Endgame of the smoking epidemic in high-income countries reflected in life expectancy sex differences: a populations-based study

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Abstract

Background Of all lifestyle behaviours, smoking caused the most deaths in the last century. Because of the time lapse between the uptake of smoking and the mortality from smoking, male and female smoking epidemiology often follows a typical double wave pattern dubbed the ‘smoking epidemic’. How is this epidemic progressing, how does it affect male-female survival differences, and how does it act on a cohort-by-age basis?Methods We examine changes in smoking-attributable mortality fractions as estimated by the Preston-Glei-Wilmoth method by age group (ages 50-85) across birth cohorts 1870-1965, utilizing data from the WHO mortality database and the human mortality database. We compare these to changes in the sex differences in life expectancy at age 50 in three geographic regions that have progressed farthest into the smoking epidemic: high-income North America, Europe and Oceania.Results We find that for older cohorts (~1910-1930) for most ages, smoking-attributable mortality has broadly been stable or declining for males while growing for females, contributing to a decline in the advantage of women in terms of life expectancy from around 4.5 years towards 2 years. Yet more recent cohorts (~1955-1965) show a precipitous decline in smoking mortality for all age groups available.Conclusions In line with previous findings, the smoking epidemic contributed materially to the male-female survival gap and to the recent narrowing of that gap. In addition, the precipitous decline in smoking mortality in recent cohorts that we find suggests that the smoking epidemic in the three selected regions is ending or at least subsiding. Our results also give a glimpse of what low- and middle-income countries may expect in term of sex differences in smoking-attributable mortality and life expectancy. Our approach shows that a cohort-by-age analysis is helpful in tracking the smoking epidemic.

Background

In 2015 worldwide, one out of ten deaths was due to smoking [1]. This makes smoking the single most important killer in the world with nearly twice as many victims as the 5% deaths from AIDS, malaria and tuberculosis combined [2]. As such, the smoking epidemic is having a huge impact on the world population and on the individual risk of transitioning to the worst possible health condition, i.e. to die. Among the 1.1 billion smokers in the world in 2015, males from a middle-income country took up the largest proportion, comprising 68% of all smokers, followed by 12% male smokers in high-income countries [3]. The proportion of female smokers was 16% with approximately half of them in high-income countries and half in middle-income countries [3].

The enormous increase and subsequent decline in smoking prevalence and later smoking-attributable mortality, and sex differences therein, has been described in detail and termed the ‘smoking epidemic’ [4,5]. The smoking epidemic model describes that men in high-income countries (particularly the Anglo-Saxon countries) were the first to take up smoking and that smoking-attributable mortality started rising some three decades after the rise in smoking prevalence. Women began to smoke later in time than males. Attention for the negative health effects of smoking and associated prevention campaigns led the proportion of males that smoke to decline and the peak in the smoking prevalence among women to be considerably lower compared to men. Because females took up smoking later than males, and because of the delay between the act of smoking and smoking-related death, there is a stage where the proportion of males dying from smoking begins to decline, but female death rates from smoking continue to rise (Figure 1) before, finally, smoking-related mortality in females also declines [4,5].

In the 1950s, 90% of males in the current nations of the European Union (EU) and 52% of males in the United States (US) were smokers. The respective shares of smoking females were 20-40% and 24% in EU and US respectively. By 2015, this had changed dramatically: for males, the proportion of smokers in the EU was 30.1% and 19.5% in the US; for females this was 23.9% and 15% respectively [6-10]. Because these numbers for males versus females are first divergent, then convergent, in line with the theoretical model outlined above and in Figure 1, we hypothesized that the smoking epidemic may have been the main contributor to the widening of the male-female survival gap in high-income countries in the second half of the 20th century, that male-female differences in life expectancy are reducing to lower levels in those countries driven by smoking mortality, and that the smoking epidemic may be drawing towards an end in high-income countries.

Methods

It has been shown that the detrimental effects of smoking take place across cohorts [11]. Where previous research has mostly focused on the period patterns of the smoking epidemic, in this article we aim to assess whether the smoking epidemic in high income countries is ending by examining changes in smoking-attributable mortality fractions between birth cohorts as well as changes in the role of smoking in life expectancy sex differences. We chart the proportion of mortality attributable to smoking by sex, cohort and age, and track these proportions over time (cohorts 1870-1965). These results are compared to life expectancy from age 50 (e50) over the period 1950-2015, with and without smoking-related mortality removed. Finally, we translate these results to patterns of male-female e50 disparity over the same period, again with and without smoking-related mortality removed.

