Annals of Epidemiology 25 (2015) 243–249

Contents lists available at ScienceDirect

Annals of Epidemiology

journal homepage: www.annalsofepidemiology.org

Original article

The role of smoking in changes in the survival curve: an empirical study in 10 European countries

Fanny Janssen PhD [a,b,*], Valentin Rousson PhD [c], Fred Paccaud PhD [c]

[a] Population Research Centre, Demography Department, Faculty of Spatial Sciences, University of Groningen, Groningen, The Netherlands
[b] Netherlands Interdisciplinary Demographic Institute, The Hague, The Netherlands
[c] Institute for Social and Preventive Medicine, University Hospital Center, Lausanne, Switzerland

A R T I C L E I N F O

Article history:
Received 2 May 2014
Accepted 9 January 2015
Available online 16 January 2015

Keywords:
Mortality
Life expectancy
Compression
Smoking-related mortality
Sex differences

A B S T R A C T

Purpose: We examined the role of smoking in the two dimensions behind the time trends in adult mortality in European countries, that is, rectangularization of the survival curve (mortality compression) and longevity extension (increase in the age-at-death).
Methods: Using data on national sex-specific populations aged 50 years and older from Denmark, Finland, France, West Germany, Italy, the Netherlands, Norway, Sweden, Switzerland, and the United Kingdom, we studied trends in life expectancy, rectangularity, and longevity from 1950 to 2009 for both all-cause and nonsmoking-related mortality and correlated them with trends in lifetime smoking prevalence.
Results: For all-cause mortality, rectangularization accelerated around 1980 among men in all the countries studied, and more recently among women in Denmark and the United Kingdom. Trends in lifetime smoking prevalence correlated negatively with both rectangularization and longevity extension, but more negatively with rectangularization. For nonsmoking-related mortality, rectangularization among men did not accelerate around 1980. Among women, the differences between all-cause mortality and nonsmoking-related mortality were small, but larger for rectangularization than for longevity extension. Rectangularization contributed less to the increase in life expectancy than longevity extension, especially for nonsmoking-related mortality among men.
Conclusions: Smoking affects rectangularization more than longevity extension, both among men and women.

Introduction

Smoking is a well-known determinant not only of individual health (e.g., studies by Doll et al. [1] and Mamun et al. [2]), but also of population-level mortality rates and trends over time, especially in high-income countries. Smoking has a strong influence on the ranking of countries by life expectancy [3], sex differences in mortality [4–6], and variations in mortality trends between countries and sexes (e.g., studies by Preston et al. [3] Janssen et al. [7], Lopez et al. [8]). The impact of smoking on mortality at the population level is an important research field with considerable relevance for a range of health-related policies.

Most previous studies on the role of smoking in mortality variations over time and between countries have examined life expectancy or overall mortality [3,6,7]. Recently, however, there has been a shift in mortality research away from looking at life expectancy alone—i.e., the expected average age-at-death—toward taking into account the full age-at-death distributions. To describe the changes over time, two scenarios have been distinguished which actually operate in tandem to increase life expectancy: first, a decline in premature mortality with no increase in the maximum lifespan, which results in more people dying at the same ages and a compressed age-at-death distribution ("mortality compression" or "rectangularization of the survival curve") [9]; and, second, a delay in aging, which manifests itself in increases in the lifespan and in the number of centenarians (here referred to as "longevity extension") (e.g., a study by Vaupel [10]). The relative roles of the two processes in the mortality trend are currently under debate but are important for the future development of life expectancy. If only "rectangularization" occurs, we would be

Conflicts of interest and source of funding: none declared.
* Corresponding author. Population Research Centre, Faculty of Spatial Sciences, University of Groningen, PO Box 800, 9700 Groningen, The Netherlands. Tel.: +31 (0)50 363 4421; fax: +31 (0)50 363 3901.
E-mail address: f.janssen@rug.nl (F. Janssen).

http://dx.doi.org/10.1016/j.annepidem.2015.01.007
1047-2797/

approaching a limit to life expectancy. If, however, “longevity extension” occurs, it is unlikely that a life expectancy limit will be reached in the near future.

Previous literature within the compression of mortality debate has focused on describing the changes in the age-at-death distribution and the survival curves through different mortality indicators (e.g., variability in age at dying), rather than on offering empirical explanations for these changes. When an explanation has been provided, it has tended to refer primarily to international differences in age-at-death variability [11–19], rather than to the various trends over time [11,13,16,20,21]. Smoking has, however, been mentioned as being one of the possible determinants of differences in age-at-death variability between countries, sexes, or educational groups (e.g., studies by Kannisto [12], Edwards and Tuljapurkar [14], and Brown [18]). Moreover, Hill [22] mentioned smoking as being a cause of the decline in age-at-death variability among recent male cohorts in England and Wales (up to birth cohort 1901). Rossi et al. [23] provided a more detailed discussion of the potential role of smoking in the patterns of rectangularization observed in nine western European countries from 1922 to 2006. These discussions have not, however, been supported with empirical analysis.

