemic 2019 (Supplementary Table 1).

LE changes throughout the pandemic entangled both direct and indirect effects of COVID-19. Examples of indirect effects could be an increase in mortality from acute cardiovascular events if people avoid hospitals for fear of infection [8] or by prolonged treatment times [9] or increase in mortality from cancer if treatments or screening have been delayed during the health system disruption in the first part of the pandemic [10, 11]. In addition to identifying organizational or public health shortcomings, separating these indirect effects could assist guide future policy and pandemic preparedness [12].

As demonstrated by Aburto et al. (2022), mortality in people aged 60 or more, and specially mortality in people aged 80 or more made the most important contribution to the decrease in LE in Spain in 2020 [3]. Additionally, we have shown that apart from infectious diseases, external causes of death and diseases of the circulatory system, but not tumours, have contributed to increases in years of life lost in Spain from 2019 to 2022 [4]. However, the contribution of each age-specific mortality rate and the impact of each cause of death on LE dropping in 2020 and later recovery until 2023 remained unstudied.

In a previous article [4] we showed that although LE in Spain in 2022 was only 0.45 years under LE in 2019, the gap between the observed and expected LE was 0.79 years, with figures slightly higher for men. In this study we extend that analysis to 2023. Moreover, the main goal in this study is to decompose the LE changes in Spain over the 2019–2023 period into age-specific and cause-of-death-specific contributions. We also compare these contributions with those occurred in the 2010/2019 period, which we take as reference of the normal (i.e., pre-pandemic) age- and cause-of-death specific contributions to changes in LE.

## Methods

### Source of data and data processing

We obtained data from the Spanish National Institute for Statistics (INE) website (https://ine.es/), which publishes estimates of LE and life tables for the whole Spanish population. We obtained life table data for years 2010–2019, 2020, 2021, 2022 and 2023 from the Spanish National Institute for Statistics (INE) [7]. Life tables were reported for 1-year wide age groups, 100 or more being the last interval. Data obtained from those life tables were age-specific mortality rate ($m_x$), average number of years lived in group $x$ for people dead in that group ($a_x$) and survivors at the beginning of age group $x$ ($l_x$).

Then the probability that people alive at the beginning of age group $x$ do not survive to age group $x+1$ is: $q_x = \frac{m_x w_x}{1+(w_x-a_x)m_x}$, where $w_x$ is the length of age group $x$.

The number of deaths in age group $x$ is: $d_x = l_x q_x$. The number of years lived in age group $x$ is $L_x = w_x l_{x+1} + a_x d_x$, and the remaining years of life for those in age group $x$ is $T_x = \sum_{i=x}^{100+} L_i$.

Data for years 2010 and 2019 were used to estimate average life expectancy changes in the pre-pandemic period.

Data of cause of death by main groups in the ICD-10 [13] were also obtained from the INE website (https://ine.es/) in the following age groups: <1 year, 1–4, then 5-year wide age groups, the last group being 95 year or more, so we collapsed life tables accordingly. In this regard, from 2020 on the "infectious diseases" group includes codes relative to COVID-19: U04.9 (severe acute respiratory syndrome [SARS], unspecified), U07.1 (COVID-19, virus confirmed), U07.2 (virus not identified) and U10.9 (multisystem inflammatory syndrome associated with COVID-19, unspecified). ICD-10 codes for each group are described in Supplementary Table 2.

**Estimation of expected life expectancy in 2023**

To estimate the expected LE had the pandemic not occurred, we obtained a linear regression model of observed LE (Y variable) on year, for years 2010–2019. Then we extrapolated this model for year 2023. We report the expected LE 95% confidence interval obtained as prediction ± 1.96× standard error of the prediction. P values were obtained via Wald test. This method extends to 2023 the predictions we have already reported for 2020–2022 [4]. The rational of using linear models in our analysis is based on both practical and theoretical considerations. Studying trends, ten-year periods could be considered short term. Then, from the theoretical point of view, any smooth function can be locally approached with a linear model (viz., using first-order Taylor's series). From the practical point of view, LE 2010–2019 linear regression has $R^2$ = 0.90, which also supports this approach.

**Decomposing the life expectancy changes by age**

Several methods have been developed to decompose LE changes. In brief, the stepwise replacement method was developed by Andreev in 2002 and Horiuchi et al. (2008) developed the linear integral decomposition method, which has been previously used to disentangle age-specific effects and impact of COVID-19 deaths on changes in LE ([3]and Aburto et al., 2022 PNAS Segunda version). Previous methods, such as Arriaga's [14] or Pollard's [15], are variants of the stepwise replacement [16]. Comparisons between different methods showed that they obtained about the same results when interaction effects are negligible [17] except when applied to relatively large changes in a long period [16].

In this section we use the terminology of Munira et al. (2023) [18]. We estimated the 1-year wide age-specific contribution to changes in LE using the Arriaga decomposition method [14, 18]. Changes in mortality rates in any age group $x$ has both direct and indirect effects on LE. Direct effect is due to the increasing or decreasing years lived within age group $x$. Indirect effect is due to the years lived in later age groups by people surviving the $x$ age group.

For instance, with the terminology used in the previous section and writing years as superscript, the direct effect of age group $x$ on life expectancy changes from 2019 to 2020 is estimated as

$$C_x^D = \frac{l_x^{2019}}{l_0}\left(\frac{L_x^{2020}}{l_x^{2020}} - \frac{L_x^{2019}}{l_x^{2019}}\right);$$

the indirect effect is

$$C_x^I = \frac{T_{x+1}^{2020}}{l_0}\left(\frac{l_x^{2019}}{l_x^{2020}} - \frac{l_{x+1}^{2019}}{l_{x+1}^{2020}}\right)$$

and the total contribution of age group $x$ to LE changes is

$$C_x = C_x^D + C_x^I.$$

In these formulas, $L_x$ is the number of years lived within age group $x$, $l_x$ is the number of people alive at the beginning of group $x$, and $T_x$ is the total number of years lived within age group $x$ and beyond.