Mortality data by age (50-85 years) and sex for the populations of 17 high-income countries during the period 1950-2015 were used. The focus on age 50 and over stems from the technique that we used to indirectly estimate smoking-attributable mortality (see below), which relies on deaths from lung cancer, which are generally rare below age 50 [12]. Furthermore, previous research has shown that most of male-female mortality differences is concentrated between ages 50 and 70 [13].

The 17 included countries were grouped into three geographical categories: high-income North America (US and Canada), high-income Europe (Austria, Belgium, Denmark, Finland, France, Italy, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and the UK), and high-income Oceania (Australia and New Zealand). Our reasons for including these countries were that in the estimation of smoking-attributable fractions that we use, the Preston-Glei-Wilmoth (PGW) method [14] (see below) was based on 20 high-income countries from around the world. We excluded countries that spent much of the 1950-2015 period behind the Iron Curtain, because the countries missed out on the cardiovascular revolution for decades, sometimes called the state socialist syndrome [15]. This led us to exclude Hungary. For Portugal, cause-specific mortality data were not available for the period 2004-2006. Hence, we imputed such missing values by using a non-parametric method (missForest) based on random forest algorithms [16]. Japan was excluded because of its atypical smoking history [17].

Death rates and person-years at risk by age, sex, year and country were retrieved from the Human Mortality Database (HMD) [18]. To estimate smoking-attributable mortality (see below), we used both all-cause mortality data and lung cancer deaths, which are defined to include malignant neoplasms of trachea, bronchus and lung (ICD-7: 162, 163; ICD-8 and ICD-9: 162; ICD-10: C33, C34). Such cause-specific death counts were retrieved from the World Health Organization Mortality Database [19].

To estimate the proportion of deaths attributable to smoking, an updated version of the Preston-Glei-Wilmoth (PGW) method [14] was used. This indirect estimation technique assumes that “after adjusting for sex and age, smoking is the only source of variation in lung cancer death rates in the populations under consideration”. It estimates smoking attributable deaths indirectly by assuming that lung cancer rates of smokers and never-smokers would match those observed among individuals in the Cancer Prevention Study II in the US. From this study, a relative risk of lung cancer between smokers and non-smokers is estimated that is assumed to be constant over time and across countries. In a second step, the model uses negative binomial regression to model smoking-related mortality from causes other than lung cancer as a function of lung cancer mortality [14].

We then smoothed smoking-attributable mortality estimates with the penalized composite link model [20], giving year-by-age estimates of the proportions of death due to smoking for all 17 countries for males and females over age 50. We used such year-by-age estimates to construct birth-cohorts’ mortality profiles between 1870 and 1965 for high income North America, Europa and Oceania by following the approach developed in reference 21. We determined the proportion of smoking-related mortality for males and females per cohort and age.

The estimates obtained from the adjusted PGW model were used to calculate life tables excluding smoking-attributed mortality. Life expectancies at age 50 (e50) were calculated following standard demographic procedures [22]. We also calculated e50 for the total population based on life tables directly retrieved from the HMD, which include smoking-related mortality. Finally, we compared male-female differences in life expectancy at age 50 (e50) with and without smoking-related mortality removed for all the countries and periods.

Results

Between 1950 and 2015, the smoking epidemic caused a total of 39 million deaths at ages 50-85 in the three high-income geographical locations. Of these, 29 million deaths were men and 10 million were women. The largest numbers of deaths attributable to smoking were in high-income North America with 7 million women and 13 million men, followed by the 13 high-income European countries with 3 million and 15 million, respectively. In Oceania the numbers were 0.2 million and 0.7 million, respectively.

For males in high-income Europe, North America and Oceania, we found a steep increase in the proportion of smoking-related mortality from the cohorts born 1870 up to about 1900-1910, when smoking mortality was the highest (Figure 2). For North America and Oceania, after reaching a peak for the 1910-1930 cohorts, there was a large drop in the proportion of smoking-related deaths in more recent cohorts. For Europe, the upsurge happened around the same time followed by a stagnation period up to the most recent cohorts, where a steep drop was seen.