We examined the role of smoking in both of the processes underlying the trends in adult mortality in 10 European countries over the period 1950 to 2009 simultaneously; that is, the rectangularization of the survival curve (compression of mortality) and longevity extension (increase in the age-at-death). Our research generates relevant information on how smoking affects trends in the full age-at-death distribution, and contributes to the current debate on the compression of mortality.

Methods

Study design and population

We conducted an ecological study which uses national mortality data by sex for 10 low-mortality, high-income European countries: Denmark, Finland, France, West Germany, Italy, the Netherlands, Norway, Sweden, Switzerland, and the United Kingdom. As we were restricted by the availability of the lung cancer mortality data needed for our approach, we studied only northern and western European countries from 1950 to 2009.

Changes in adult survival

To study changes in survival after age 50 years, period life table data were obtained from the Human Mortality Database (www.mortality.org). Using the approach developed by Rousson and Paccaud [23, 24], we assessed trends in (i) trimmed life expectancy (tLE_50), calculated by excluding the 10% of deaths at the highest ages to get more stable indicators [25]; (ii) rectangularity; and (iii) longevity. Rectangularity (R) represents the area under the survival curve divided by the area of the smallest rectangle containing that curve. The higher the R, the more rectangular the survival curve. Longevity (L) is the age at which survival from age 50 years equals 10%. Subsequently, tLE_50 $= R \times (L - 50)$.

We decomposed the gain in tLE_50 between 1950 and 2009 into the contribution of rectangularization (first term) and longevity extension (second term), as follows:

$$\mathrm{tLE\_50}_{2009} - \mathrm{tLE\_50}_{1950} = [(R_{2009} - R_{1950}) \times (L_M - 50)] + [(L_{2009} - L_{1950}) \times R_M]$$

where R_M is the average of R_{1950} and R_{2009}, and L_M is the average of L_{1950} and L_{2009}. The percentage of tLE_50 which is attributed to rectangularization is defined as follows [24]:

$$\mathrm{LEAR} = [(R_{2009} - R_{1950}) \times (L_M - 50)]/(\mathrm{tLE}_{2009} - \mathrm{tLE}_{1950})$$

The role of smoking

We explored the role of smoking by (i) correlating the time trends in indirectly estimated age- and sex-standardized lifetime smoking prevalence with the time trends in the three indicators; (ii) comparing the trends in the indicators for all-cause mortality with those for nonsmoking-related mortality; and (iii) comparing the relative contributions of rectangularization and longevity extension in the gains in life expectancy over time for all-cause mortality and nonsmoking-related mortality.

Lifetime smoking prevalence and nonsmoking-related mortality were estimated using an adapted version of the indirect Peto-Lopez method [26,27]. The methodology uses lung cancer mortality but also takes into account the effect of smoking on other causes of death. The country- and sex-specific lung cancer deaths by 5-year age groups (up to 80+ years) were obtained through WHOSIS (http://www.who.int/whosis/mort/download/en/) and additional national sources. To adjust for lung cancer mortality not due to smoking, the lifetime smoking prevalence (p) by sex and 5-year age groups were estimated by comparing the obtained lung cancer mortality rates with the smoothed age- and sex-specific lung cancer rates of the smokers and the never-smokers in the ACS CPS-II study [26]. This lifetime smoking prevalence reflects the smoking prevalence about 30 years earlier and the risk of lung cancer mortality associated with this prevalence, which is strongly related to the dose consumed. To enable us to compare the lifetime smoking prevalence levels in different countries, we calculated for each country and sex an age- and sex-standardized average, using the population of the United Kingdom in 2009 as the standard population.

The survival curve for nonsmoking-related mortality was estimated through the age-specific mortality probabilities for nonsmoking-related mortality, which were obtained by multiplying the age-specific mortality probabilities for all-cause mortality with one minus the age-specific smoking-attributable mortality fractions (= the share of all-cause mortality due to smoking) (SAF). The SAFs were calculated by applying the age- and sex-specific relative risks (RRs) of dying from smoking for all-cause mortality to the lifetime smoking prevalence (p) using the formula $\mathrm{SAF} = p(\mathrm{RR} - 1)/(p(\mathrm{RR} - 1) + 1)$. The RRs were obtained from the ACS CPS-II study [26] and were subsequently smoothed by applying a second-degree polynomial. To take into account residual confounding and to obtain conservative estimates, the RRs were adjusted downward by reducing the excess risk by 30% [27,28]. The obtained SAFs by 5-year age groups were turned into single-year values by a least squares linear regression which applied the SAF for those aged 80 years and older to the single ages 83 to 110+.

Results

Figure 1 shows the trends over 1950 to 2009 in rectangularity (R) and longevity (L) for all-cause mortality (gray) and nonsmoking-related mortality (black), for five selected countries. The trends for all countries, including as well (trimmed) life expectancy at age 50 years (tLE_50) are available in Supplementary Figure 1.

