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Contributions of age groups and causes of death to the sex gap in lifespan variation in Europe

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Abstract

Much less is known about the sex gap in lifespan variation, which reflects inequalities in the length of life, than about the sex gap in life expectancy (average length of life). We examined the contributions of age groups and causes of death to the sex gap in lifespan variation for 28 European countries, grouped into five European regions. In 2010–15, males in Europe displayed a 6.8-year-lower life expectancy and a 2.3-year-higher standard deviation in lifespan than females, with clear regional differences. Sex differences in lifespan variation are attributable largely to higher external mortality among males aged 30–39, whereas sex differences in life expectancy are due predominantly to higher smoking-related and cardiovascular disease mortality among males aged 60–69. The distinct findings for the sex gap in lifespan variation and the sex gap in life expectancy provide additional insights into the survival differences between the sexes.

Keywords: Sex gap; lifespan variation; life expectancy; Europe; cause-specific mortality

Introduction

It is well known that males live, on average, shorter lives than females worldwide (WHO 2018a; Thornton 2019). In Europe, a disadvantage in life expectancy for males has been recorded for more than 200 years (Glei and Horiuchi 2007). Currently in Europe, the sex gap in life expectancy amounts to almost seven years, albeit with substantial regional differences (Janssen 2020a). The many previous studies on sex differences in life expectancy have generally shown that both biological factors and sex differences in risky health behaviours contribute to the lower life expectancy among males than females (see e.g. Rogers et al. 2010; McCartney et al. 2011; Luy and Wegner-Siegmundt 2015; Austad et al. 2016). There is also evidence that mortality related to cardiovascular disease (CVD), smoking, alcohol consumption, and external causes, mainly at adult ages, contributes substantially to the sex gap in life expectancy (Spijker and Blanes-Llorens 2009; Beltrán-Sánchez et al. 2015; Trias-Llimós and Janssen 2018; Janssen 2020a; Zarulli et al. 2021). However, much less is known about the sex gap in inequality in length of life (age at death), also known as lifespan variation. This is the case even though the added academic and societal value of studying lifespan variation as well as life expectancy has been clearly demonstrated in demography in recent years (e.g. Tuljapurkar 2010; van Raalte et al. 2018).

The extensive body of literature on the sex gap in life expectancy has shown that the life expectancy advantage for females can be explained by both biological and social factors, with differences in health-related behaviours being a clear manifestation of the latter (Rogers et al. 2010; McCartney et al. 2011; Luy and Wegner-Siegmundt 2015; Austad et al. 2016). Among the biological factors that have been documented are that females have two X chromosomes, whereas males have only one, increasing their susceptibility to disease (Viña et al. 2005, Migeon 2006; Marais et al. 2018). It should, however, be noted that the most recent literature has painted a more

complex picture involving several additional mechanisms, such as cellular senescence, protein synthesis, and epigenetic alterations (Hägg and Jylhävä 2021). The role of biological differences in the sex gap in life expectancy has been empirically demonstrated by studies showing that even in conditions where the lifestyles of males and females are similar—such as in convents of nuns and cloistered monks (Luy 2004) or in adverse situations, such as famines and epidemics (Zarulli et al. 2018)—survival rates are, on average, higher for females than males.

However, in addition to biological factors, sex differences in health behaviour also play an important role in the sex gap in life expectancy. In particular, young males' higher propensity to engage in risky and violent behaviours appears to explain part of their disadvantage in life expectancy (Gjonça et al. 2005; Rogers et al. 2010). For example, compared with females, males have historically consumed more tobacco, alcohol, and psychoactive substances; have been more likely to engage in dangerous driving; and have exhibited less knowledge and awareness about the dangers of risky behaviours (Waldron 1985; Courtenay 2000; Wardle et al. 2004, Natterson-Horowitz and Bowers 2019). Moreover, unhealthy dietary habits and low levels of engagement with preventive health measures among males may contribute to their observed disadvantage (Vaidya et al. 2012). Of the different lifestyle factors, cigarette smoking has been identified as a particularly important factor in determining the sex differences in life expectancy in high-income countries (Beltrán-Sánchez et al. 2015; Janssen 2020a; Janssen et al. 2021). Janssen (2020a) estimated that smoking-attributable mortality contributed, on average, three out of seven years to the sex differences in life expectancy in 30 European countries in 2014. Trias-Llimós and Janssen (2018b) found that in eight Central and Eastern European countries, alcohol-attributable mortality accounted for at least 15 per cent of the sex gap in life expectancy in 2012 (which was, on average, 10 years). These contributions are substantially larger than those of the biological component of

the sex gap in life expectancy, which has been estimated to range from 0.5 to 2.0 years (Luy and Wegner-Siegmundt 2015).

It should be acknowledged, however, that some of the sex differences in behaviours may be explained by the higher concentration in males of certain sex hormones, such as testosterone, which has been linked to an increased tendency to engage in high-risk behaviours (Archer 2006). It is also important to acknowledge the influence of social factors (Rogers et al. 2010), such as culturally defined gender roles, responsibilities, and experiences. Indeed, many behaviours typical of males or females might be dictated by social roles and social norms (e.g. women are encouraged to engage in healthy behaviours and caregiving roles, whereas men are encouraged to engage in hazardous behaviours). Moreover, while there has been a tendency to consider environmental and social factors as non-biological and genetic factors as biological, recent discoveries have led to a blurring of this classic dichotomy. It thus appears that the magnitude of the sex gap in ageing and survival is variable and depends on complex interactions between genetic and environmental factors, which, in humans, also include socio-cultural factors (Lemaître et al. 2020).

In particular, the biological and health-behaviour-related factors that contribute to the life expectancy disadvantage for males can be translated into specific sex differences in causes of death. For example, the higher levels of oestrogen in females provide protection from certain cardiovascular diseases, such as ischaemia/reperfusion, hypertensive heart diseases, and heart failure (Xiang et al. 2021). Sex differences in cigarette smoking can be linked to sex differences in mortality from lung cancer, other smoking-related cancers, and chronic obstructive pulmonary diseases (COPD) (Freedman et al. 2008). Similarly, sex differences in heavy drinking can be tied to sex differences in mortality from liver cirrhosis or alcohol poisoning (Room et al. 2005), and sex differences in dangerous driving and intentional injuries can be linked to sex differences in

external causes of death, such as accidents (Room et al. 2005). Indeed, previous research has documented the large contributions of CVD (Beltrán-Sánchez et al. 2015), smoking-related mortality (Janssen 2020a), alcohol-related mortality (Trias-Llimós and Janssen 2018), and external causes of death (Spijker and Blanes-Llorens 2009) to the life expectancy disadvantage for males. Importantly, however, the causes of death that contribute the most to sex differences in life expectancy are not the same in all countries or regions (Beltrán-Sánchez et al. 2015; Trias-Llimós and Janssen 2018; Janssen 2020a; Feraldi and Zarulli 2022).

Like the causes of death that contribute most to the sex gap in life expectancy, the age groups that contribute most to this gap are also well known. For example, higher premature mortality among males than females contributed substantially to the sex gap in life expectancy in Europe in the 1950–70 period (Glei and Horiuchi 2007). Moreover, since 1950, the contribution of mortality at older ages has been increasing because old-age mortality rates have declined more rapidly among females than males (Zarulli et al. 2020; Zarulli et al. 2021). Nonetheless, the contributions of different age groups to the sex gap in life expectancy vary across European regions (Glei and Horiuchi 2007; Zarulli et al. 2020; Feraldi and Zarulli 2022).

However, much less is known about the sex gap in lifespan variation. Although interest in researching lifespan variation alongside life expectancy has increased over the last decade (Aburto et al. 2020), studies that focus on sex differences in lifespan variation are still lacking. This is an important omission, because as an indicator of *average* length of life, life expectancy conceals the *variation* in length of life, which can be substantial and may differ considerably between males and females (Vaupel et al. 2021; Bergeron-Boucher et al. 2022). Lifespan variation—which can be captured by indicators of dispersion in age at death, such as the standard deviation (SD)—provides additional information about longevity that is not conveyed by life expectancy alone

(Edwards and Tuljapurkar 2005; Aburto and van Raalte 2018). Lifespan variation is an important concept in the study of longevity, as it reflects inequality in length of life at the population level (Smits and Monden 2009) and can be interpreted as an indicator of the uncertainty in age at death at the individual level (Gillespie et al. 2014). High lifespan variation, which indicates high uncertainty about the remaining length of life for individuals and patients, could negatively affect both personal and medical spending or investments because of their lower—or at least less certain—expected utility (Edwards 2013; Nepomuceno et al. 2022). Moreover, when monitoring health conditions across nations, lifespan variation is a powerful measure for assessing the degree of heterogeneity in population health (van Raalte et al. 2018).