For North-American females, the upsurge in smoking-related mortality was delayed by about 30 years relative to males (Figure 2). At the highest ages, which are necessarily older cohorts, the peak in the proportion of overall mortality does not seem to have been reached as yet, although some indication exists. For the younger ages, the peak was reached for the 1930 cohorts, with a steep decline after, interrupted only by the 1950 cohorts. European females have seen an rise in smoking-related mortality that was, viewed over all its individual countries, less steep and peaked less high than North-American and, for most of its countries, later in time. Any decline in smoking-related mortality in European females is seen in the most recent cohorts only, necessarily at younger ages (as these cohorts have not yet reached older ages); at higher ages, the proportion of smoking-attributed mortality is still on the increase. For Oceania, the pattern was similar to that of the Europe, but without any significant drop to date.

In terms of absolute levels of smoking-related mortality (rather than trends), smoking-related mortality was higher in males than for females in Europe for all age groups and all cohorts, even though for recent cohorts the absolute differences were small (Figure 2). For the US and Oceania, smoking-related mortality was higher for males than for females for most cohorts and age groups, in particular those that drove recent changes. However, for recent cohorts at relatively young ages, smoking-related mortality was similar between sexes, even slightly higher for females than for males.

Removing smoking-related mortality resulted in a large and gradual increase in e50 for males across 1950-2015, compared to the trends for e50 for all-cause mortality where a stagnation in the 1950s and 1960s was observed (Figure 3, top panels). This was particularly pronounced for Belgium, The Netherlands and the UK, while the increase was smallest for Sweden (Supplemental Figure). For females, on the other hand, removing smoking-related mortality made little difference overall. Recently, however, this observation has begun to change: removing smoking-related mortality now makes less of a difference for males, but more of a difference for females.

The sex gap in e50 was about 3 years in 1950, then increased to some 4.5 years around 1975, and afterwards decreased towards 2 years (globally, over all three regions) (Figure 3, bottom panels). Omitting smoking-related deaths, the male-female difference in e50 would have been much lower and much more constant over time than for the total population.

The contribution of smoking to male-female differences in life expectancy is now on the decline (Figures 2 and 3). In some countries (Italy, New Zealand, Finland, Spain), this is due to declining smoking-related mortality in males. In other countries (Sweden, Norway, Iceland), this is mainly due to increasing smoking-related mortality in females. Finally, there are countries (Canada, Austria, UK, US, Netherlands, Australia) where the decline is caused by an approximately equal contribution to each side of the gap (Supplemental Figures).

Discussion

In this study we found that the declining sex differences in life expectancy at age 50 (e50) reflect the end game of the smoking epidemic in three high-income regions of the world: high-income Europe, North America and Oceania. Partly, the decline in the sex gap is due to females dying from smoking at higher-than-previous rates. On the other hand, and with the exception of Oceanian females, a decline in the proportion of smoking-related deaths is seen in the most recent cohorts for both sexes within all three regions. Even for Europe, where the proportion of smoking-related mortality has remained almost flat for a long time in males, possibly because Europe is a heterogenous group of countries, and where the proportion of smoking-related mortality is still going up for females in most age groups, the most recent cohorts show a clear decline for both sexes. The decline in smoking-related mortality for males, and the rise in smoking-related mortality for females overall, has led to a sharp decline in the life expectancy gap between sexes, which may continue in the near future. If the smoking epidemic continues to phase out, at one point smoking will be unable to explain the sex gap in life expectancy (which may remain due to other causes, see below) simply because people do not die from smoking at all, but this point has not yet been reached.

The linkage we here present between the cohort-by-age patterns of the smoking epidemic and the resulting observed changes in e50 and the sex gap therein provides novel insights. An important consequence of the smoking epidemic was the change in the sex gap in e50 during the last 65 years. In 1950 the sex gap was 2-3.5 years, subsequently it extended to 4.3-4.5 years at the maximum, and then decreased to 1.8-2.5 in 2015 for the three regions. Most of the observed changes were due to smoking-attributable deaths. This clearly illustrates how the patterns of the smoking epidemic modulate sex differences in life expectancy in the high-income regions studied. Because women took up smoking later than men and because they peaked in smoking prevalence later in time, the effects on their mortality is seen later in time than for men [4,5]. Although the major part of the decline in the sex gap hitherto is caused by the steep drop in smoking-related mortality in males, more and more so this is also due to the increases in smoking-related mortality in females overall, regardless of a drop in the most recent cohorts. Thus, both sides of the male-female life expectancy gap are affected such that male and female life expectancy are converging, but more and more so this is affected by the trends in smoking-attributable mortality among women. Notwithstanding these trends and the crossover for recent cohorts at relatively young ages, to date, by and large, male smoking-related mortality still exceeds that of females. Hence, if these trends continue, we suggest that we have not yet seen the end of the narrowing in sex differences in life expectancy in these regions. Even though there is evidence that non-smoking mortality may contribute to an increasing gap [23], the vast contribution that we find smoking has made to this gap hitherto suggests this factor could overwhelm the contribution of non-smoking mortality to the sex gap. In countries with a high proportion of women taking up smoking some decades ago, smoking-attributable mortality for men and women could potentially cross over (e.g. U.K., Denmark and the Netherlands) [7], as we have found for the most recent cohorts in the US and Oceania.