It is note worthing that the indirect effect depends on the number of years lived after the studied age group $x$ ($T_{x+1}$), so it tends to be lower when age increases, the last age group having no indirect effect.

Of note, the sum of contributions of all age groups should equal the total LE change:

$$\sum_{i=0}^{95+} C_x = LE_{2020} - LE_{2019}$$

**Decomposing the life expectancy changes by cause**

In order to estimate life expectancy changes by cause, we collapsed the 1-year wide age groups data into 5-year wide groups. Then, the contribution of age group $x$ to change in LE in 2020, $C_x$, can be decomposed into proportions due to each cause of death $i$, using the following formula:

$$C_x^i = C_x\left(\frac{R_x^{i,2020}m_x^{2020} - R_x^{i,2019}m_x^{2019}}{m_x^{2020} - m_x^{2019}}\right)$$

Where $R_x^{i,2020}$ is the proportion of deaths in age group $x$ due to cause $i$ in year 2020.

All the analyses were carried-out using Stata 18/SE (Stata Corp., College Station, Tx, USA) [19].

**Changes needed in age-specific mortality rates to contribute 0.1 year to life expectancy**

Interpreting LE changes as small as 0.1 year could be challenging. In order to make it easier the interpretation

**Table 1** Observed and expected life expectancy in 2023

| Sex | Observed LE | Expected LE (95% confidence interval) | *P* value |
|---|---|---|---|
| Both | 83.77 | 84.01 (83.63, 84.40) | 0.08 |
| Men | 81.11 | 81.43 (81.04, 81.81) | 0.10 |
| Women | 86.34 | 86.52 (86.13, 86.90) | 0.35 |

of our results, we provide as reference a conversion between changes in mortality rates and LE changes. In fact, there is no one-to-one correspondence between mortality rates and LE; therefore, this section is only intended to facilitate interpretability with a metric that is both easier to interpret and less accurate than LE.

We calculated changes needed in mortality rates in each group $x$ to contribute 0.1 year to LE in 2019–2020 (both sexes) as:

$$\frac{\left(m_x^{2019} - m_x^{2020}\right)}{C_x \times 10}$$

### Note on terminology

Although the period the WHO consider COVID-19 a public health emergency of international concern was from 30th January 2020 to 5th May 2023 (WHO, 2023), in order to make the writing more fluid, elsewhere in the text we call the period 2010/19 the pre-pandemic period; 2020/22 the pandemic period, and 2023 the post-pandemic period.

## Results

### Expected vs. observed life expectancy in 2023

Spanish population lost 1.25 years in LE in 2020 (Suppl. Tables 1 and 3); this figure was worse for men (−1.27 years; Suppl. Table 4) than for women (−1.16 years; Suppl. Table 5). LE rebounded in 2021 (+0.74 years); paused in 2022 (+0.06 years) and rebounded again in 2023 (+0.69 years) (Suppl. Figure 2). Observed vs. expected LE in 2023 is shown in Table 1. Observed LE in 2023 was 0.34 years under what could have been expected had the pandemic not occurred. This difference was 0.32 years for men and 0.18 years for women. In all three results the observed LE was inside the 95% confidence interval of the prediction, so we cannot rule out these results were due to random variation.

### Pre-pandemic contributions to changes in life expectancy

In the whole article, we use the pre-pandemic (2010/19) results as reference for both the pandemic and the post-pandemic results. In this section we briefly present the pre-pandemic trend.

Regarding age-specific contributions to changes in LE, results are displayed in Fig. 1 and Suppl. Tables 3, 4 and 5, second column. All ages contributed positively to