From previous studies reporting on lifespan variation among males and females, we know that lifespan variation is higher for males than for females (Edwards and Tuljapurkar 2005; Colchero et al. 2016). However, we know far less about the causes of death or age groups that contribute the most to either increasing or decreasing the sex gap in lifespan variation, research which could shed light on the factors underlying the sex differences in lifespan variation. We cannot assume that the factors contributing to the sex gap in lifespan variation are similar to those that contribute to the sex gap in life expectancy, given that lifespan variation and life expectancy are generally negatively correlated, with higher life expectancy usually being accompanied by lower lifespan variation (van Raalte et al. 2014; Permanyer et al. 2018). Moreover, a negative correlation between their trends over time has been observed: that is, throughout the twentieth century, life expectancy at birth increased while lifespan variation declined (Engelman et al. 2010; Vaupel et al. 2011; Permanyer and Scholl 2019; Aburto et al. 2020).

Therefore, our objective in this paper is to analyse the contribution of different causes of death and age groups to the sex gap in lifespan variation and to assess how these differ from those

contributing to the sex gap in life expectancy. Our analysis covers 28 European countries, both individually, grouped into five European regions, and combined (Europe), using data from 2000 to 2015. We focus on the results for Europe as a whole and for the five European regions, for the most recent five-year period (2010–15).

In addition to providing a recent picture of the sex gap in lifespan variation in Europe, this paper is, to our knowledge, the first to assess the contributions of age groups and causes of death to the sex gap in lifespan variation. Our findings are expected to add to the literature on lifespan variation and, in particular, to our understanding of the sex gap in lifespan variation and any regional differences in it. In addition, our findings should help policymakers seeking to reduce health inequalities, by identifying which age groups and which causes of death should be the focus of efforts to reduce the sex gaps in both life expectancy and lifespan inequality in Europe.

We expect to find that the causes of death and age groups that contributed the most to the sex gap in lifespan variation in Europe in 2010–15 differ from those that contributed the most to the sex gap in life expectancy. This hypothesis is driven in part by the observation by Seligman et al. (2016) that the causes of death that contribute to increases in life expectancy over time are not necessarily the same as those that contribute to decreases in lifespan variation over time. Moreover, while saving lives at younger ages is known to reduce lifespan variation because it compresses the age-at-death distribution, saving lives at older ages is known to increase lifespan variation because it expands the age-at-death distribution (e.g. van Raalte et al. 2014). Today, life expectancy levels are driven mainly by developments in mortality at older ages (Aburto et al. 2020).

Data and methods

Data

Using data for 28 European countries, we analysed Europe as a whole, five European regions (Nordic countries, Western Europe, Southern Europe, Central and Eastern Europe (CEE), and former Soviet republics (FSR)), and 28 individual countries for the 2000–04, 2005–09, and 2010–15 time periods. We selected all European countries for which data were available from our two main data sources (see later), unless their population was less than 1 million (Luxembourg, Iceland). We combined the data for several years to obtain more robust results.

The allocation of countries to regions for this paper follows the broader geographical concept of the Iron Curtain, which historically reflected different economic, political, and demographic dynamics in Europe (Emanuele et al. 2018). The non-Eastern-European regions are the Nordic countries (Denmark, Finland, Norway, and Sweden), the Western European countries (Austria, Belgium, Germany, France, Ireland, the Netherlands, Switzerland, and the United Kingdom), and the Southern European countries (Greece, Italy, Portugal, and Spain). The Eastern European regions are the CEE countries (Bulgaria, the Czech Republic, Hungary, Poland, Slovakia, and Slovenia) and the FSR countries (Belarus, Estonia, Latvia, Lithuania, Russia, and Ukraine).

We retrieved exposure, death count, and life table data by sex, single year of age (0–110+), and year from the Human Mortality Database (HMD 2019). The HMD is well known for its high data quality due to its strict protocols (Barbieri et al. 2015).

For information on causes of death by age, sex, country, and year, we used two data sources. For the non-Eastern-European countries and the CEE countries, we used death counts from the World Health Organization (WHO) Mortality Database (WHO 2019), while for the FSR

countries, we used cause-specific death counts from the Human Cause-of-Death Database (HCD 2021). We relied on two different data sources because in the WHO database, only a condensed list of causes of death is available for Belarus, Russia, and Ukraine, whereas a more detailed list of causes of death is available for the other countries. Drawing on the HCD information for Belarus, Russia, and Ukraine enabled us to use the same causes of death for these countries as for the others. See Appendix Table A1 for the availability of data by country in the three data sources.

Cause-specific death counts from both WHO and the HCD are categorized into five-year age groups, and the last open-ended age group is either 85+ or 90+, depending on the country. To end up with data by single year of age—in line with the HMD data and the aim of our analysis—we smoothed the age-specific deaths from WHO and the HCD and created an upper open-ended age group of 110+. For this purpose, in line with Aburto et al. (2018) and Wensink et al. (2020), we used the efficient estimation of smooth distributions by Rizzi et al. (2015), which was implemented in the R package 'ungroup' (Pascariu et al. 2018). This smoothing technique maintains total deaths across ages for the different causes of death. Supplementary material 1 illustrates, for those regions with data up to high ages, that the smoothing technique captured the original age-at-death distributions very well.

Cause-of-death classification

We selected 11 cause-of-death groups: (1) cancers attributable to smoking; (2) sex-specific cancers; (3) other cancers; (4) ischaemic heart diseases (IHD) & stroke; (5) rest of circulatory diseases; (6) mental disorders and nervous system diseases; (7) alcohol-attributable causes of death; (8) external causes of death; (9) infectious (respiratory) diseases; (10) non-infectious respiratory diseases; and (11) rest of causes of death. The detailed causes of death covered within

each cause-of-death group, and the associated ICD-9 and ICD-10 codes, can be found in Appendix Table A2.

The cause-of-death groups were selected based on two main criteria. The first related to their known contributions to the sex gap in life expectancy. The second related to their expected effects on either premature or old-age mortality because of the differential effects of premature and old-age mortality on lifespan variation (see Introduction). These expected effects are shown in Appendix Table A3 and described next.

The contributions to the sex gap in life expectancy of smoking-related mortality (e.g. Janssen 2020a; Wensink et al. 2020), alcohol-related mortality (e.g. Trias-Llimós et al. 2018a; Trias-Llimós, et al. 2018b, external causes of death (e.g. Spijker and Blanes-Llorens 2009), and circulatory diseases (e.g. Beltrán-Sánchez et al. 2015) are well documented. In addition, alcohol-related mortality has contributed substantially to recent trends in lifespan variation in Eastern European countries (Aburto and van Raalte 2018). Furthermore, we selected the 'mental disorders and nervous system diseases' cause-of-death group because these causes substantially affect old-age mortality (Bergeron-Boucher et al. 2020), and we included the 'infectious (respiratory) diseases' cause-of-death group because mortality at very young ages is due mostly to infectious diseases (Ferkol and Schraufnagel 2014).

In our analysis, we separated IHD & stroke from other of circulatory diseases because IHD & stroke affect females more than males, especially at older ages (Gao et al. 2019) and may therefore affect the sex gap in lifespan variation differently from other circulatory diseases. We studied the effects of smoking-related mortality by examining cancers sensitive to smoking and non-infectious respiratory diseases (including COPD), both following Aburto et al. (2018). We studied alcohol-related mortality by focusing on the causes of death wholly related to alcohol (e.g.

poisoning due to alcohol), in line with Trias-Llimós et al. (2018b). In addition, we studied sex-specific cancers (e.g. breast and prostate cancers) as a separate cause-of-death group, because breast cancer is much more prevalent among females and prostate cancer is much more prevalent among males (López-Abente et al. 2014).

To minimize the potential effects of differences between countries in classifying causes of death (Alter and Carmichael 1996), we used—in line with common practice—rather broad cause-of-death groups, as well as more selected causes of death, particularly for cancer mortality, for which national differences in coding are less important. However, national differences in the contributions of IHD & stroke, in particular, to sex differences in lifespan variation and life expectancy should be interpreted with caution, given that the tendency to attribute deaths to 'symptoms and ill-defined conditions' instead of to CVD varies across countries (e.g. Lozano et al. 2001). External causes of death and smoking-related cancers are less likely to be affected.

Methods

In this paper we focus on our main analysis: the results for Europe as a whole and the five European regions over the 2010–15 period. We report the results for 2000–04 and 2005–09 for the European regions in supplementary material 2 and the results for individual countries for the 2010–15 period in supplementary material 3.

In applying our method, we first aggregated the death and population numbers over the different countries comprising the different regions and then aggregated the yearly data over the different years. To estimate the sex gaps in lifespan variation and life expectancy, we aggregated by sex the yearly all-cause death numbers and exposure numbers from the HMD and obtained the relevant age-specific all-cause mortality rates. We applied standard period life table calculations (Preston et al. 2000) to the age-, sex-, and year-specific all-cause mortality rates to obtain life

expectancy at birth by sex. To measure lifespan variation, we computed the SD (σ) of the age-at-death distribution—the d_x column in the life table—from age zero up to age 110+. While there are several absolute and relative measures of lifespan variation, all are highly correlated (van Raalte and Caswell 2013). We used the SD because, being an absolute measure of variation, it is expressed in years, which makes it easy to interpret in conjunction with life expectancy (Edwards and Tuljapurkar 2005; García and Aburto 2019).