Focusing first on all-cause mortality, we can see an overall increase in all indicators, and more regularly for women than for men. The gain in tLE_50 was between 3.4 and 9.3 years. The

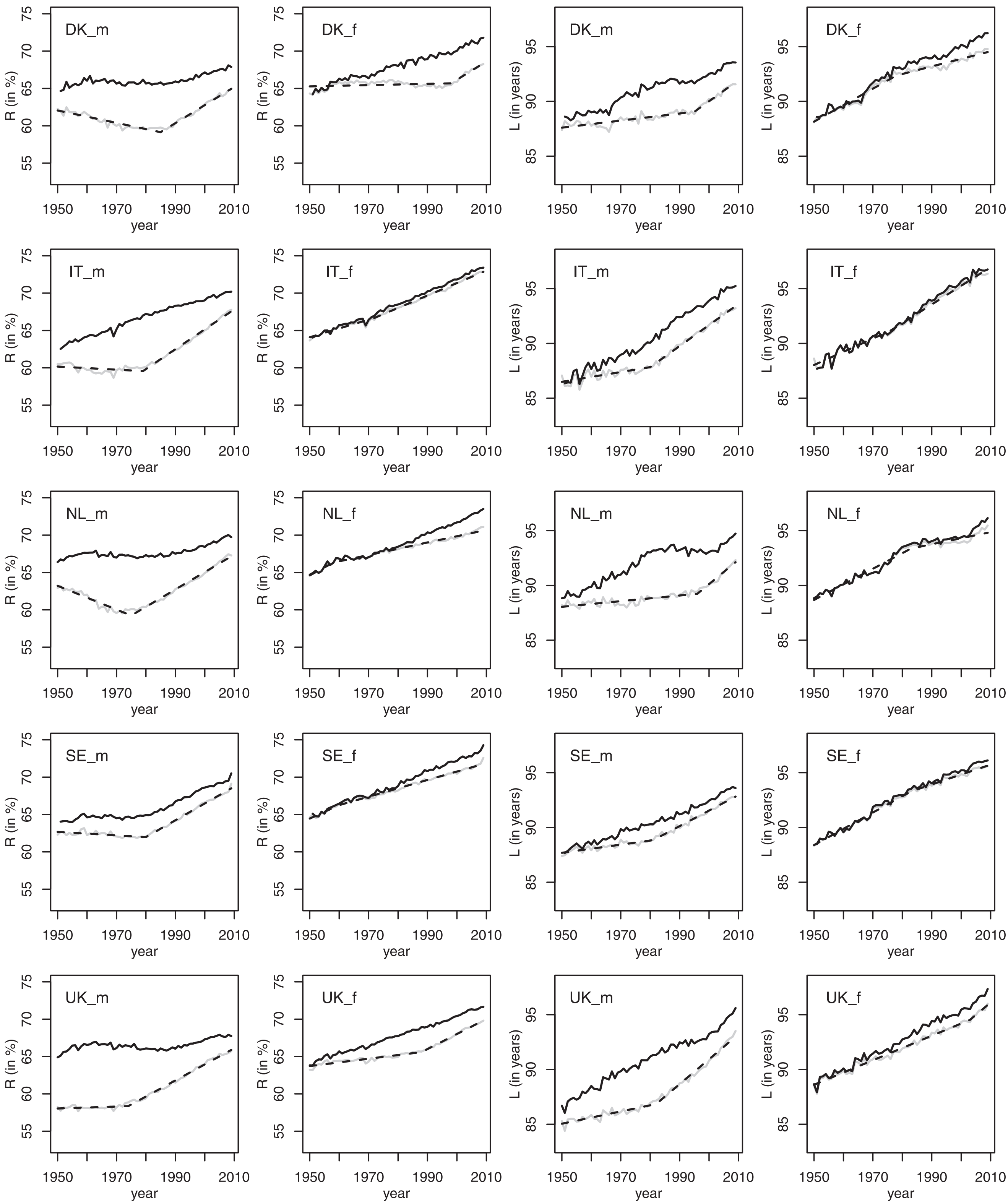

Fig. 1. Trends in rectangularity (R) and longevity (L) for all-cause mortality (gray) and nonsmoking-related mortality (black), for five selected countries, 1950 to 2009, by country and sex; the dotted line represents a two-segment regression line for all-cause mortality. DK = Denmark; f = females; IT = Italy; m = males; NL = the Netherlands; SE = Sweden; UK = the United Kingdom.

increases in rectangularity and longevity reflect a decline in premature mortality after age 50 years and a decline in old-age mortality, respectively. The two-segment regression lines (dotted lines) [23,29] indicate a change among men from derectangularization to rectangularization, which occurred around 1980 in almost all the countries. Among men, longevity extension also accelerated, albeit at very different speeds in different countries, and without declines in longevity (except in