For all-causes mortality, it has previously been found that a reduction in the male-female life expectancy gap is, for most countries, due to men dying at lower rates, rather than women at higher rates [24,25]. For smoking-related mortality, the same is not necessarily true, and we show that some countries are clearly on a path where the reduction in male-female differences is due to males improving, while others have taken a different path: females dying due to smoking at a higher rate. Males and females dying of smoking at the same rate is not an end to the smoking epidemic, but the decline in smoking-attributable mortality for both sexes seen in the more recent cohorts bodes hopeful in this respect.

If and when smoking ceases to explain the sex gap in high income countries, this has a great impact on the public health agenda since efforts will need to be redirected towards other determinants that narrow the sex gap and promote equality in survival. Likewise, the reduced sex gap must be considered in the forecasting of life expectancy. Thus, insurances and pension funds might need to recalibrate their forecasting assumptions accordingly. In addition, social behaviors such as smoking play a major role in longevity outcomes. For example, female centenarians massively outnumber their male counterparts. Generations of male centenarians have been wiped out due to diseases associated to the prevalence of smoking [26]. Thus, the ending of the smoking epidemic will not only change the sex difference in life expectancy but also the influx of individuals surviving to ages above 100 years. If the smoking epidemic is reaching its end, female and male centenarians may become (more) equal in numbers, and perhaps also in health and vitality trajectories.

Our results are in line with previous studies addressing smoking effects on the population level. The huge impact of smoking on survival has been found for the US [27] in European countries [11,28-34] and worldwide [35]. Smoking affects various causes of death, such as various forms of cancer, cardiovascular disease and multifarious diseases of the respiratory tract [36,37]. Also, the rise, stagnation and decline in the sex differences has been described in detail elsewhere [13,23,24,38], and smoking behaviour has been found to explain international differences in the life expectancy sex gap [39-41], as well as between countries [42]. Finally, the historical trajectories of divergence between life expectancy with and without smoking-related mortality that we found are broadly similar to those previously found for specific countries [43].

One clear limitation of our study is the indirect calculation of the smoking-attributable deaths. Such a limitation is unavoidable: comparisons between different methods to estimate smoking-attributable mortality did not reveal a best-practice method [44,45], and even if good estimates of smoking prevalence are available, other factors like smoking intensity are often harder to measure. Since the PGW method [14] extrapolates the relative lung cancer risk of smokers versus non-smokers from a US study to other countries, there may be a bias in our estimates for those countries. Also, the PGW is based on study participants that are more likely than the US overall population to be Caucasian middle class and to have achieved a relatively high level of education [45]. However, previous analyses have shown that the indirect estimation by PGW resulted in roughly similar outcomes compared to other indirect estimation techniques [29,30,46], so we are confident that our results are broadly reliable. As a further limitation, our estimates of smoking-related mortality were smoothed over ages, which may lead to minor distortions, although we do not expect that to be the case here due to relatively regular source data.

It is interesting to speculate about the meaning of our findings for low- and middle-income countries and directions this may give for future research. The main theater of the smoking epidemic is now middle-income countries [2,3]. Our findings give a hint of what these countries may expect in terms of male-female life expectancy divergence, as well as the proportions of smoking-related mortality that are ahead. Depending on where in the smoking epidemic each country is, our results suggest that the sex gap in e50 may be on the eve of a large increase. This is especially true because of the large difference in male and female smoking behavior that tends to be observed in those countries [5]. For instance in China, were smoking became increasingly fashionable during the seventies and eighties, smoking prevalence among males is some 53%, while for females this figure is less than 3% [47]. Although the proportion of countries where at least one anti-smoking measure has been fully implemented continues to rise [3], a glance at the annual report of a major tobacco company suggests that smoking prevalence is not significantly declining in most regions [48]. Some have predicted that 1 billion people could die in the next century from smoking-related causes [49]. Since most of these will be males, the e50 sex gap seems set to rise in low- and middle-income countries.