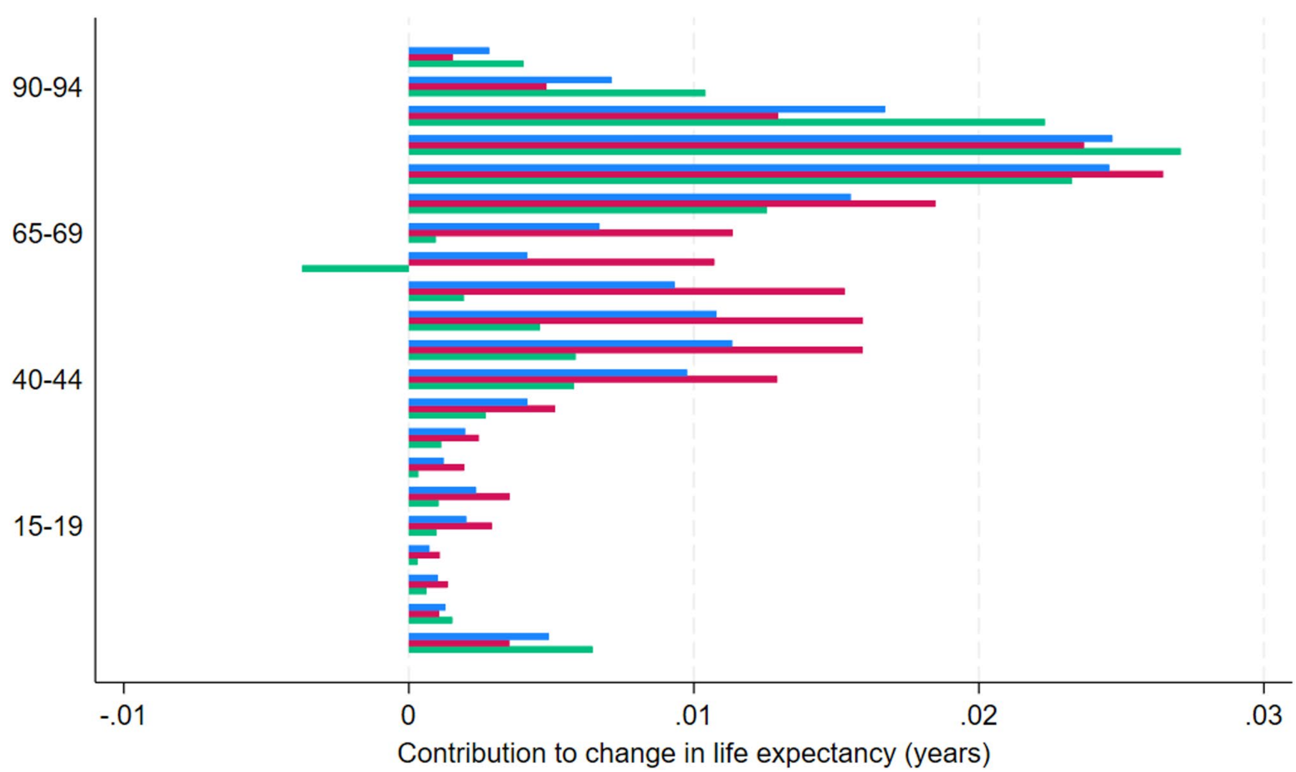


**Fig. 1** Contribution to change in life expectancy by age groups: Yearly average change in the pre-pandemic 2010/19 period. Blue: both sexes, green: women, red: men. Positive results indicate improvement in life expectancy

changes in life expectancy in 2010/19, with higher contributions in middle aged adults (40–59 years old) and people aged 70 years or more, with smaller contribution in people aged 60–69. There were, however, differences between men and women. Age-specific contributions to changes in LE for men were higher than those for women in all ages from 10 to 79 years old. In people older than 80, the contribution for women was higher than that for men. Of note, the “valley” in women aged 60–69 makes these ages contributing negatively or close to zero, which is not seen in men.

Regarding cause-specific contributions to changes in LE, results are displayed in Suppl. Table 6, third column. In the pre-pandemic period, LE was increasing in 0.162 years per year on average, with faster increase in men (0.195) than in women (0.130). The groups of diseases more contributing to this increase were diseases of the circulatory system (0.075 years for both sexes, 0.079 for men, 0.083 for women) and tumours (0.048 years for both sexes, 0.071 for men, 0.022 for women). The third group of diseases was those not elsewhere classified, with figures far lower than those due to tumours (0.011 years for both sexes, 0.017 for men, 0.009 for women). The contribution of infectious diseases was only 0.007 for both sexes (0.010 for men, 0.005 for women). Diseases of the nervous system, mental disorders and diseases of the musculoskeletal system contributed slightly negatively to changes in LE. The higher differences between men and women happened in tumours, diseases of the respiratory system and not elsewhere classified (all of them with lower contribution for women), and mental disorders (with lower contribution for men).

### Pandemic and post-pandemic contribution of age groups to changes in life expectancy

Figure 2 displays the impact of each age-group in changes in LE in 2019/2020 (orange line), 2020/2021 (green line), 2021/2022 (red line) and 2022/2023 (blue line). The solid black line shows the total for 2019/2023 period. In 2020 (orange line), all age-group from 20 years old on contributed negatively to changes in LE. The 2020-line clearly departures from the 0-reference from 50 years-old on; the higher contribution being made by 75–79 years-old group for men and 80–84 years-old group for women.

The partial recovery in LE in 2021 (green line) was mainly due to improvements in mortality in age groups over 65 years-old for both women and men. Changes in LE in 2022 (red line) were mixed, with positive results for men aged 50–70 and negative for men aged 85 + and women aged 70 + years old. Finally, changes in LE in 2023 (blue line) were positive in almost age groups and clearly positive for both men and women 50 years old or more. Numeric results on age-group contributions to changes in LE appear in Supplementary Tables 3–5.