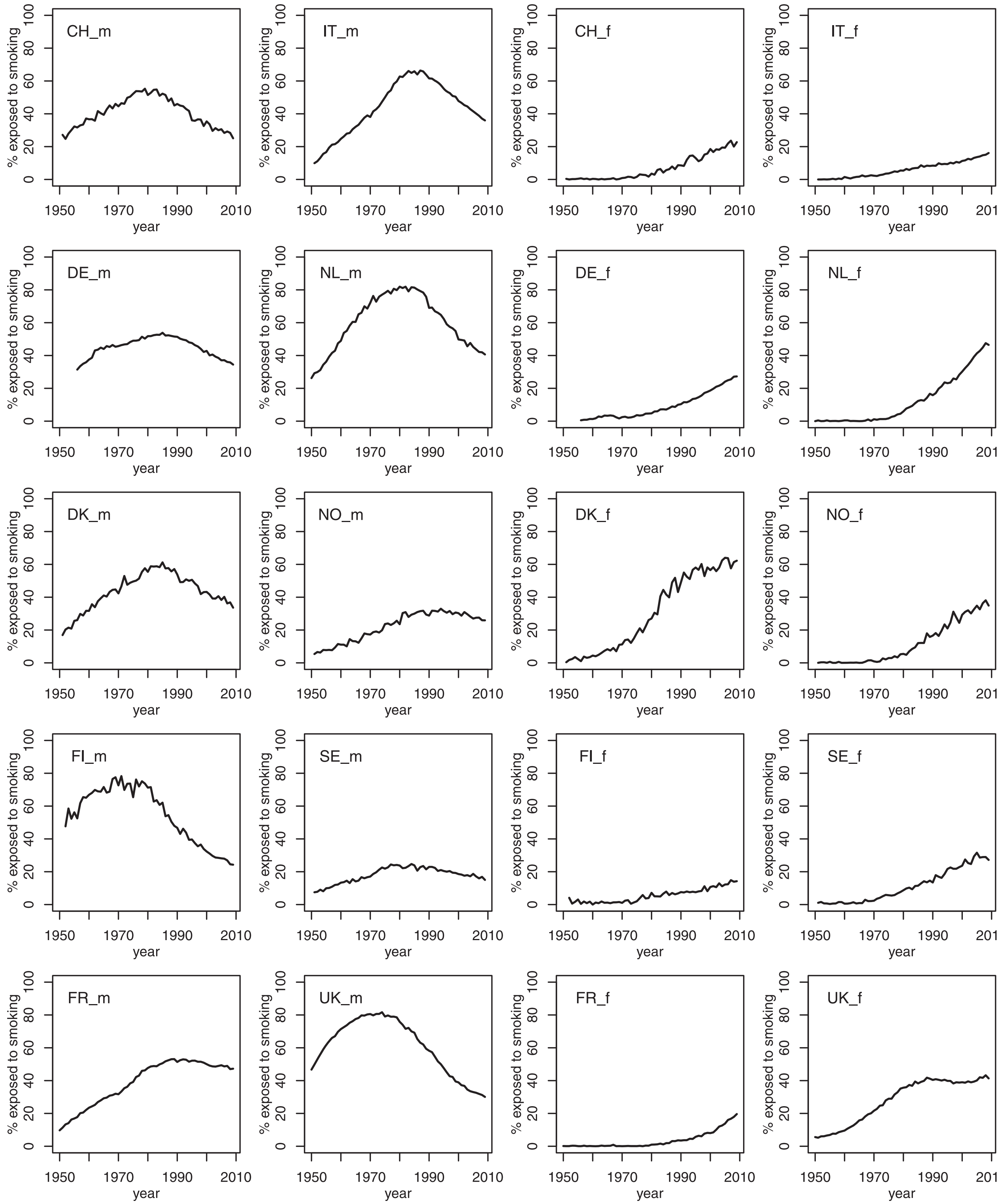

Fig. 2. Estimated age- and sex-standardized lifetime smoking prevalence (% exposed to smoking), 1950 to 2009, by country and sex. CH = Switzerland; DE = West Germany; DK = Denmark; f = females; FI = Finland; FR = France; IT = Italy; m = males; NL = the Netherlands; NO = Norway; SE = Sweden; UK = the United Kingdom.

Norway). Among women, an acceleration in rectangularization recently occurred in Denmark and United Kingdom, but a deceleration in longevity extension has been occurring in Denmark, the Netherlands, Sweden, and Switzerland.

The trends over 1950 to 2009 in indirectly estimated age- and sex-standardized lifetime smoking prevalence clearly differed between men and women (Fig. 2). Among men, the high initial levels continued to rise up to around 1980 and began to decline thereafter.