Conclusion

In conclusion, the smoking epidemic in the three selected regions is ending when judged from the declines in smoking-attributable mortality over the more recent birth cohorts and from the decline in the sex difference in life expectancy. This means that men and women will live longer together. Until the smoking epidemic is completely set to a halt in high-income countries, we hypothesize a further decline in the male-female survival gap, after which it might increase slightly as both males and females start dying from smoking-related causes less often. These developments provide a hint of what middle-income countries may expect in terms of smoking-attributable mortality fractions and male-female life expectancy differences.

Declarations

Ethics approval

All data are publicly available on an aggregate basis. Consequently, no ethics approval was necessary.

Consent for publication

Not applicable.

Availability of data and materials

All data are publicly available on the indicated webpages.

Competing interests

The authors declare that they have no competing interests.

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Authors contributions

MW drafted the paper with help from JA, FJ and RL. JA and SR performed data analysis. RL conceived

of the study. All authors critically interpreted and discussed the results.

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Figures

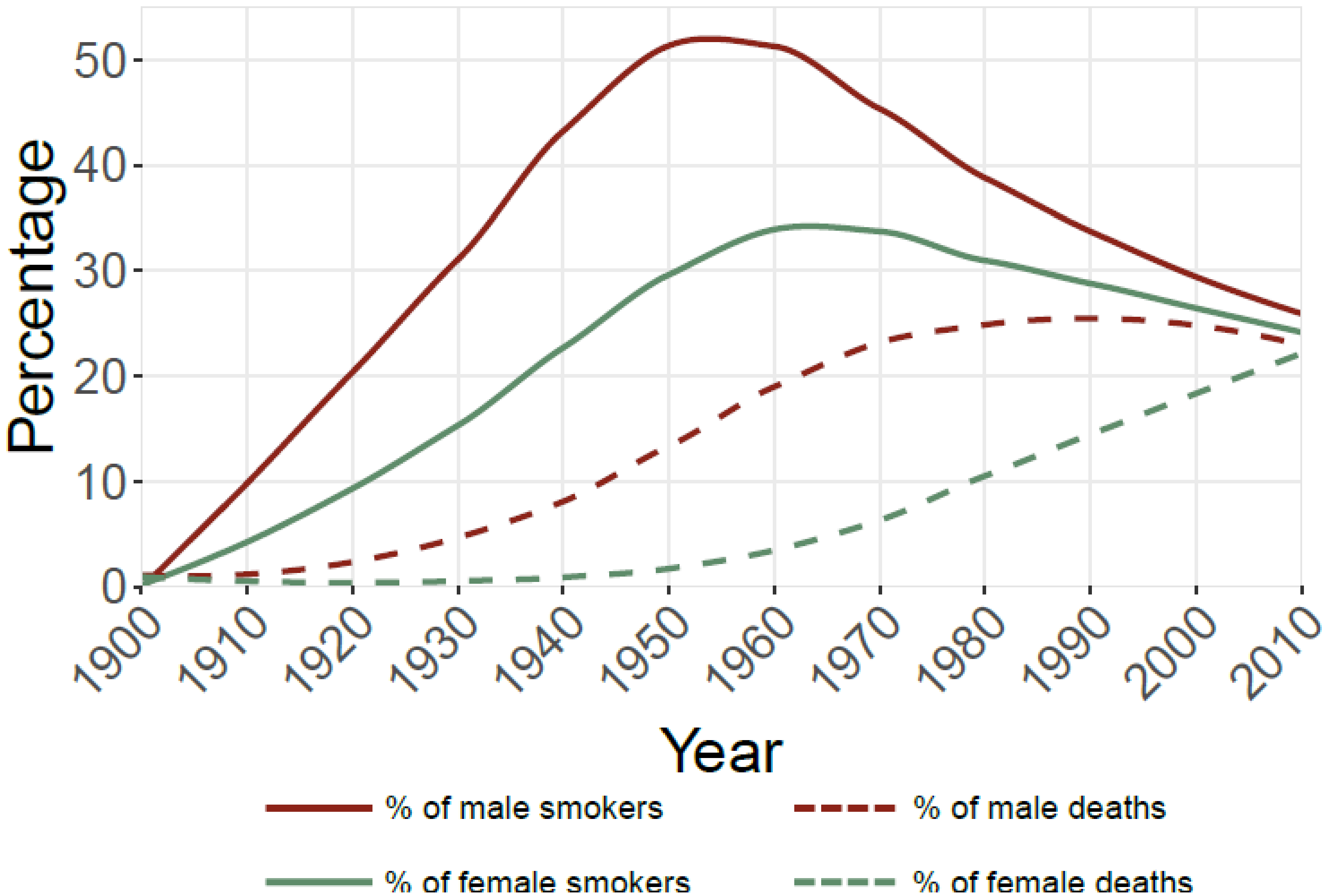

Figure 1

Illustration of smoking epidemic, after reference 5. Males (red) take up smoking (solid line) at a steady pace until smoking-related mortality surges (dashed line) and the proportion smoking starts to decline. Females (green) take up smoking later than males and reach a less high proportion smoking. Smoking-related mortality in females is the last to increase to significant proportions. An essential feature of the model is the large time gap between the act of smoking and dying from it.

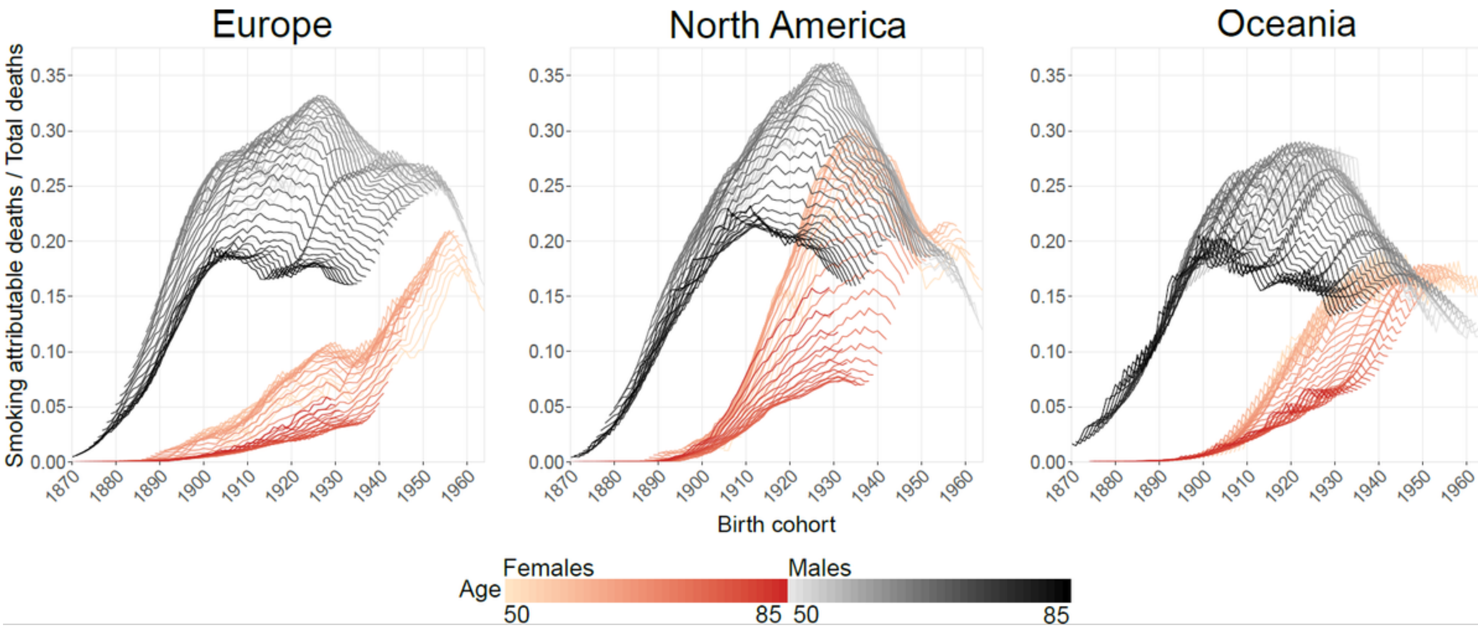

Figure 2

Cohort-by-age analysis of the proportion of overall mortality that is attributed to smoking. Individuals stay on a single vertical line that marks their cohort. Darker shades indicate higher ages. The more recent a cohort, the smaller the number of age groups for which data are available (cohorts have not yet reached the higher ages). Ages included were 50-85. Regions included were high-income Europe (13 countries), high-income North America (2 countries) and high-income Oceania (2 countries).