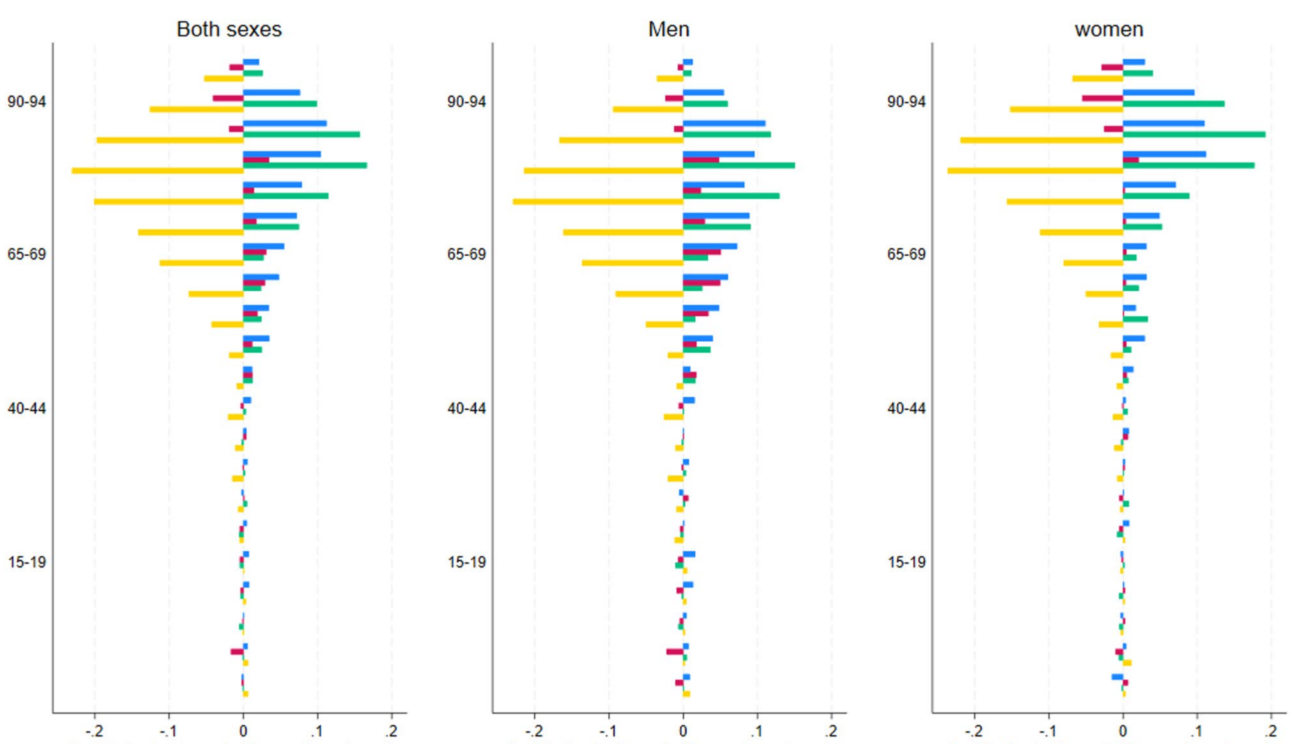


**Fig. 2** Contribution to change in life expectancy by age groups: pandemic and post-pandemic period. Orange: 2020, green: 2021, red: 2022, blue: 2023. Total change in 2019/2023 (black solid line). Positive results indicate improvement in life expectancy

The comparison between the yearly average in the pre-pandemic period 2010/2019 (black line) and the pandemic/post-pandemic period 2019/2023 (blue line) appears in Fig. 3. In almost age groups the contribution to changes in LE in 2019/2023 is still under the trend in the pre-pandemic period. Of note, most age groups under 45 years old and the group 95 years or more still have negative contributions to changes in LE four years after the beginning of the pandemic.

The same information of Fig. 2 appears in Fig. 4, this time organized to compare the contribution of each age group for men and women in each analysed year. In the first pandemic year (2020), the contribution to change in LE was more negative for men (red line) than for women (green line) in age groups 55–79 years old. In groups older than 80, the contribution for women was more negative. In the second pandemic year (2021), the contribution to changes in LE was more positive for men in age groups 60–75 years old and more positive in women in age groups 80 years old or more. In 2022, some positive contribution to change LE can be found for men 45–84 years old. Then, negative contributions to change in LE appeared for women 85 years old and more and, in less amount, for men in the same age groups. Finally, in the first post-pandemic year (2023), all groups from 50 years old on positively contributed to changes in LE for both women and men, although the contribution for men was higher than for women from 50 to 74 years-old people.

### Pandemic and post-pandemic contribution of causes of death to changes in life expectancy

The contribution of each group of causes of death to changes in LE appears in Fig. 5, Supplementary Figs. 1–5 and Supplementary Table 6. Figure 5 shows that the group of infectious diseases (including COVID-19) was the main contributor to the sharp drop in LE in 2020 accounting for – 1.333 years in the total population, with a more severe impact in men (– 1.427 years) compared to women (– 1.158 years). From 2021 onwards, its contribution became positive, with a net effect close to zero by 2023 (– 0.111 in men; –0.196 in women). Other groups that have small negative contribution to LE in the whole period were external causes, diseases of the genitourinary system and, for men, endocrine diseases. For men, the group tumours has the most positive contribution in the whole period (+ 0.253 years), followed by diseases of the circulatory system (+ 0.085 years) and diseases of the respiratory system (+ 0.077 years). For women, however, tumours group has only a small positive contribution in 2019/23 (+ 0.053 years), while the group of diseases of circulatory system (+ 0.156 years) made the main positive contribution to LE change in the whole period for women.

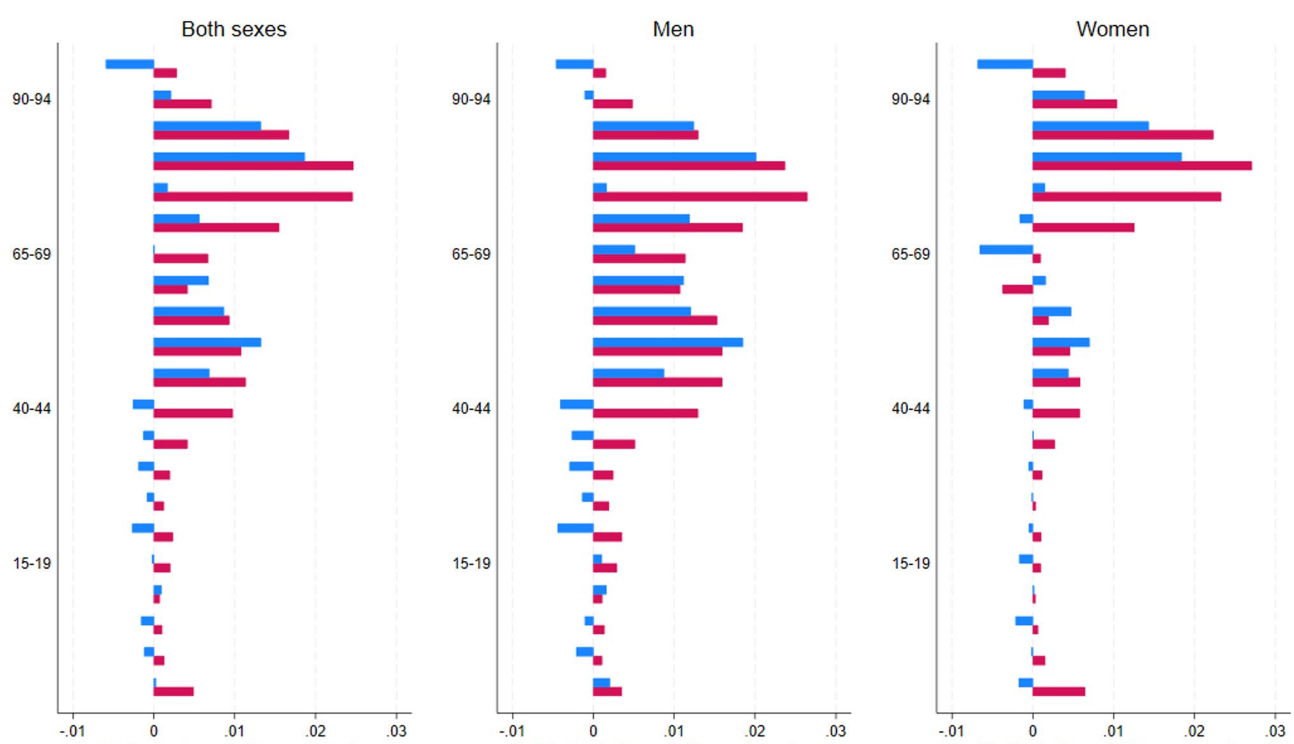


**Fig. 3** Contribution to change in life expectancy by age groups: comparing pre-pandemic with pandemic/post-pandemic periods. Blue: yearly average in 2019/23. Red: yearly average in 2010/19. Positive results indicate improvement in life expectancy