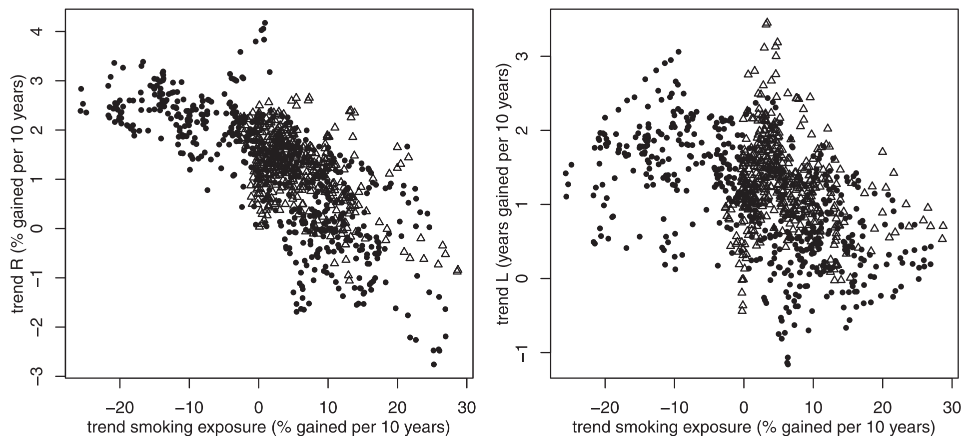

Fig. 3. Correlation of 10-year trends in age-standardized lifetime smoking prevalence with 10-year trends in rectangularity (R) and longevity (L) over the different periods and countries, by sex (circles refer to males, triangles to females).

Among women, lifetime smoking prevalence was still almost zero in 1950 but started to increase between 1950 and 1980. The increases in prevalence levels were greatest among women in the Netherlands, Denmark, and the United Kingdom but have stagnated in recent years.

Among men, in most of the countries studied, the timing of the decline in lifetime smoking prevalence (Fig. 2) was in line with the acceleration of rectangularization in all-cause mortality (Fig. 1; Supplementary Figure 1). This kind of correspondence is less visible among women.

To investigate this relationship in greater depth, we calculated trends over 10 years (1950–1960, 1951–1961, ..., 1999–2009) for each indicator, using slopes of regression lines. We then correlated these trends in lifetime smoking prevalence with the trends in both rectangularity and longevity across the 10-year periods and countries, by sex (see Fig. 3). Among men, the Spearman correlation between the trends in lifetime smoking prevalence and the trends in rectangularity was strongly negative (−0.82). The correlation was less negative between the trends in lifetime smoking prevalence and the trends in longevity (−0.62). Among women, the correlations were weaker but again stronger for rectangularity (−0.40) than for longevity (−0.13).

The trends in the survival curve indicators were more linear for nonsmoking-related mortality than for all-cause mortality (Fig. 1; Supplementary Figure 1), especially among men. For nonsmoking-related mortality no sudden acceleration in rectangularization occurred among men in most of the countries around 1980. Among women, the accelerations in rectangularization for nonsmoking-related mortality were weaker than for all-cause mortality in most of the countries, whereas for longevity clear differences were uncovered for Denmark and the United Kingdom only.

For both all-cause mortality and nonsmoking-related mortality, the contribution of rectangularization (LEAR) to the overall gain in tLE_50 between 1959 and 2009 was consistently less than 50%, which indicates that longevity extension contributed more of the years gained (Fig. 4). But among men, LEAR was lower for nonsmoking-related mortality (around 30%) than for all-cause mortality (around 40%). Among women, LEAR was almost the same for all-cause and nonsmoking-related mortality, at around 40%.

Discussion

Our results suggest that smoking affects rectangularization of the survival curve more than longevity extension. Trends in lifetime smoking prevalence correlated negatively with both rectangularization and longevity extension, but more negatively with rectangularization. The acceleration of rectangularization for all-cause mortality around 1980 among men, and more recently among women in Denmark and the United Kingdom, disappeared when we considered only nonsmoking-related mortality. Among men, the contribution of rectangularization to the increase in life expectancy was less for nonsmoking-related mortality than for all-cause mortality.

The more important impact of smoking on rectangularization may be related to the fact that smoking kills a substantial proportion of people at relatively young ages [8,26,28,30]. Ezzati and Lopez [28] estimated that, in 2000, smoking caused 2.43 million deaths in adults aged 30 years and older in industrialized countries, a figure which represents 19% of total adult mortality. Among people aged 30 to 69 years, an estimated 1.19 million deaths were attributable to smoking, or about one-third of all deaths at these ages. As smoking is clearly the largest cause of premature mortality, it delays the rectangularization process. Cardiovascular disease mortality, which is one of the earliest and most frequent consequences of smoking, plays a very important role in the impact of smoking on premature death, and thus on rectangularization.

For both sexes, the observed acceleration of rectangularization can be clearly linked to the decline in smoking prevalence about 30 years earlier. This shift occurred much earlier among men than among women, a pattern which has also been described in the smoking epidemic model [8]. Among men, the decline in smoking prevalence in western European countries around the 1950s [30] resulted in the observed acceleration of rectangularization in the 1980s. The recent acceleration of rectangularization among women in Denmark and the United Kingdom can be traced back to the early onset of the smoking epidemic, the high levels of smoking reached [30], and the stagnation and decline in smoking prevalence about 30 years earlier [31] in these two populations.

Our observation that smoking affects rectangularity more than longevity is, at first glance, more obvious among men than among women. This is likely due to the higher levels of smoking prevalence and the more important changes in smoking prevalence among men than among women, which we can also see from the trends in lifetime smoking prevalence. When women started smoking a couple of decades after men, their smoking prevalence levels were lower because the negative effects of smoking were already well known [8].