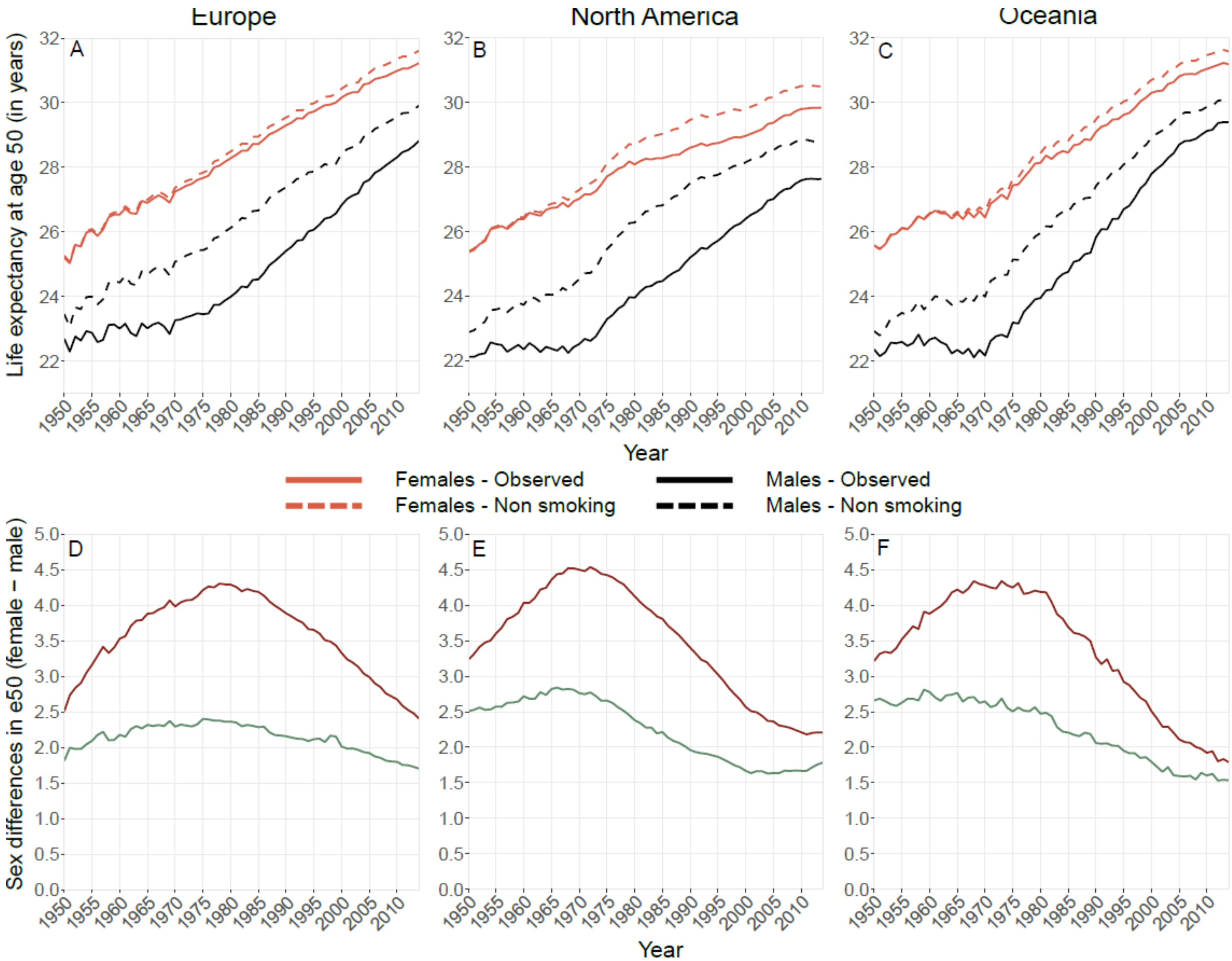

Figure 3

Upper panel: Historical development of life expectancy at age 50 (in years) for males (black) and females (red) with the observed mortality rates (solid) and with the smoking-attributable mortality omitted (dashed) for the three studied regions. Lower panel: Sex differences in life expectancy at age 50 with observed mortality (total population), and when smoking-attributable mortality was removed, for the three studied regions.

Supplementary Files

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- supplement1.pdf
- supplement2.pdf