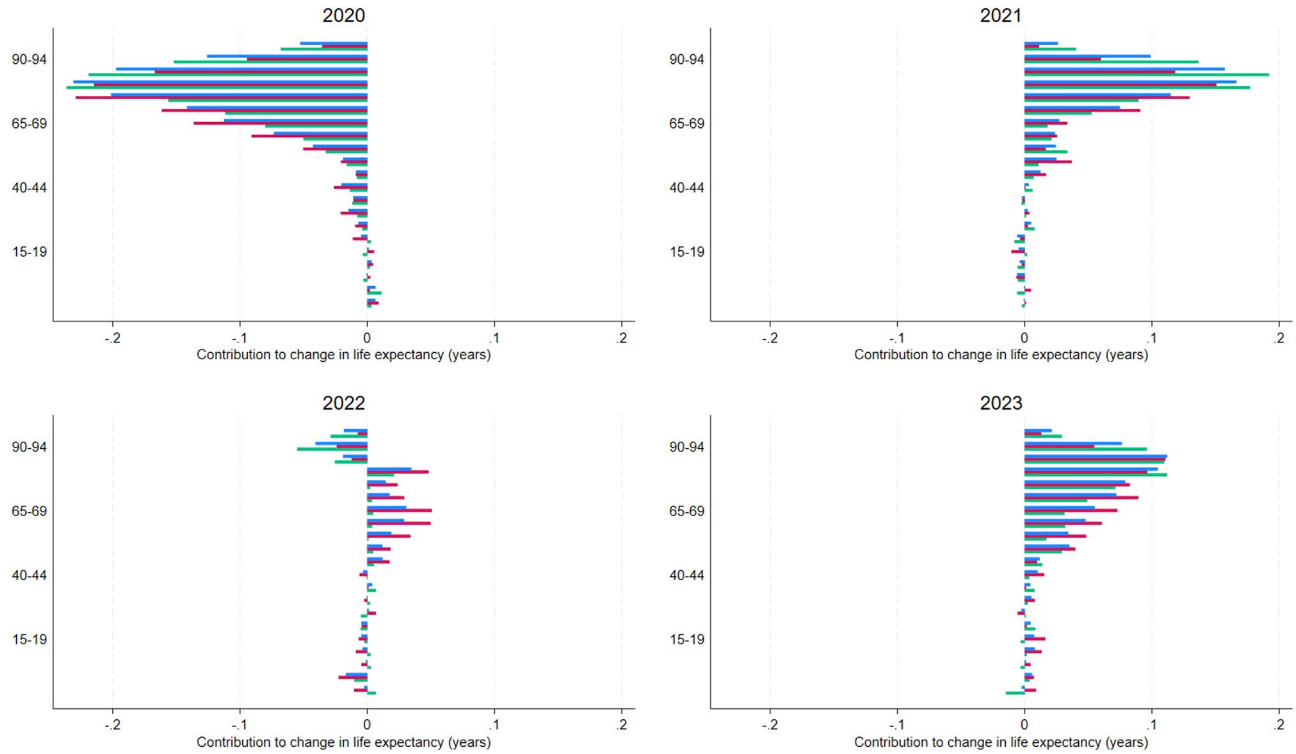


**Fig. 4** Contribution to change in life expectancy by age groups: comparing sexes, 2020 to 2023. Blue: both sexes, red: men, green: women. Each graph represents one year. Positive results indicate improvement in life expectancy