Nonetheless, we found clear similarities between the sexes in the ways in which smoking affected rectangularization relative to

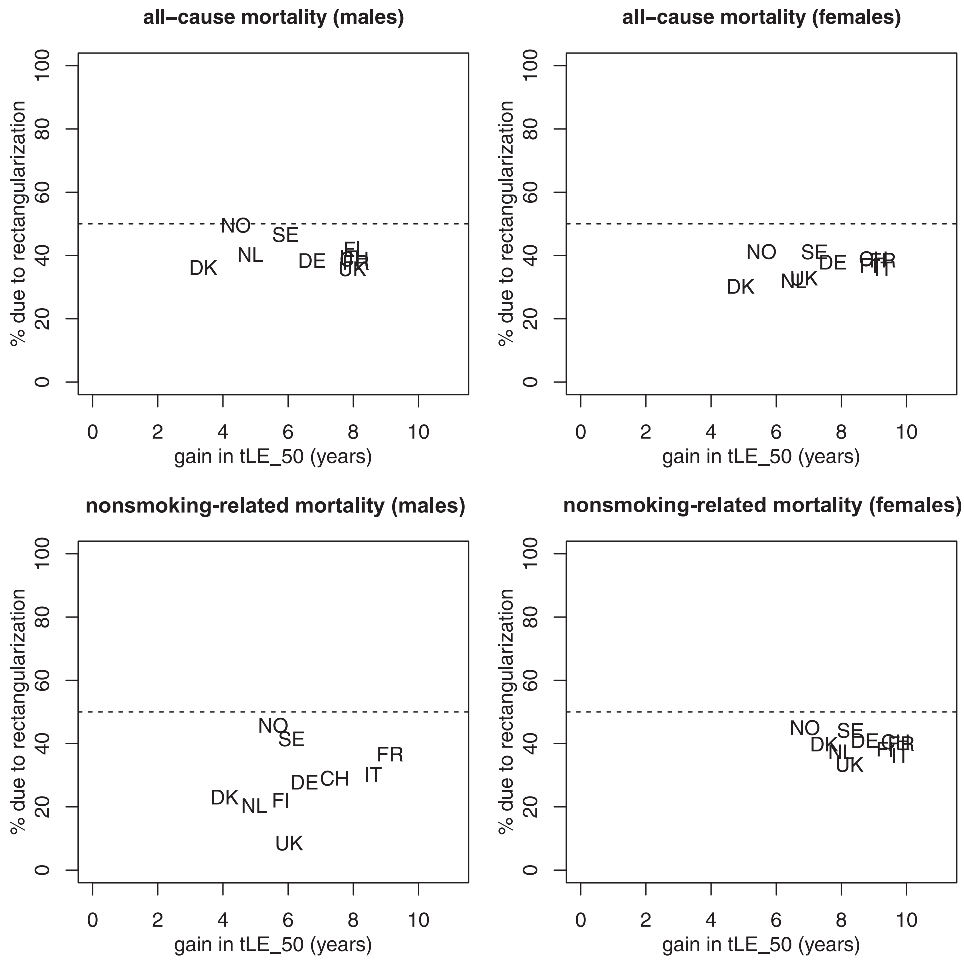

Fig. 4. Contribution of rectangularization to the overall gain in trimmed life expectancy at age 50 years (tLE_50) between 1956 and 2009 (because of missing data in West Germany before 1956) for the different countries, for all-cause mortality and nonsmoking-related mortality, by sex. CH = Switzerland; DE = West Germany; DK = Denmark; FI = Finland; FR = France; IT = Italy; NL = the Netherlands; NO = Norway; SE = Sweden; UK = the United Kingdom.

longevity extension. In Figure 3, women and men are in similar portions of the plot. The lower correlation observed among women seems mainly attributable to the absence of negative trends and many near-zero trends among women. Additional analysis which excluded trends calculated over years in which the lifetime smoking prevalence was under 10% resulted in fairly similar results for men and women: a correlation of −0.82 among men and of −0.63 among women between trends in lifetime smoking prevalence and trends in rectangularity; and of −0.62 and −0.40, respectively, between trends in lifetime smoking prevalence and trends in longevity (see Supplementary Figure 2).

Moreover, in Denmark, the United Kingdom, Germany, the Netherlands, Norway, Sweden, and Switzerland, where the smoking prevalence among women was large enough to result in a sizable difference between all-cause and nonsmoking-related mortality, this difference was larger for rectangularity than for longevity, as also observed among men.

Although in general smoking was found to be more important for rectangularization than for longevity extension, a few countries, and particularly the Netherlands, exhibited more similar patterns in longevity extension between men and women for nonsmoking-related mortality than for all-cause mortality. This could indicate that smoking can have an influence even on old-age mortality, especially in terms of sex differences in mortality [7,32]. These similarities were particularly large for the period up to 1980, resulting in a small remaining overall sex difference, largely explained by biological factors. The more positive nonsmoking-related mortality trends among women than men from 1980 onward, observed as well in other countries, are most likely the result of behavioral factors again [5,33].