To quantify the contributions of different ages and cause-of-death groups to the sex gaps in life expectancy and lifespan variation, we applied the stepwise replacement decomposition method by Andreev et al. (2002) (see also van Raalte and Nepomuceno 2020). This demographic decomposition method allows for the accurate estimation of the contributions of different ages and causes of death to the differences in aggregate measures, such as the sex differences in life expectancy and lifespan variation. In both instances, we decomposed the advantage of females; thus, we decomposed the larger e_0 and smaller lifespan variation for females than for males. To obtain robust outcomes, we applied the decomposition method to data from age zero up to age 100 (instead of up to age 110+).

As the input for the decomposition method, we used the smoothed cause-specific mortality rates by age (0–100), sex, and period, which we aligned with the all-cause mortality rates by age, sex, and period based on the HMD. That is, we first calculated by period and sex the share of the smoothed age-specific cause-of-death numbers as part of age-specific, all-cause mortality (obtained by taking the sum of the smoothed age- and cause-specific deaths over the different causes of death). Second, we multiplied these shares by the respective HMD all-cause mortality rates to obtain the cause-specific mortality rates by age, sex, and period that were used—in matrix

format—as the input to the decomposition. We used the R package 'DemoDecomp' to perform the decomposition analysis (Riffe 2018).

Results

Over the 2010–15 period, European males displayed a 6.8-year-lower life expectancy at birth and a 2.3-year-higher SD in lifespan than European females (Table 1). However, there were clear regional differences in the sex gaps in life expectancy and lifespan variation. The sex gaps were considerably larger in Eastern Europe compared with non-Eastern Europe: 9.2 vs 4.8 years for life expectancy and 2.0 vs 1.3 years for lifespan variation. Sex differences in both life expectancy and lifespan variation were largest in the FSR countries and smallest in the Nordic countries.

<Table 1 about here>

Figure 1 shows the contributions of different age groups to the sex gaps in life expectancy and lifespan variation. We express the contributions in terms of their contributions to the advantage for females (or, conversely, to the disadvantage for males). For example, for Europe, we decomposed the 6.8-year-higher life expectancy among females than males and the 2.3-year-lower lifespan variation among females than males. Thus, for both measures, a positive contribution means that it contributed to the advantage for females (= the disadvantage for males). It is clear that all age groups contributed positively to the higher life expectancy among females, which indicates that mortality was lower for females than males across all age groups. However, when we look at lifespan variation, we see that the 70+ age groups—unlike other age groups—were negatively contributing to the sex gap in lifespan variation. The 60–69 age group contributed the most to the disadvantage in life expectancy for males, predominantly in the FSR. However, the 30–39 age group contributed the most to the disadvantage in lifespan variation for males, again mainly in the FSR. More generally, it can be observed that infant mortality was still playing an

important role in sex differences in longevity in Europe in 2010–15. Also, the contribution of mortality at young adult ages to the differences was particularly large in Eastern Europe, especially in the FSR.

<Figure 1 about here>

Figure 2 shows the contributions of the different causes of death to the sex gaps in life expectancy (upper panel) and lifespan variation (lower panel). In the 28 European countries combined, smoking-related cancers, IHD & stroke, and external causes contributed the most to the disadvantage in life expectancy for males, at 4.2 years out of 6.8 years (65.6 per cent). In the FSR countries, the contribution of external causes of death was particularly large (3.5 out of 11 years), whereas in the Nordic countries, the contribution of IHD & stroke was especially large (1.2 out of 4.4 years). In the remaining European regions, the contribution of smoking-related cancers was the largest.

<Figure 2 about here>

Turning to the sex differences in lifespan variation, external causes of death contributed the most to the disadvantage for males in lifespan variation across all European regions (1.4 out of 2.3 years). Interestingly, however, smoking-related cancers and IHD & stroke contributed only very marginally to the sex gap in lifespan variation. In the Western and Southern European countries, smoking-related cancers contributed positively to the higher lifespan variation among males than females. However, in the Eastern European regions, smoking-related cancers contributed negatively to the sex gap in lifespan variation.

The sex-specific cancers made a negative contribution to the disadvantage for males in both life expectancy and lifespan variation. This result is likely driven by breast cancer mortality among females occurring at younger ages than prostate cancer mortality among males.

By simultaneously examining the contributions of the age groups and causes of death to the sex gap in life expectancy (Figure 3), we found that the largest contribution to the sex gap in life expectancy in Europe was from the higher mortality among males aged 60–64 from smoking-related cancers and circulatory diseases. While IHD & stroke and smoking-related cancers at ages 75–79 contributed the most to the disadvantage for males in life expectancy in non-Eastern Europe, external mortality at ages 30–34 made the largest single contribution to this gap in Eastern Europe. Sex-specific cancers had a slightly counterbalancing impact at ages 30–79.

<Figure 3 about here>

When simultaneously examining the contributions of the age groups and causes of death to the sex gap in lifespan variation (Figure 4), it is relevant to consider what is happening below and above what we refer to as the threshold age. We define the threshold age as the age below which sex differences in mortality contribute positively to the higher lifespan variation among males than females; above the threshold age, sex differences in mortality contribute negatively to the higher lifespan variation among males. In the 28 European countries combined, the threshold age was between ages 70 and 75, but in the FSR countries, the threshold age was much lower (between ages 60 and 65), and in the Nordic and Southern regions, the threshold age was highest (between ages 75 and 80). External causes operated mainly below the threshold age and thus contributed substantially to the higher lifespan variation among males. Smoking-related cancers and IHD & stroke operated at ages both below the threshold age (positive contribution) and above it (negative contribution); hence, when added together, they contributed only marginally to the sex gap in lifespan variation. Sex-specific cancers were the only cause of death that contributed negatively to the sex gap in lifespan variation below the threshold age.

<Figure 4 about here>

Figure 5 categorizes the different age groups according to their contributions to the sex gaps in life expectancy and lifespan variation. It is clear that mortality below age 60 and mortality at ages 70+ both contributed to the higher life expectancy among females and therefore contributed to increasing the sex gap in life expectancy. Similarly, mortality below age 70 contributed to the lower lifespan variation among females and therefore also acted to increase the sex gap in lifespan variation. However, mortality at ages 70+ contributed to decreasing the sex gap in lifespan variation. Figure 5 also indicates that mortality at younger ages, particularly ages 10–29, contributed to increasing the sex gap in lifespan variation more than to increasing the sex gap in life expectancy. However, mortality at older ages, particularly ages 70–89, acted to increase the sex gap in life expectancy more than to decrease the sex gap in lifespan variation.

<Figure 5 about here>

Similarly, in Figure 6 we classify the causes of death according to their contributions to the sex gaps in life expectancy and lifespan variation. While external causes of death contributed to increasing the advantage for females in both lifespan variation and life expectancy, sex-specific cancers contributed to decreasing the sex differences in both indicators. The relative contributions of external causes of death were larger for the sex differences in lifespan variation than in life expectancy. In the majority of regions, smoking-related cancers and IHD & stroke contributed substantially to increasing the sex differences in life expectancy but not as much to the sex differences in lifespan variation. Moreover, we see that in the FSR countries, these two groups of causes acted to decrease the sex gap in lifespan variation.

<Figure 6 about here>

The results of additional analyses are shown in the supplementary material. Our analysis that covered the 2000–04 and 2005–09 periods (supplementary material 2) showed a modest

decline in the sex gap in lifespan variation in Europe but a modest increase in Eastern Europe from 2000–04 to 2010–15 (Figure S2.1). The threshold age increased slightly over time (Table S2.2). However, the contributions of the age groups and causes of death remained largely similar over time (Figures S2.2–S2.7).

Supplementary material 3 reports the results for the individual European countries over the 2010–15 period, indicating important differences between countries within the different European regions.

Our additional analysis which used the lifespan disparity measure e-dagger (Vaupel and Canudas-Romo 2003; Vaupel et al. 2011) instead of the SD (see supplementary material 4, Table S4.1) revealed small differences in the sex gap in lifespan variation, except in the FSR, where the sex difference when using e-dagger was 36 per cent larger than when using SD. This is because lifespan disparity measures such as e-dagger are generally more sensitive than SD to variation at very young ages (Vaupel et al. 2011). We observed no large differences in the contributions of the ages and causes of death (Figure S4.1).

Our additional analysis which analysed the sex gap in lifespan variation after age 15 instead of from birth (see supplementary material 4, Table S4.2) found that this resulted in a 20–30 per cent smaller sex gap in lifespan variation for the different regions, with the largest differences being found in CEE. This illustrates that the sex gap in lifespan variation is sensitive to mortality in the first years of life (Edwards and Tuljapurkar 2005), particularly in CEE. The contributions of age groups and causes of death to the sex gap in lifespan variation were largely similar. We compared our decomposition results using stepwise-replacement with those using Horiuchi decomposition technique, as part of sensitivity check but our results remain the same (Figure S4.2)

Discussion and concluding remarks

The sex gap in lifespan variation in Europe explained

Our paper contributes to the health inequalities literature by closely examining the sex differentials in survival through the lens of lifespan variation for the first time. We showed that in the 28 European countries combined in 2010–15, the SD in lifespan was 2.3 years higher for males, on average, than for females. This was in addition to the 6.8-year-lower average life expectancy for males than for females in Europe. Our findings indicate that in Europe, not only can males expect to live for fewer years than females, but there is also greater uncertainty about their age at death and, consequently, their remaining length of life. Uncertainty about length of life can have important implications at both the individual level, such as when planning for the future (e.g. additional schooling), and at the population level, for example in the areas of public health policy, medical spending, and/or investments by public health professionals (Nepomuceno et al. 2022). Moreover, our results provide a more complete picture of the heterogeneity in survival patterns in Europe.