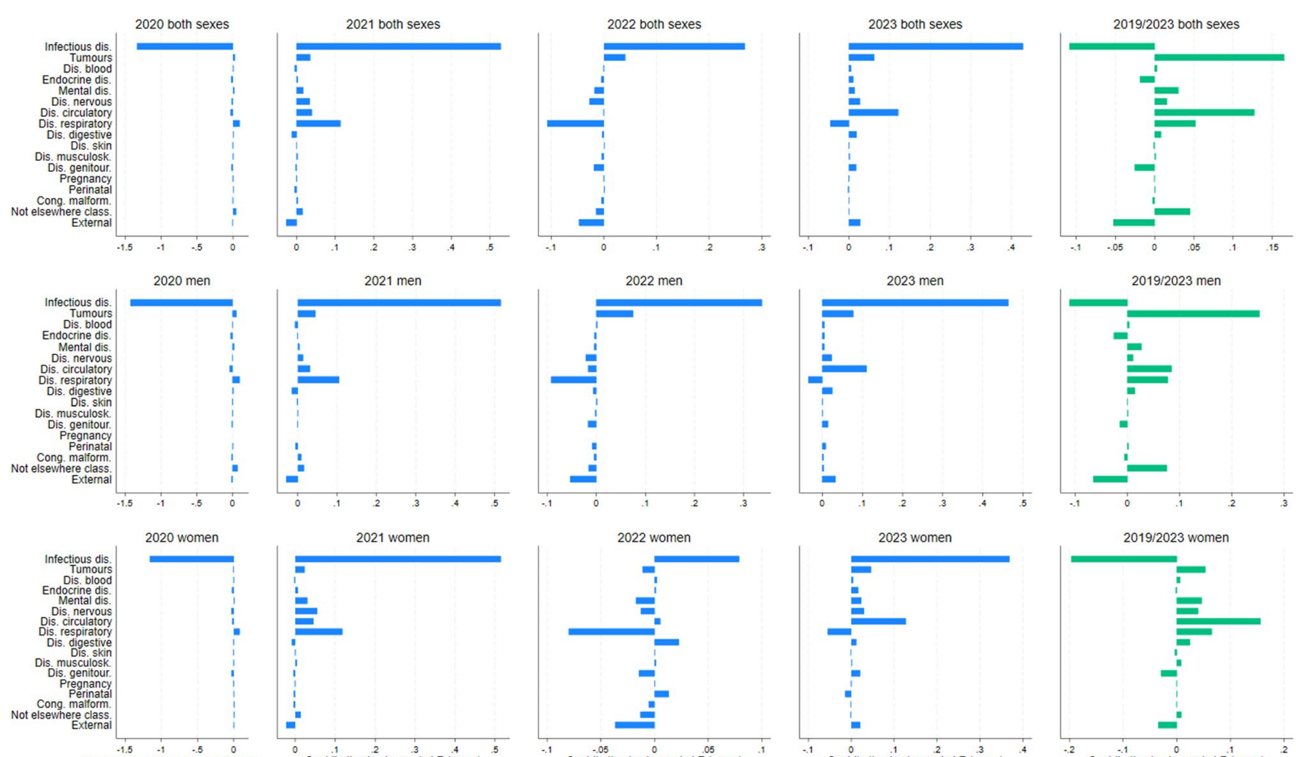


**Fig. 5** Contribution to change in life expectancy by each cause of death, 2020 to 2023. Each graph shows all causes in the same year. Results for the whole pandemic/post-pandemic period are marked in green. Positive results indicate improvement in life expectancy

In Supplementary Figs. 1–5 and Supplementary Table 6, we display the contribution to LE change of each group of causes of death separately, so that the trend for each cause of death could be properly seen. In Suppl. Figures 1–5, all groups of causes are classified according to the magnitude of their contribution to LE change. Suppl. Figure 1 presents the contribution to LE of infectious diseases. Suppl. Figure 2 presents the contributions to changes in LE of the following four groups in magnitude: diseases of the circulatory system, diseases of the respiratory system, tumours and causes not elsewhere classified. The next quartet of groups in importance appears in Suppl. Figure 3: external causes, diseases of nervous system, mental diseases and endocrine diseases. Suppl. Figure 4 displays the following groups of causes of death in importance: diseases of the digestive system, diseases of the genitourinary system, diseases of the musculoskeletal system and diseases of the skin. Finally, Suppl. Figure 5 shows the evolution of the contribution to LE of the four causes of death with lower magnitude: congenital malformations, perinatal period, diseases of the blood and pregnancy. In all these Figures, the mean contribution in 2010/19 is provided as reference.

The infectious diseases group contributes with a 1.333-years decrease in 2020 LE; the decrease was deeper for men (−1.427 years) than for women (−1.1586 years). In further years, the infectious diseases group contributes positively to changes in LE, although the total contribution in 2019/23 period was negative (−0.109 years for both sexes; −0.111 years for men; −0.196 years for women) (Suppl. Figure 1 and Supp. Table 6).

The group of causes of death more contributing to LE increases in the period 2019/23 is that of tumours (+ 0.165 years), although it is remarkable that tumours behave differently for men than for women. For women, its pre-pandemic contribution to change in LE was small; then, its contribution was slightly negative in 2020 and 2022, and positive in 2021 and 2023, making a total in 2019/2023 of + 0.053 years. In men, however, tumours positively contributed to change in LE in each year from 2020 to 2023, with a total for the whole period of 0.253 years (Suppl. Figure 2 and Suppl. Table 6).

Diseases of the circulatory system contributed slightly negative to changes in LE in 2020 (−0.033 years), although its contribution in the whole 2019/2023 period was positive (0.127 years for both sexes; 0.085 years for men and 0.156 years for women). It is note worthing that almost of it was due to improvements in 2023. The contribution of the diseases of the respiratory system group to changes in LE was irregular, with positive contributions in 2020 and 2021 -the main pandemic years- and negative contributions in 2022 and 2023.

External causes of death have a small negative contribution to LE in 2020, 2021 and 2022, as well as in the whole 2019/23 period (Suppl. Figure 3 and Suppl. Table 6). Other causes of death have lower contributions to changes in LE (Suppl. Figures 3–5 and Suppl. Table 6).

### Changes needed in age-specific mortality rates to contribute 0.1 year to life expectancy

Using data from 2019 to 2020 years, Supplementary Table 7 provides the changes in age-specific mortality rate needed to contribute 0.1 years to LE. Equal changes in mortality rate in two age groups have different effects on LE. Altogether, the younger the age group, the lower the change needed in mortality rate. For instance, the same effect on LE would be produced by increasing (or decreasing) mortality rate by 1.22 per 1,000 newborns, by 2.50 per 1,000 people aged 40–44, by 6.20 per 1,000 people aged 60–64, and by 20.44 per 1,000 people aged 80–84 years. It should be highlighted that the relationship between age and change needed in mortality to produce the same effect on LE is far from lineal.

Of note, results displayed in Supplementary Table 7 are year-specific and could be different for changes in years other than 2019/2020. As indicated in the Methods section, these results are only provided to have an approximate conversion rule, which could facilitate the interpretation of small changes in LE.