It should be noted that we assessed the role of smoking indirectly. An advantage of using an indirect method rather than relying on the scarcely available smoking prevalence data is that it allows us take into account the different dimensions of smoking, including the dose consumed. Therefore, these indirect methods are often used (e.g., a study by Lim et al. [34]). The crucial assumptions of the Peto-Lopez method are (i) the use of similar RRs of dying from smoking over time and across countries, based on the American Cancer Prevalence Study II, despite clear national differences in smoking levels and changes in the RRs over time ([35,36]); (ii) the use of the same ratio between background lung cancer mortality (lung cancer mortality not due to smoking) and smoking-attributable lung cancer mortality, despite likely changes in environmental risk factors for lung cancer mortality [37]; and (iii) a similar lag time between smoking and mortality for lung cancer mortality and other causes of death. Yet despite these assumptions, our estimates of smoking-attributable mortality for 2000 were reasonably similar to those generated by other indirect estimation techniques [38,39]. A sensitivity analysis in which we allowed our RRs to vary over time following the trend estimates by Mehta and Preston [35] resulted in a higher increase in trimmed life expectancy for nonsmoking-related mortality, but our conclusions were not affected.

Of the many indicators which could be used to study the rectangularization of the survival curve or the compression of mortality [11,40], we chose to assess rectangularization using the approach by Rousson and Paccaud [24], which follows the "moving rectangle" principle introduced by Wilmoth and Horiuchi [11]. Although our method excluded 10% of deaths at the highest ages to obtain stable indicators, among its advantages is the fact that the method's indicators can be easily calculated and combined to allow for the decomposition of a change in life expectancy [24]. A sensitivity analysis which used the proportion of the area under the survival curve in a rectangle drawn up to age 100 years as the rectangularity indicator resulted in similar conclusions.

Wilmoth and Horiuchi [11] showed a high correlation between the moving rectangle measure and various measures of the variability in the age-at-death distribution (such as the interquartile range). It should be noted, however, that although measures of rectangularization are often interpreted in practice as being measures of variability, there are scenarios in which we can have rectangularization of the survival curve without necessarily having a reduction in variability in the age-at-death distribution.

In conclusion, our analysis has clearly shown that smoking affects rectangularization more than longevity extension, which is likely due to the fact that smoking kills a substantial proportion of people at relatively young ages. Despite large differences in the extent of the smoking epidemic among men and women, clear similarities between the sexes exist in the ways in which smoking affects rectangularization relative to longevity extension.

Male life expectancy—and particularly survival from premature mortality—would have been substantially higher if smoking had not reached epidemic proportions among men in high-income countries during the 20th century. Because the smoking epidemic has not yet reached its peak among women, we can expect that female life expectancy—and especially female survival from premature mortality—will be lower than its potential level for some time to come.

The important effects of smoking on past mortality trends, and particularly the resulting nonlinear trends in rectangularization, need to be considered when predicting future mortality.

Supplementary data

Supplementary data related to this article can be found online at doi:10.1016/j.annepidem.2015.01.007