The observed sex gap in SD of 2.3 years in the 28 European countries combined was larger than in any of the separate European regions (see Table 1). This is because of large cross-national differences in mortality profiles, particularly for males. In Eastern Europe, the age pattern of mortality was relatively young for males, whereas in non-Eastern Europe, the age pattern of mortality was more concentrated at older ages and more alike for males and females (see supplementary material 5, Figure S5.1). As a consequence, the lifespan variation for European males as a whole was rather large and was close to that for non-Eastern-European males, because it resulted from the combination of the two age patterns just mentioned. However, for European females, the age pattern of mortality was more similar across countries, and the lifespan variation

better represented a weighted average of the lifespan variation for females in the different regions. Consequently, the sex difference in lifespan variation was larger in Europe as a whole than in any of the separate European regions, including Eastern Europe.

We observed that sex differences in mortality at ages 30–39 contributed the most to the sex differences in lifespan variation. This can be explained partly by the large role of (sex differences in) mortality in this age group in determining (sex differences in) lifespan variation. Although this age group is well below the central age of death, mortality rates are higher at ages 30–39 than at younger ages because mortality increases exponentially starting at age 30 (Gompertz 1825). More importantly, sex differences in mortality were larger in this age group than in younger age groups (see supplementary material 5, Figure S5.1, 'Europe' plot). Specifically, this plot shows that from approximately ages 18–20 onward, sex differences in mortality slowly increase and grow rather large in the 30–39 age group.

It appears that the tendency of males to engage in more unhealthy and risky health behaviours (e.g. dangerous driving resulting in accidents; violence; extreme sports) (see Introduction) starts at young ages (e.g. Bina et al. 2006) and eventually leads to large sex differences in mortality in the 30–39 age group, consistent with previous research highlighting that mortality differences at young adult ages contribute substantially to sex differentials in mortality (e.g. Remund et al. 2018). Our observation that external mortality was the cause of death that made the largest contribution to the sex gap in lifespan variation, both in general and specifically at these young ages, further supports these findings. Indeed, there is ample evidence that violence, (transport) accidents, and (accidental) poisoning, which account for a large share of external mortality, are much more common among European males than European females (WHO 2020), especially at young ages (Aburto and van Raalte 2018).

The reasons for young adult men being more likely than (young adult) women to engage in risky behaviours have been previously discussed (e.g. Byrnes et al. 1999, Archer 2006; Rogers et al. 2010). Biological factors are among these reasons. For example, the higher concentration of testosterone in males might lead men to take more risks than women (Archer 2006; Batrinos 2012). However, most previous studies have focused on the role of psychological and social factors. Thus, they have linked the finding that men are more likely than women to engage in risky health behaviours to men having sensation-seeking personalities in response to their lower levels of arousal; to men regarding risk as a positive value (in line with the 'risk as value' hypothesis); and, more generally, to (perceived) gender roles and social norms (e.g. restrictions placed on risk-taking by society) (Byrnes et al. 1999; Courtenay 2000; Waldron et al. 2005; Roger et al. 2010; Hawkes and Buse 2020). Gender roles and stereotypes are important in determining how we interact with society, how we are perceived, how we perceive others, and what type of risks we are or choose to be exposed to (Courtenay 2000; Hawkes and Buse 2020). Indeed, the construction of masculinity in modern societies, in which men are expected to be strong, independent, and resilient, has likely spurred their greater propensity to take risks. Moreover, in line with the 'risk as value' hypothesis, risk-taking is regarded as a highly valued masculine tendency.

Outcomes for the sex gap in lifespan variation compared with outcomes for the sex gap in life expectancy

Our finding that external mortality, predominantly at young adult ages, was the main cause of death driving the sex differences in *lifespan variation* might seem to contradict our (and previous) findings that in recent decades, the sex gap in *life expectancy* in high-income countries has been attributable largely to higher mortality among males from smoking-related cancers and IHD & stroke at older ages, particularly ages 60–69 (Beltrán-Sánchez et al. 2015; Janssen 2020a).

However, these differences (and other observed differences) in the contributions of causes of death to the sex gaps in lifespan variation or life expectancy can be linked to the observation by Seligman (2016) that the causes of death that contribute to increases in life expectancy over time are not necessarily the same as those that contribute to decreases in lifespan variation. This observation appears to be relevant not only when studying trends over time but also when studying sex differences.

The differences in the contributions of causes of death to the sex gaps in lifespan variation vs life expectancy can be explained largely by the contributions of different age groups to the sex gaps in the two indicators. That is, while sex differences in (cause-specific) mortality in all age groups were contributing to increasing the sex gap in life expectancy, this was not the case for the sex gap in lifespan variation. Instead, sex differences in (cause-specific) mortality below age 70 were acting to increase the sex gap in lifespan variation, whereas (cause-specific) mortality differences above age 70 were acting to decrease the sex gap in lifespan variation. Because lifespans are longer for females than males (Zarulli et al. 2021), higher mortality at older ages compressed the age-at-death distribution more among males than females and thus contributed to decreasing the sex gap in lifespan variation.

Smoking-related cancers and IHD & stroke, which are known to contribute substantially to the sex gap in life expectancy (Beltrán-Sánchez et al. 2015), were found to have only a very small effect on sex differences in lifespan variation in Europe as a whole, because these causes of death were reported both above and below the threshold age. Thus, their effects were offset.

On the other hand, external mortality at young adult ages contributed much less to the sex gap in life expectancy than to the sex gap in lifespan variation, because the former is determined less by the distance of that particular age (and cause-of-death) group from the central age of death

and more by the size of the mortality gap between males and females. The 'Europe' plot of Figure S5.1 (supplementary material 5) clearly shows that at ages 60–69, mortality was much higher for males than females. Consequently, that age group contributed the most to the sex differences in life expectancy.

However, our findings regarding the sex differences in both lifespan variation and life expectancy indicate that the sex gap in longevity is attributable mainly to sex differences in mortality from causes of death that are (partly) linked to health behaviours (e.g. smoking, alcohol abuse, risky behaviour resulting in accidents, violence).

The link between the importance of external mortality (particularly at ages 30–39) for sex differences in lifespan variation and the role of sex differences in risky health behaviours have already been discussed in the previous subsection. However, the causes of death that contributed the most to sex differences in life expectancy can also be linked to health behaviours. That is, although not all deaths from IHD & stroke can be attributed to health behaviours, sex differences in mortality from IHD & stroke can be explained largely by sex differences in health behaviours (Beltrán-Sánchez et al. 2015). Moreover, there is evidence of large sex differences in health behaviours in Europe. For instance, in 1980, smoking prevalence was 39 per cent among males and 18 per cent among females in Europe (IHME 2017), a difference which has led to much higher smoking-attributable mortality among European males than European females today (25 vs 8 per cent of deaths) (Janssen 2020b). Alcohol-attributable mortality in Europe is also higher among males than females (Janssen et al. 2020), in line with reports of higher levels of alcohol abuse among males than females (Allamani et al. 2000; Gjonça et al. 2005). In Europe in 2016, the percentage of current drinkers among people aged 15 and older differed by sex, at 69.9 per cent for males and 51.7 per cent for females (WHO 2018b). Moreover, among these current drinkers,

the prevalence of heavy episodic drinking was 56.5 per cent for males and 24.5 per cent for females (WHO 2018b).

While sex differences in lifespan variation are driven particularly by health behaviours related to age—for example, by men engaging in more risky behaviours at young adult ages than women (see previous subsection)—sex differences in life expectancy are driven particularly by the longer-term effects of men engaging in more unhealthy behaviours (e.g. smoking and drinking) throughout the life course than women (Rogers et al. 2010). However, the short-term effects of men engaging in fewer healthcare-seeking behaviours than women may also play a role (Courtney W. 2002).

Regional differences in the sex gap in lifespan variation

The clear regional differences we observed in the sex gap in lifespan variation are consistent with regional differences in the sex gap in life expectancy in Europe (e.g. Janssen 2020a). That is, in Eastern Europe, males displayed a greater overall longevity disadvantage compared with females, whereas in the Nordic countries, males showed the smallest overall longevity disadvantage compared with females. These findings highlight the heterogeneity in survival patterns in Europe.