## Discussion

After being harshly damaged by the irruption of the COVID-19 pandemic in 2020, 2023 is the first year LE in Spain is higher than that of the pre-pandemic 2019. Contrary to the government campaign [20], overcoming pre-pandemic LE level does not mean that we are stronger than in 2019; firstly, because years of life lost in the pandemic period cannot be retrieved [21]; secondly, because the mean LE improvement in 2019/23 (0.06 years) is still less than a half of that in 2010/19 (0.15 years). Vaccination against COVID-19 and restrictive measures as lockdowns as well as changes in case fatality rate by emerging SARS-CoV-2 variants could have contributed to the rebound in LE after the first pandemic waves; however, the LE bouncing back has not been homogeneous across ages and causes of death. The threat of COVID-19 is receding, although understanding the differences in age and causes of death would allow to identify areas where consequences of the pandemic are still deleterious, which could eventually lead to identify priorities for both public health and research.

### Differences in life expectancy contribution by age

The variation in contribution to LE changes by age shows that age groups higher than 20 years old had negative contribution in 2020 and, most of them, positive contribution in each year from then. Paradoxically, the most affected groups in 2020 have positive contribution to LE changes in the whole 2019/2023 period, while age groups under 45 years old have still negative contributions to LE. Of note, the yearly trend in 2019/2023 is still under that of the pre-pandemic 2010/19 period for almost age groups, highlighting that the toll for the pandemic has not completely been overcome.

The fact that age groups over 45 years old had positive contributions to LE changes in the whole 2019/2023 period, while younger groups had negative contributions could be related to the differential implementation of non-pharmaceutical interventions (NPIs) across age groups during the pandemic. In Spain, as in many European countries, mitigation strategies were not uniformly applied to children, adolescents, and adults, reflecting evolving scientific evidence, societal priorities, and governance structure.

In the paediatric population, particularly among school-aged children, NPIs were specifically designed to preserve in-person education while minimizing the risk of transmission. The Ministry of Health, together with regional authorities, implemented comprehensive protocols for the academic year 2021–2022 that included mandatory use of face masks from the age of six, stable classroom cohorts ("bubble groups"), enhanced ventilation protocols, and systematic management of outbreaks based on case counts within classrooms [22, 23]. Classroom closures were no longer mandatory unless ≥ 20% of students tested positive within a seven-day period [22, 23]. These educational policies were strongly driven by concerns over the indirect consequences of prolonged school closures on children's cognitive development, psychosocial wellbeing, mental health, and widening social inequalities [24, 25].

By contrast, NPIs targeting the adult population predominantly focused on limiting mobility, restricting public gatherings, enforcing curfews, and temporarily closing non-essential businesses depending on regional epidemiological trends [20, 26]. The decentralised health system in Spain allowed for regional tailoring of interventions, resulting in heterogeneity in the timing and intensity of restrictions across autonomous communities.

The differential approach by age was underpinned by epidemiological evidence available at the time, indicating a lower risk of severe COVID-19 outcomes among children compared to adults [27]. Nevertheless, emerging variants of concern, such as Delta and Omicron, with higher transmissibility across all age groups, prompted successive adaptations of prevention strategies during late 2021 and 2022 [25, 28].

Vaccination policies also followed an age-prioritised rollout, with elderly and high-risk populations receiving the first doses and subsequent boosters [29], while paediatric vaccination for children aged 5–11 years was initiated in December 2021 [30]. Actually, vaccination rates by age were unequal. In spite of Spain having succeeded in rapidly vaccinating, the initial COVID-19 vaccination protocol reached 80% or more in all age groups over 50 years all by July 2021, while vaccination in people aged 25–49 was about 50% coverage and hardly reached 10% in people aged 18–24 [31].

#### Differences in life expectancy contribution by cause

The group of infectious diseases, which from 2020 on included COVID-19, had little, although positive, contribution to changes in LE in the pre-pandemic period. Then, its contribution to changes in LE was by far the most negative in 2020 and the most positive in each year from 2021 to 2023. In the whole 2019/2023 period, its contribution is still negative. We could assume that COVID-19 was responsible for this contribution. The first and second COVID-19 waves happened in 2020, leading to increases in age-specific mortality rates and huge increases in years of life lost [4], while vaccination against SARS-CoV-2 and new emerging virus variants with lower case mortality rate led to lower figures from 2021 on [4].

Apart from the infectious diseases group, we limited our discussion to the three groups showing higher contributions to LE changes: tumours, diseases of the circulatory system and diseases of the respiratory system.

Before the pandemic, tumours were contributing more to LE changes for men (+ 0.07 years/year) than for women (+ 0.02 years/year). In the pandemic/post-pandemic period, tumours also have more positive contribution to changes in LE in men than in women. Changes in mortality by cancer in other developed countries show contradictory results. A slightly decrease in mortality rates has been reported in Sweden, but not in Denmark, Finland and Norway in the pandemic period [32]. In Denmark, actually, cancer contribution to LE in 2020 and 2021 was even more positive than that of the 2014-19 reference period [33]. Other studies are still limited to the 2020/21 period. A study on 16 countries found changes in mortality rates ranging − 13.9% in Georgia-2021 to + 2.6% in Austria-2020 [34]. Small increases in mortality rates were found in the US [35], where cancer contribution to changes in LE -although positive- was much lower than that of 2010-19 period [36]. Our results suggest that COVID-19 had no or little short-run influence on cancer mortality [37], although COVID-19 operating as a competing cause of death in patients with cancer could partially explain the decreases in mortality rates happening in the pandemic, but not the post-pandemic, period [34, 38].

In the pre-pandemic period, the only group of causes of death contributing more positively than tumours to LE changes was that of diseases of the circulatory system. Contrasting with its pre-pandemic behaviour, in the pandemic period cardiovascular diseases contribution to LE was about nil; therefore, its positive contribution for the whole period is mainly due to the post-pandemic 2023. A remarkable feature is that the contribution for women LE about doubled that for men LE. Other studies limited to the pandemic period have found an increase in mortality due to cardiovascular diseases in four Scandinavian countries, especially in Norway and Finland [32], while in Denmark they contributed positively to LE in 2020 but negatively in 2021 [33]. Pizzato et al. (2025) in their study on mortality in 2020–2021 found important excess cardiovascular mortality in 9 out of 16 countries. Aburto et al. (2022) showed that cardiovascular diseases contributed negatively to LE in the US, especially in black people [36]. Relevant increases in mortality rates by heart disease and stroke were also found in the first two years of the pandemic in the US [35] and by cardiac arrhythmias, heart failure and hypertensive diseases in England and Wales [39].