References

[1] Doll R, Peto R, Wheatley K, Gray R, Sutherland I. Mortality in relation to smoking: 40 years' observations on male British doctors. BMJ 1994;309(6959):901–11.
[2] Mamun AA, Peeters A, Barendregt J, Willekens F, Nusselder W, Bonneux L. Smoking decreases the duration of life lived with and without cardiovascular disease: a life course analysis of the Framingham Heart Study. Eur Heart J 2004;25(5):409–15.
[3] Preston SH, Glei DA, Wilmoth JR. Contribution of smoking to international differences in life expectancy. In: Crimmins EM, Preston SH, Cohen B, editors. International differences in mortality at older ages - dimensions and sources. Washington: The National Academies Press; 2011. p. 105–31.
[4] Waldron I. Recent trends in sex mortality ratios for adults in developed countries. Soc Sci Med 1993;36(4):451–62.
[5] Pampel F. Forecasting sex differences in mortality in high income nations: the contribution of smoking. Demogr Res 2005;13(18):455–84.
[6] McCartney G, Mahmood L, Leyland AH, Batty GD, Hunt K. Contribution of smoking-related and alcohol-related deaths to the gender gap in mortality: evidence from 30 European countries. Tob Control 2011;20:166–8.
[7] Janssen F, Kunst AE, Mackenbach JP. Variations in the pace of old-age mortality decline among seven European countries, over the period 1950 to 1999: the role of smoking and factors earlier in life. Eur J Popul 2007;23(2):171–88.
[8] Lopez AD, Collishaw NE, Piha T. A descriptive model of the cigarette epidemic in developed countries. Tob Control 1994;3(3):242–7.
[9] Fries JF. Aging, natural death, and the compression of morbidity. N Engl J Med 1980;303(3):130–5.
[10] Vaupel JW. Biodemography of human ageing. Nature 2010;464(7288):536–42.
[11] Wilmoth JR, Horiuchi S. Rectangularization revisited: variability of age at death within human populations. Demography 1999;36(4):475–95.
[12] Kannisto V. Measuring the compression of mortality. Demogr Res 2000;3:24.
[13] Shkolnikov V, Andreev E, Begun AZ. Gini coefficient as a life table function: computation from discrete data, decomposition of differences and empirical examples. Demographic Res 2003;8:305–58.
[14] Edwards RD, Tuljapurkar S. Inequality in life spans and a new perspective on mortality convergence across industrialized countries. Popul Dev Rev 2005;31(4):645–74.
[15] Smits J, Monden C. Length of life inequality around the globe. Soc Sci Med 2009;68(6):1114–23.
[16] Shkolnikov VM, Andreev EM, Zhang Z, Oeppen J, Vaupel JW. Losses of expected lifetime in the United States and other developed countries: methods and empirical analyses. Demography 2011;48(1):211–39.
[17] Ouellette N, Bourbeau R. Changes in the age-at-death distribution in four low mortality countries: a nonparametric approach. Demogr Res 2011;25:593–628.
[18] Brown DC, Hayward MD, Montez JK, Hummer RA, Chiu CT, Hidajat MM. The significance of education for mortality compression in the United States. Demography 2012;49(3):819–40.
[19] van Raalte AA, Kunst AE, Lundberg O, Leinsalu M, Martikainen P, Artnik B, et al. The contribution of educational inequalities to lifespan variation. Popul Health Metr 2012;10(3):1–10.
[20] Nusselder WJ, Mackenbach JP. Rectangularization of the survival curve in The Netherlands: an analysis of underlying causes of death. J Gerontol B Psychol Sci Soc Sci 1997;52(3):145–54.
[21] Engelman M, Canudas-Romo V, Agree EM. The implications of increased survivorship for mortality variation in aging populations. Popul Dev Rev 2010;36(3):511–39.
[22] Hill G. The entropy of the survival curve: an alternative measure. Can Stud Popul 1993;20(1):43–57.
[23] Rossi IA, Rousson V, Paccaud F. The contribution of rectangularization to the secular increase of life expectancy: an empirical study. Int J Epidemiol 2013;42(1):250–8.
[24] Rousson V, Paccaud F. A set of indicators for decomposing the secular increase of life expectancy. Popul Health Metr 2010;8(1):18–27.
[25] Rossi IA, Rousson V, Paccaud F. Author's response to "Limitless longevity": the contribution of rectangularization to the secular increase in life expectancy: an empirical study. Int J Epidemiol 2013;42(3):916–7.
[26] Peto R, Boreham J, Lopez AD, Thun M, Heath C. Mortality from tobacco in developed countries: indirect estimation from national vital statistics. Lancet 1992;339(8804):1268–78.
[27] Janssen F, van Wissen LJ, Kunst AE. Including the smoking epidemic in internationally coherent mortality projections. Demography 2013;50(4):1341–62.
[28] Ezzati M, Lopez AD. Measuring the accumulated hazards of smoking: global and regional estimates for 2000. Tob Control 2003;12(1):79–85.
[29] Lerman PM. Fitting segmented regression models by grid search. J R Stat Soc Ser C App Stat 1980;29(1):77.
[30] Thun M, Peto R, Boreham J, Lopez AD. Stages of the cigarette epidemic on entering its second century. Tob Control 2012;21(2):96–101.
[31] Graham H. Smoking prevalence among women in the European community 1950-1990. Soc Sci Med 1996;43(2):243–54.
[32] Janssen F, Kunst AE. Cohort patterns in mortality trends among the elderly in seven European countries, 1950-99. Int J Epidemiol 2005;34(5):1149–59.
[33] Trovato F, Lalu NM. Narrowing sex differentials in life expectancy in the industrialized world: early 1970's to early 1990's. Soc Biol 1996;43(1-2):20–37.
[34] Lim SS, Vos T, Flaxman AD, Danaei G, Shibuya K, Adair-Rohani H, et al. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010. Lancet 2012;380(9859):2224–60.
[35] Mehta N, Preston S. Continued increases in the relative risk of death from smoking. Am J Public Health 2012;102(11):2181–6.
[36] Oza S, Thun MJ, Henley SJ, Lopez AD, Ezzati M. How many deaths are attributable to smoking in the United States? Comparison of methods for estimating smoking-attributable mortality when smoking prevalence changes. Prev Med 2011;52(6):428–33.
[37] Dresler C. The changing epidemic of lung cancer and occupational and environmental risk factors. Thorac Surg Clin 2013;23(2):113–22.
[38] Preston SH, Glei DA, Wilmoth JR. A new method for estimating smoking-attributable mortality in high-income countries. Int J Epidemiol 2010;39(2):430–8.
[39] Rostron BL. A modified new method for estimating smoking-attributable mortality in high-income countries. Demographic Res 2010;23(14):399–420.
[40] Cheung SL, Robine JM, Tu EJ, Caselli G. Three dimensions of the survival curve: horizontalization, verticalization, and longevity extension. Demography 2005;42(2):243–58.