These regional differences in the sex gap in longevity are driven mainly by regional variation in sex differences in premature mortality. Specifically, sex differences in premature mortality were larger in FSR and CEE than in the non-Eastern-European countries and were smallest in the Nordic countries (see supplementary material 5, Figure S5.1). The higher premature mortality among males in Eastern European countries is attributable largely to the higher mortality from external causes of death for males than females (see supplementary material 2, Figures S2.3b and S2.4b). In non-Eastern Europe, particularly in the FSR countries, mortality from external causes of death was much higher among males than females (Aburto and van Raalte 2018). Indeed,

in the FSR countries, mortality from external causes of death among males was the highest in Europe (Grigoriev et al. 2014). However, the sex differences in mortality from smoking-related cancers around ages 60–69, circulatory disease mortality around ages 50–79, and alcohol-related mortality around ages 50–59 were larger in Eastern Europe than in non-Eastern Europe (see Figure 4).

Although most of the sex differences in external mortality, CVD mortality, alcohol-related mortality, and smoking-related mortality in Eastern Europe can be attributed to sex differences in risky and unhealthy behaviours—which can, in turn, be attributed to gender roles and social norms—these findings do not reflect the full story, because regional differences in health policies and medical progress might also play an important role in the regional variation in the sex differences in mortality. For example, compared with Western Europe, CEE and FSR countries have benefited much more recently from the so-called cardiovascular revolution, which was brought about through the adoption of health policies aimed at reducing CVD mortality by changing health behaviours, and from advances in medical interventions (e.g. cardiovascular surgery), pharmacology, and technology (Vallin and Meslé 2004; Grigoriev et al. 2014; Meslé and Vallin 2017; Hrzic et al. 2021). For example, Grigoriev and Andreev (2015) reported that alcohol-attributable mortality declined in Estonia and Russia in 2005–06 and 2012 (Estonia) as a result of the anti-alcohol measures introduced in these two countries in the 2000s. The late start to the cardiovascular revolution in Eastern Europe was also due to the severe economic crisis that the region experienced in the early 1990s (Aburto and van Raalte 2018). Moreover, this crisis aggravated the tendency of adult Eastern European men to engage in risky behaviours (including unhealthy drinking patterns) (Shkolnikov et al. 1998). Although premature mortality among Eastern European men has been converging with that of Eastern European women and non-

Eastern-European men (Aburto and van Raalte 2018), the large initial differences between these groups means that some differences remain today.

Overall conclusion

Our results shed light on sex differences in longevity through the lens of lifespan variation and contribute to a broader understanding of the survival gap between men and women and the regional differences in this gap. Adding to previous studies that have examined sex differences in life expectancy, and which showed that the current lower life expectancy among males than females was driven mainly by their higher smoking-related mortality and CVD mortality at older ages, we demonstrated that the higher lifespan variation among males was driven primarily by higher external mortality at younger ages.

Our observation that different age groups and causes of death contributed very differently to the sex gap in lifespan variation compared with the sex gap in life expectancy not only provides important insights into the survival differences between the sexes and their effects; it also indicates that life expectancy at birth and lifespan variation should be studied simultaneously.

Increasing average health and reducing health inequality are both prominent goals of most countries around the world. Our findings suggest that further action aimed at improving health behaviours, particularly among males, is needed to achieve health equity and that these actions should be focused on relatively young age groups in order to reduce the sex differences in life expectancy and in lifespan variation simultaneously.

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3 Data sharing statement: The data on which this study is based are available from the web pages of the Human Mortality Database (www.mortality.org), the Human Cause-of-Death Database (www.causesofdeath.org), and the World Health Organization Mortality Database (www.who.int/data/data-collection-tools/who-mortality-database). The R code and the data selections used as input for the figures and tables will be made available in the Github repository of the first author.

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MAIN TABLES AND FIGURES

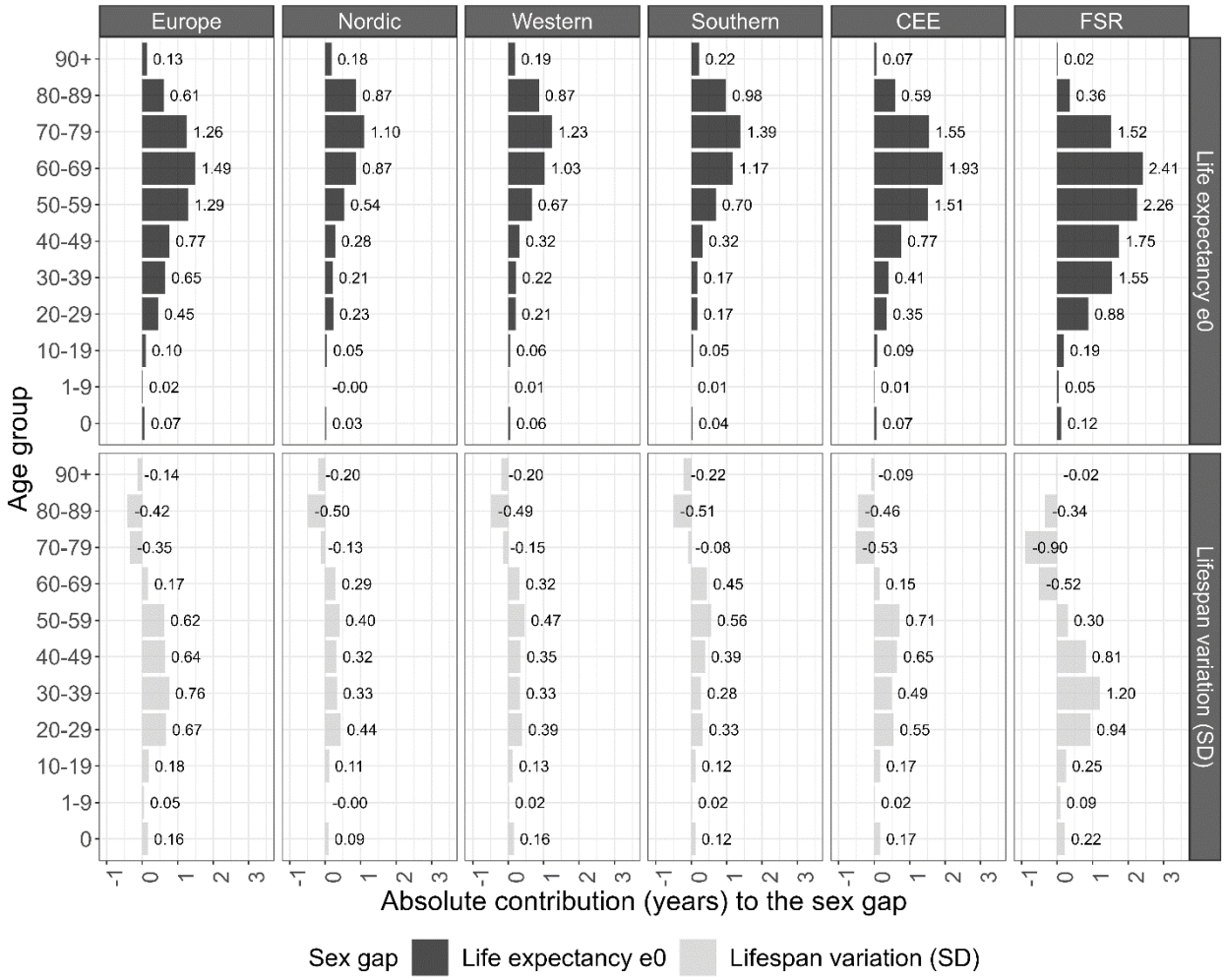
Table 1 Sex gaps in life expectancy at birth and lifespan variation for the 28 European countries combined ('Europe') and by European region, 2010–15.

Region	Life expectancy			Lifespan variation		
	Female	Males	Sex gap	Female	Males	Sex gap
Europe	81.3	74.5	6.8	14.4	16.8	2.3
Non-Eastern Europe	83.9	79.0	4.8	12.9	14.3	1.3
Nordic countries	83.4	79.0	4.4	12.8	14.1	1.2
Western Europe	83.5	78.7	4.9	13.4	14.7	1.3
Southern Europe	84.7	79.5	5.2	12.5	14.0	1.5
Eastern Europe	78.4	69.3	9.2	14.8	16.8	2.0
Central and Eastern Europe	80.3	72.9	7.4	13.8	15.6	1.9
Former Soviet Republics	76.6	65.6	11.0	15.9	17.9	2.1

Notes: Lifespan variation is measured by the standard deviation (SD) in the age-at-death distribution from age zero onwards. The sex gap in life expectancy is calculated as e_0 females minus e_0 males, whereas the sex gap in lifespan variation is calculated as SD males minus SD females, so that both reflect the advantage for females.

Source: Authors' analysis of data from the Human Mortality Database (HMD 2019).