Diseases of the respiratory system had remarkable positive contributions to LE changes in 2020 and 2021, and negative contributions in 2022 and 2023. Under-mortality by respiratory diseases has been reported in the four Scandinavian countries (Denmark, Finland, Norway and Sweden) in 2020-22 [32] and the US in 2020–2021 [35]. Low influenza and other respiratory virus circulation in 2020 and 2021 (ECDC, 2023), probably due to NPIs measures [40] could have responsible for positive contributions to LE in those years; as decreases in deaths close to 80% of baseline had been reported [35]. Then, an influenza epidemic in 2022 (ECDC, 2023) could have contributed to negative contributions to LE in 2022 and 2023.

The indirect effect of the COVID-19 pandemic on mortality in 2020–2022 varied across countries, according to a study conducted in 24 countries. This suggests that mortality displacement is not a satisfactory explanation for the cross-country variation, and that the COVID-19's variable impact across countries has further diversified LE trajectories [12], although that study was limited by the fact that most studied countries -including Spain- had no data on LE in 2022 by the time the authors made their analysis.

### Strengths and limitations

This article has some limitations. This article has some limitations. First, a harvesting effect may have influenced our findings, as COVID-19 disproportionately affected individuals with chronic conditions (e.g., cancer, ischemic heart disease, chronic respiratory diseases) [41–45]. The pandemic may have accelerated deaths that would otherwise have occurred later, particularly during 2020–2021. Such mortality displacement, which has been described in influenza epidemics [46] or heat waves [47], could partially account for the positive contributions to LE observed in subsequent years, notably for cardiovascular diseases. In addition, there may be some heterogeneity in the classification of causes of death throughout the study period. During the early waves of the pandemic, deaths among individuals with underlying conditions—such as cancer—who also had COVID-19 were likely primarily attributed to COVID-19. However, as the pandemic progressed and public concern on COVID-19 diminished, such deaths were more frequently classified under the underlying condition rather than COVID-19. This variability in cause-of-death assignment may affect comparability across different phases of the pandemic. Analysing COVID-19 mortality as part on the infectious diseases group instead of as its own category is a methodological constraint. By one hand, it makes it questionable to attribute mortality changes to the pandemic. By the other hand, it sidesteps the issue of eventual misclassification of cause-of-death as the pandemic goes by. Finally, we do not present results on age-cause decomposition analysis, which could have provided valuable information to interpret the trends found in early ages. However, results on such age-cause decomposition analysis proved to be too noisy even for frequent causes of death as circulatory diseases or cancer; therefore, we consider those results uninformative and leaved them out of the paper.

As for the strengths, firstly we have used nationwide population data from the Spanish office for statistics (INE). Secondly, we have compared pandemic and post-pandemic results with 10-year pre-pandemic trends obtained from the same source. Thirdly, to our knowledge this is the first article including LE estimates for the whole 2023, which allows to detect some changes in trend, such as in diseases of the circulatory system, which have about no influence in LE changes in 2019/22, and then made a relevant positive contribution in 2023. Previous studies including data only to May 2023 (the formal end of the pandemic) failed in detecting the improving in LE happening in 2023 in several European countries, including Spain [48].

## Conclusion

In conclusion, 2023 is the first year after the COVID-19 pandemic that LE in Spain overcomes that of the 2019; however, the yearly average LE improvement in 2019/2023 is still less than a half of that in 2010/2019. The rebound in LE after the first pandemic waves has not been homogeneous across ages and causes of deaths. Four years after the beginning of the pandemic, age groups under 45 years old have still negative contributions to LE and the yearly trend in 2019/2023 is still under that of the pre-pandemic period for almost age groups. Tumours and cardiovascular diseases have the more positive contribution to LE changes in 2019/2023. Nevertheless, while tumours contributed positively each single year, cardiovascular diseases only made a relevant positive contribution in the post-pandemic 2023. Respiratory diseases had positive contribution to LE changes in the first two years of the pandemic (2020 and 2021), and then negative contributions in 2022 and 2023. Differences in age and causes of death contributions to LE changes would allow to identify areas where consequences of the pandemic are still deleterious, which could lead to identify priorities for public health.

**Abbreviations**

| | |
|---|---|
| INE | Spanish Institute for Statistics |
| LE | Life expectancy |
| NPIs | Non-pharmaceutical interventions |

## Supplementary Information

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Supplementary Material 1.

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Not applicable.

**Authors' contributions**
J.L. contributed to the conception and design of the study. All authors were involved in data acquisition and contributed to drafting the manuscript. The first draft was written by J.L., I.G.A., J.A.M. and T.D.S. All authors reviewed and provided input on the final version of the manuscript.

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**Data availability**
All data analysed in this study are publicly available. The dataset supporting the conclusions of this article can be accessed and downloaded for non-commercial research purposes via the following anonymised OSF view-only link: [https://osf.io/mnz9p/?view_only=28f119a5daea4160a191a1e31154eb96 ] (https://osf.io/mnz9p/?view_only=28f119a5daea4160a191a1e31154eb96).

## Declarations

**Ethics approval and consent to participate**
All data we used are in the public domain. Therefore, we did not ask for authorization of any ethics committee.

**Consent for publication**
Not applicable.

**Competing interests**
The authors declare no competing interests.

**Author details**
[1]Preventive Medicine Group, University of Cantabria, Avda. Herrera Oria s/n, Santander 39011, Spain
[2]IDIVAL-Valdecilla Health Research Institute, Santander, Spain
[3]Consortium for Biomedical Research in Epidemiology and Public Health (CIBERESP), Institute of Health Carlos III, Madrid, Spain

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## Publisher's Note