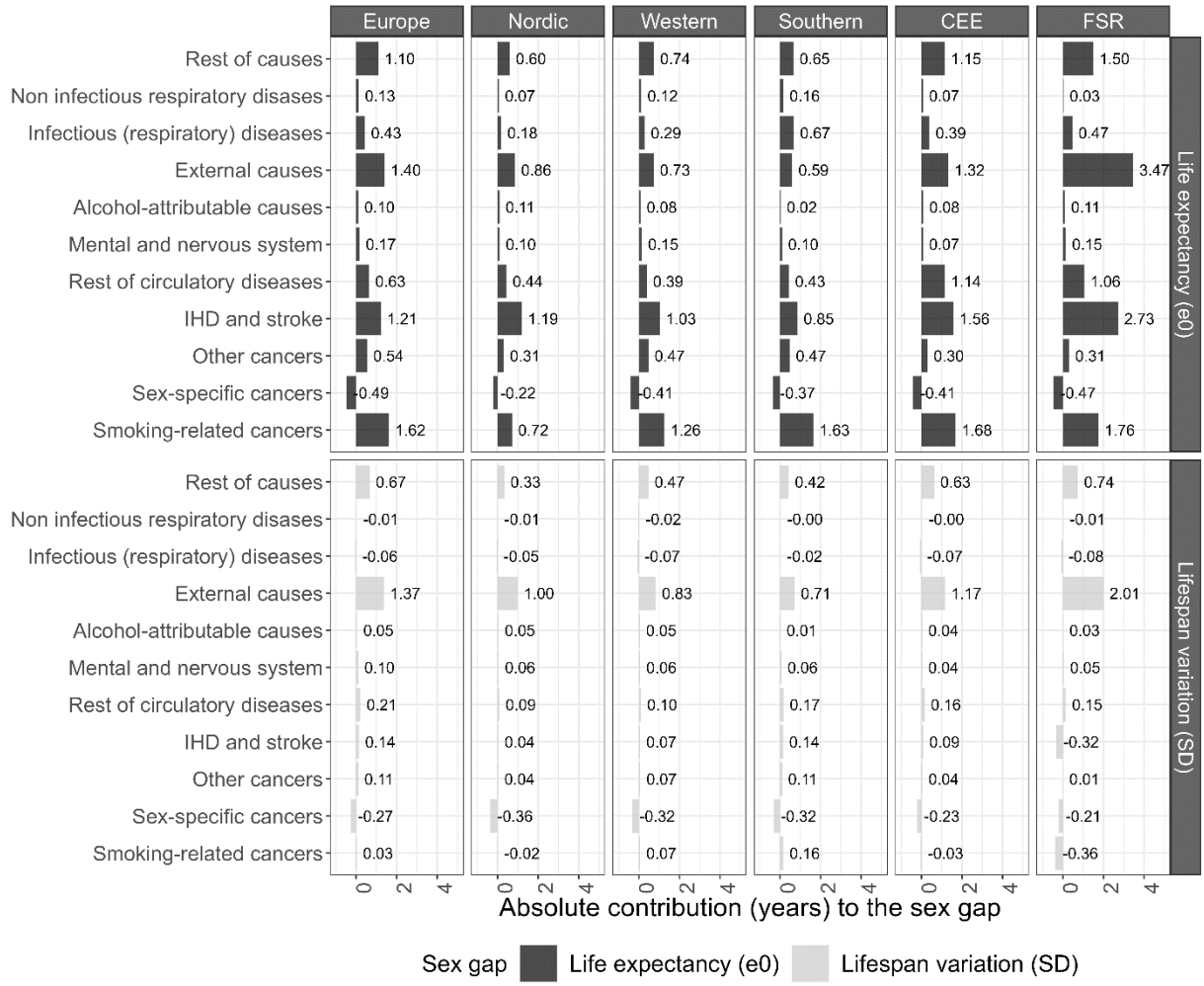
Figure 1 Absolute contributions of different age groups to sex differences in life expectancy at birth (females minus males) and sex differences in lifespan variation (males minus females) for the 28 European countries combined and by European region, 2010–15



Note: Nordic = Nordic countries; Western = Western Europe; Southern = Southern Europe; CEE = Central and Eastern Europe; FSR = former Soviet republics.

Source: Authors' analysis of data from the Human Mortality Database (HMD 2019).

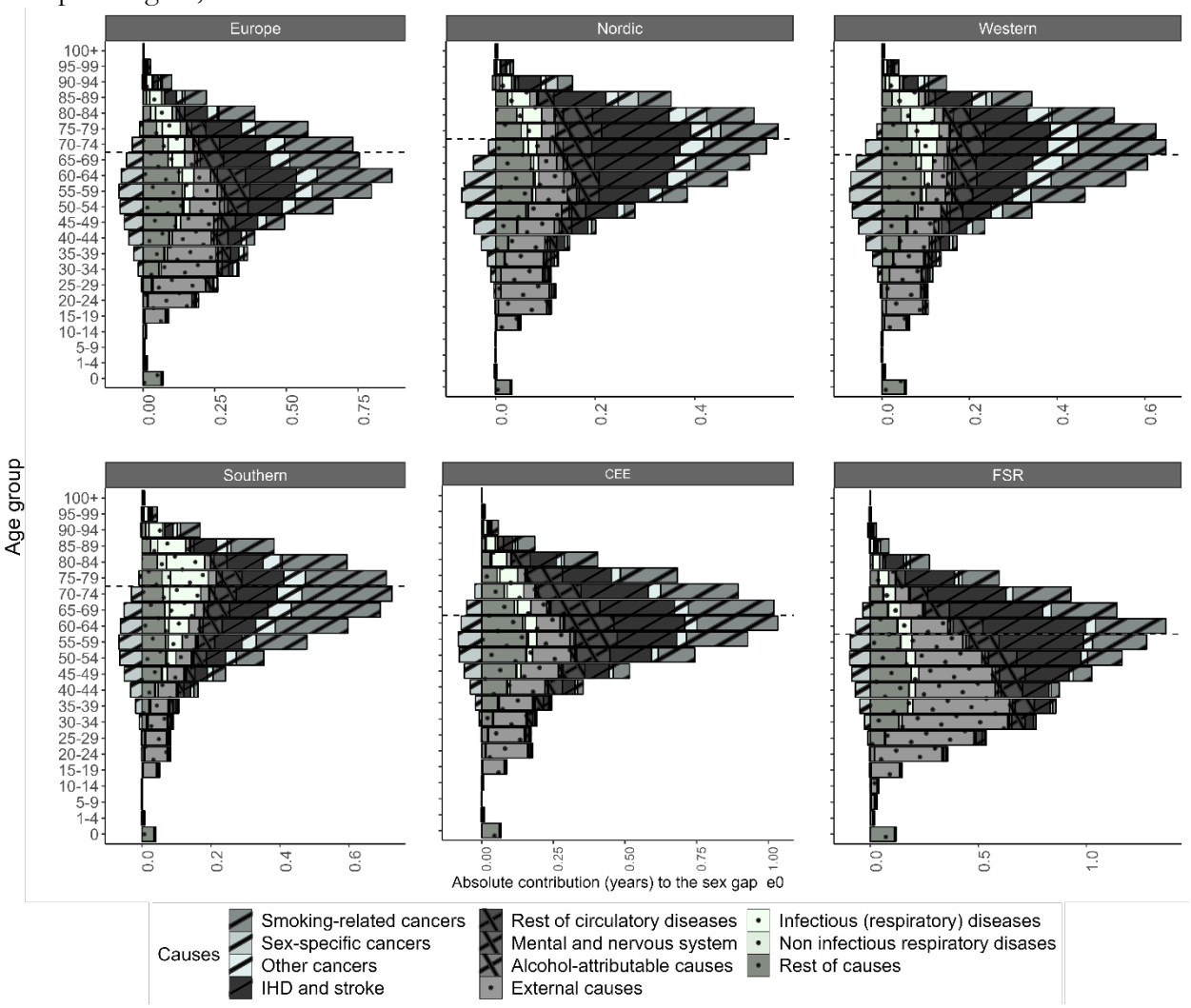
Figure 2 Absolute contributions of different cause-of-death groups to sex differences in life expectancy at birth (females minus males) and sex differences in lifespan variation (males minus females) for the 28 European countries combined and by European region, 2010–15



Note: Nordic = Nordic countries; Western = Western Europe; Southern = Southern Europe; CEE = Central and Eastern Europe; FSR = former Soviet republics.

Source: Authors' analysis of data from the Human Mortality Database (HMD 2019), WHO Mortality Database (WHO 2019), and Human Cause-of-Death Database (HCD 2021.

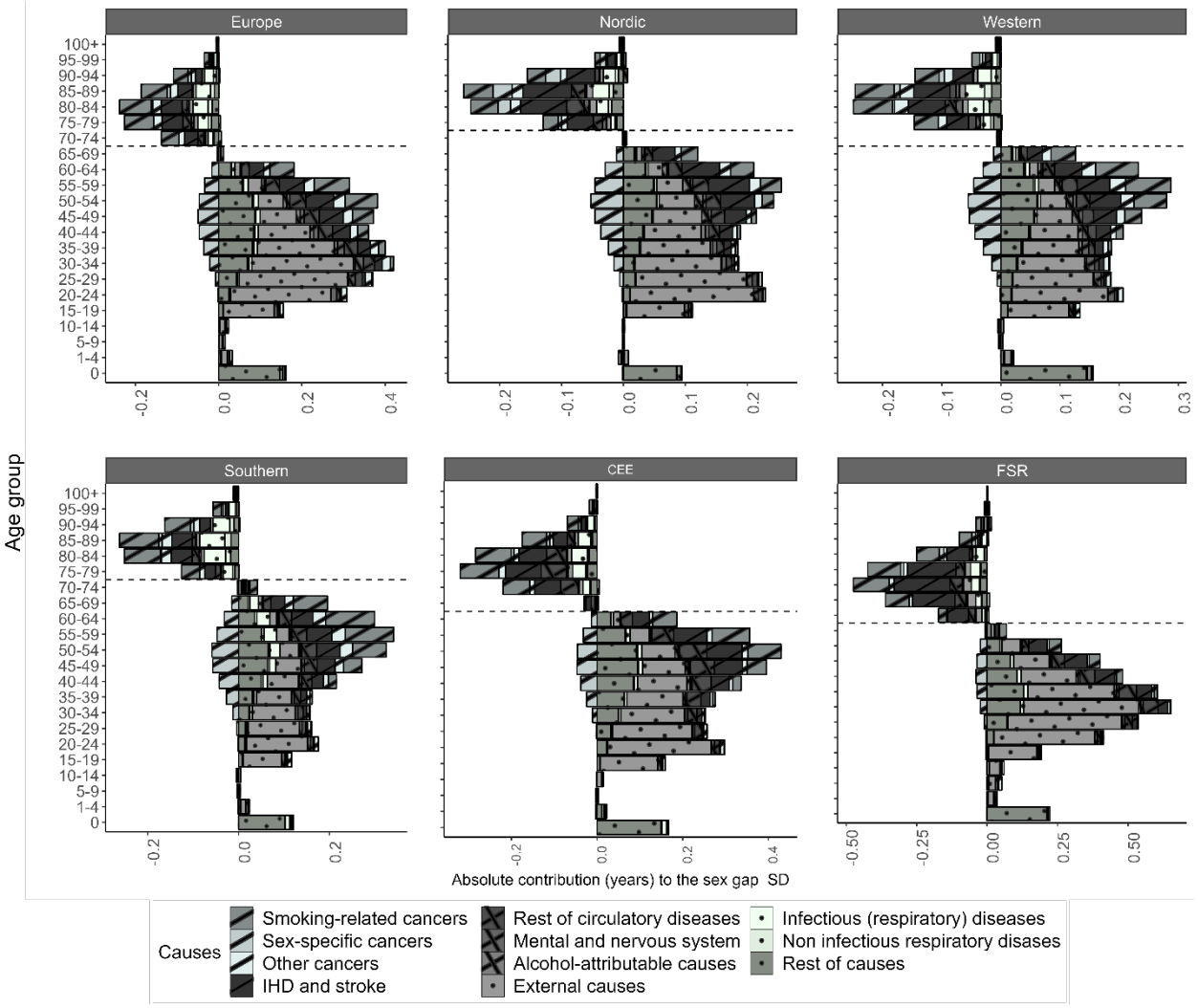
Figure 3 Absolute contributions of different age groups and cause-of-death groups to the sex gap in life expectancy at birth (females minus males) for the 28 European countries combined and by European region, 2010–15



Note: Nordic = Nordic countries; Western = Western Europe; Southern = Southern Europe; CEE = Central and Eastern Europe; FSR = former Soviet republics.

Source: As for Figure 2.

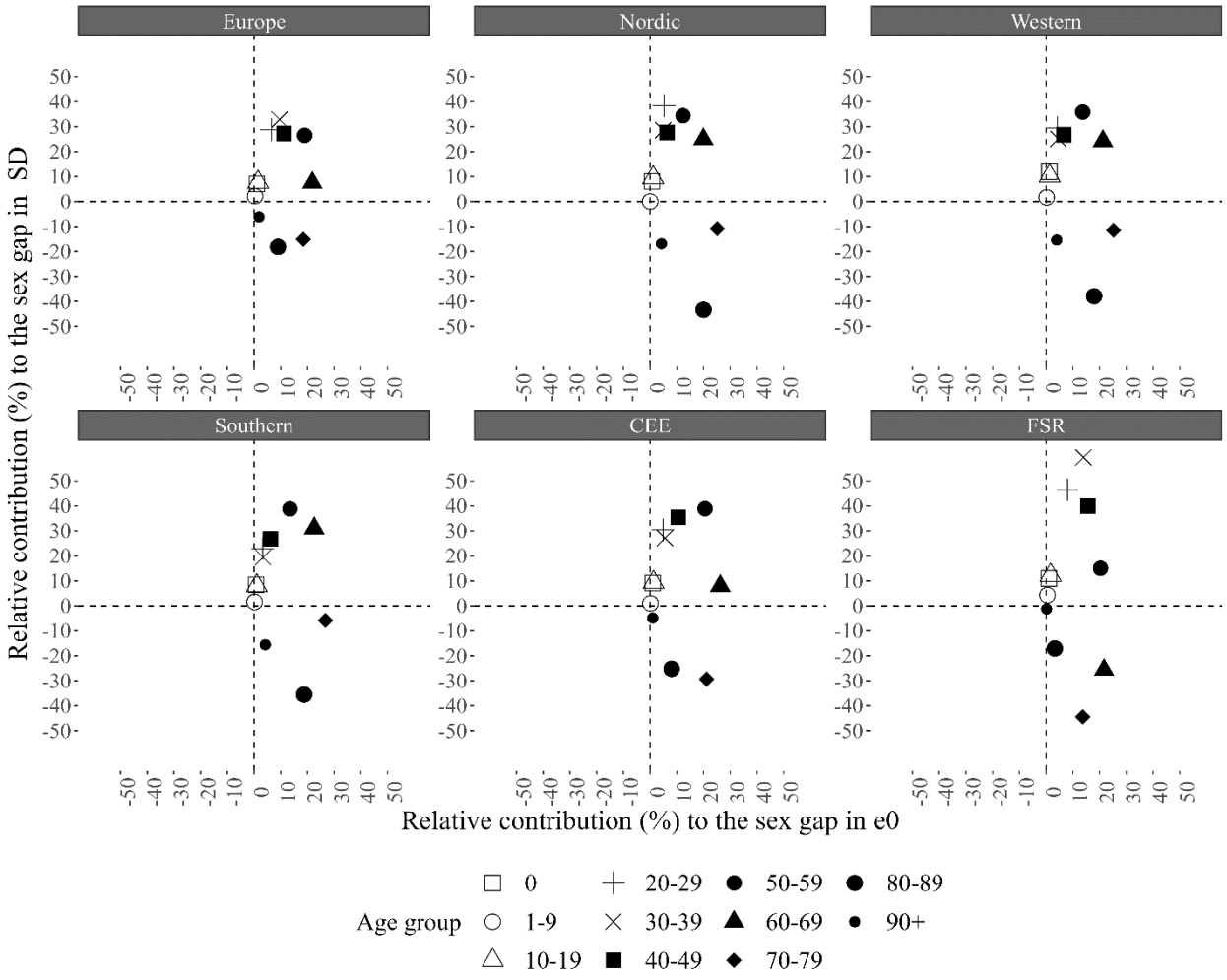
Figure 4 Absolute contributions of different age groups and cause-of-death groups to the sex gap in lifespan variation (males minus females) for the 28 European countries combined and by European region, 2010–15



Notes: Nordic = Nordic countries; Western = Western Europe; Southern = Southern Europe; CEE = Central and Eastern Europe; FSR = former Soviet republics. The dashed horizontal lines indicate what we define as the threshold age: that is, the age below which sex differences in mortality contribute positively to the higher lifespan variation among males than females, and above which sex differences in mortality contribute negatively to the higher lifespan variation among males than females. The threshold age falls somewhere in the first five-year age group above the dashed line.

Source: As for Figure 2.

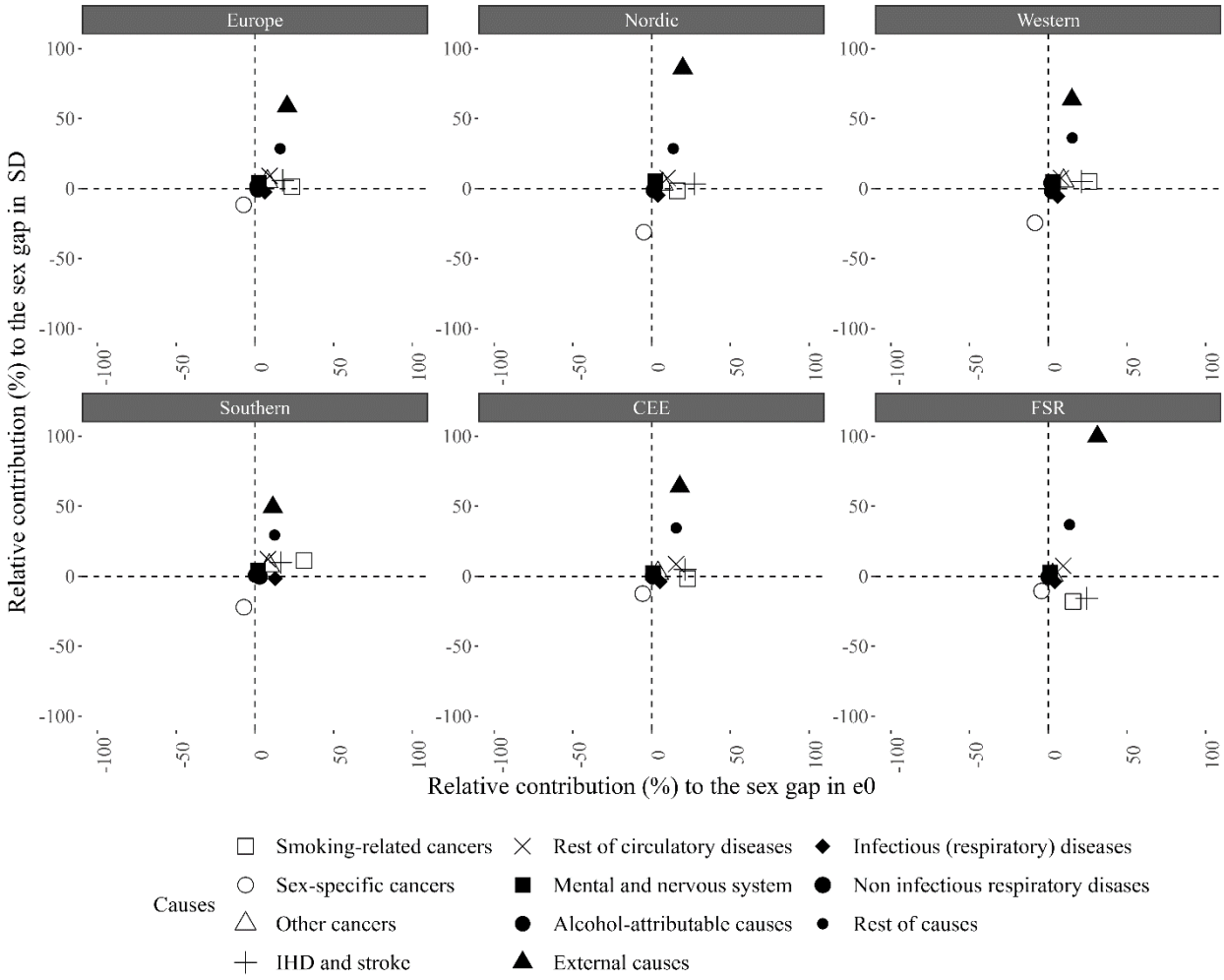
Figure 5 Comparison of the relative contributions (percentages) of different age groups to the sex gap in life expectancy (e_0 females minus e_0 males) vs the sex gap in lifespan variation (SD males minus SD females) for the 28 European countries combined and by European region, 2010–15



Note: Nordic = Nordic countries; Western = Western Europe; Southern = Southern Europe; CEE = Central and Eastern Europe; FSR = former Soviet republics.

Source: As for Figure 2.

Figure 6 Comparison of the relative contributions (percentages) of the different cause-of-death groups to the sex gap in life expectancy (e_0 females minus e_0 males) vs the sex gap in lifespan variation (SD males minus SD females) for the 28 European countries combined and by European region, 2010–15



Note: Nordic = Nordic countries; Western = Western Europe; Southern = Southern Europe; CEE = Central and Eastern Europe; FSR = former Soviet republics.
Source: As for Figure 2.

APPENDIX TABLES

Table A1 List of selected countries by European region and data availability by year for the main data sources used: the Human Mortality Database (HMD) and the WHO Mortality Database

Regions	Countries	HMD and HCD	WHO ICD-10	WHO ICD-9
Nordic countries	Denmark	2000–15	2000–15	–
	Finland	2000–15	2000–15	–
	Norway	2000–15	2000–15	–
	Sweden	2000–15	2000–15	–
Western European countries	Austria	2000–15	2002–15	2000–01
	Belgium	2000–15	2000–15	–
	France	2000–15	2000–15	–
	Germany	2000–15	2000–15	–
	Ireland	2000–15	2007–15	2000–06
	Netherlands	2000–15	2000–15	–
	Switzerland	2000–15	2000–15	–
	United Kingdom	2000–15	2001–15	2000
Southern European countries	Greece	2000–15	2014–15	2000–13
	Italy	2000–15	2003–15	2000–02
	Portugal	2000–15	2002–15	2000–01
	Spain	2000–15	2000–15	–
Central and Eastern European countries	Bulgaria	2000–15	2005–15	2000–04
	Czech Republic	2000–15	2000–15	–
	Hungary	2000–15	2000–15	–
	Poland	2000–15	2000–15	–
	Slovakia	2000–15	2000–14	–
	Slovenia	2000–15	2000–15	–
	Belarus[1]	2000–15	2002–15	2001–02

Former Soviet republics	Estonia	2000–15	2000–15	–
	Latvia	2000–15	2000–15	–
	Lithuania	2000–15	2000–15	–
	Russia[1]	2000–14	2000–14	–
	Ukraine[1]	2000–13	2005–13	2000–05

[1]For Belarus, Russia, and Ukraine, only ICD-10 is used, because the HCD classifies all causes of death according to the ICD-10 revision. Note that the data for Russia include the entire country, including its Asian part.

Note: For countries with no ICD-10 data since 2000, we used ICD-9 data.

Table A2 List of the selected cause-of-death groups, the specific causes of death assigned to each group, and the associated ICD-9 and ICD-10 codes

#	Cause of death group	Specific causes of death	ICD-9 codes	ICD-10 codes
1	Smoking-related cancers	Malignant neoplasms of buccal cavity and pharynx, of oesophagus, of stomach, of colon, of rectum and anus, of larynx, trachea, bronchus and lung, of pancreas, and of bladder	B08, B090–B094, B096, B100–B101, B120, B126	C00–C21, C25, C30–C34, C64–C68
2	Sex-specific cancers	Malignant neoplasms of breast, of cervix uteri, of other parts of the uterus, of ovary, and of prostate	B113, B120–B123, B124–129	C50, C53, C54–55, C56, C61
3	Other cancers	All remaining cancers aside from smoking-related cancers and sex-specific cancers	B095, B099, B109, B11, 179, 181–187	Rest of C00–C99
4	IHD & stroke	Ischaemic heart diseases (IHD) and stroke	B27, B29	I20–I25, I60–I69
5	Rest of circulatory diseases	All remaining circulatory diseases aside from IHD and stroke	B25–B26, B28, B30	I00–I19, I26–159, I70–I99
6	Mental and nervous system	All diseases of the mental and nervous system	B21–B219, B22–B229	F01–F99, G00–G98
7	Alcohol-attributable causes	Mental and behavioural disorders due to the use of alcohol Chronic liver disease External injuries and poisoning (of which accidental poisoning by exposure to alcohol)	B215, B347, B48	F10, K70, X45

8	Infectious (respiratory) diseases	Infectious and parasitic diseases, plus infectious diseases of the respiratory system	B01–B17, B310–B312, B320–B322, B323–B325	A00–B89, B99, J00–J06, J09–J18, J20–J22, J34.0, J36, J39.0, J39.1, J85, J86
9	Non-infectious respiratory diseases	Non-infectious diseases of the respiratory system, including COPD and chronic lower respiratory diseases	B313–B315, B319, B326–B327, B329	J30–J33, J34.1–J34.3, J34.8, J35, J37, J38, J39.2, J39.3, J39.8, J39.9, J40–J47, J60–J70, J80–J82, J840–J841, J848–J849, J90–J99
10	External causes	External causes of death (not including accidental poisoning by exposure to alcohol)	B47–B56	S00–T89, V01–Y84
11	Rest of causes	All remaining causes of death not included in the previous cause-of-death groups	B01–B17, B184–B185, B15–B17, B180, B182–B183, B189, B19–B23, B33–B46	D00–D48, D50–D89, E00–E07, E15–E16, E20–E35, E40–E46, E50–E68, E70–E90, H00–H59, H60–H95, K00–K93, L00–L99, M00–M99, N00–N99, O00–O99, P00–P96, Q00–Q99, R00–R99

Note: We used the ICD-9 codes as part of the basic tabulation list, in line with Aburto et al. 2018b.

Source: WHO 2019.

Table A3 Cause-of-death groups according to the two criteria we used to select them: whether they are known to contribute to the sex gap in life expectancy; and their expected effects on premature and old-age mortality

Number	Cause-of-death group	Known to contribute to sex gap in life expectancy	Expected effect on mortality	
			Premature	Old-age
1	Smoking-related cancers	x		x
2	Sex-specific cancers	x	x	x
3	Other cancers			
4	Ischaemic heart diseases & stroke	x		x
5	Rest of circulatory diseases	x		
6	Mental and nervous system			x
7	Alcohol-attributable causes	x	x	
8	Infectious (respiratory) diseases		x	x
9	Non-infectious respiratory diseases	x		
10	External causes	x	x	
11	Rest of causes			

Source: Authors' own.