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

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Abstract

Purpose: We examined the role of smoking in the two dimensions behind the time trends in adult mortality in European countries: i.e., 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 and over 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 non-smoking-related mortality, and correlated them with trends in lifetime smoking prevalence.

Results: For all-cause mortality, rectangularization accelerated around 1980 among men in all of 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 non-smoking-related mortality, rectangularization among men did not accelerate around 1980. Among women, the differences between all-cause mortality and non-smoking-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 non-smoking-related-mortality among men.

Conclusion: Smoking affects rectangularization more than longevity extension, both among men and women.

Key words: mortality; life expectancy; compression; smoking-related mortality; sex differences

INTRODUCTION

Smoking is a well-known determinant not only of individual health (e.g.(1,2)), 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.(3,7,8)). 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 smoking plays 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—towards 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 ageing, which manifests itself in increases in the lifespan and in the number of centenarians (here referred to as “longevity extension”) (e.g.(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 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.(12,14,18)). Moreover, Hill (1993)(22) mentioned smoking as being a cause of the decline in age-at-death variability among recent male cohorts in England & Wales (up to birth cohort 1901). Rossi et al. (2013)(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; i.e., the rectangularization of the survival curve (compression of mortality) and longevity extension (increase in the age at death). Our paper 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 employed 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, period life table data were obtained from the Human Mortality Database (www.mortality.org). Using the approach developed by Rousson & Paccaud (2010)(23,24), we assessed trends in (i) trimmed life expectancy (tLE₅₀), 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 equals 10%. Subsequently, $tLE_{50} = R * (L - 50)$.

We decomposed the gain in tLE₅₀ between 1950 and 2009 into the contribution of rectangularization (first term) and longevity extension (second term), as:

$$tLE_{50_{2009}} - tLE_{50_{1950}} = [(R_{2009} - R_{1950}) * (L_M - 50)] + [(L_{2009} - L_{1950}) * R_M]$$

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 tLE₅₀ which is attributed to rectangularization is defined as:

$$LEAR = [(R_{2009} - R_{1950}) * (L_M - 50)] / (tLE_{2009} - tLE_{1950}). \quad (24)$$

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 non-smoking-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 non-smoking-related mortality.

Lifetime smoking prevalence and non-smoking-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 five-year age groups (up to 80+) 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 five-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 non-smoking related mortality was estimated through the age-specific mortality probabilities for non-smoking-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 $SAF = p(RR-1)/(p(RR-1)+1)$. 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 downwards by reducing the excess risk by 30% (28). (27) The obtained SAFs by five-year age groups were turned into single-year values by a least squares linear regression which applied the SAF for age 80+ to the single ages 83-110+.

RESULTS

Figure 1 shows the trends over 1950-2009 in rectangularity (R) and longevity (L) for all-cause mortality (grey) and non-smoking-related mortality (black), for five selected countries. The trends for all countries, including as well (trimmed) life expectancy at age 50 (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 increase in rectangularity and longevity reflect a decline in premature mortality after age 50 and a decline in old-age mortality, respectively. The two-segment regression lines (dotted lines) (23,29) indicate a change among men from drectangularization to rectangularization, which occurred around 1980 in almost all of the countries. Among men, longevity extension also accelerated, albeit at very different speeds in different countries, and without declines in longevity (except in 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 1950-2009 in indirectly estimated age- and sex-standardized lifetime smoking prevalence clearly differed between men and women (Figure 2). Among men, the high initial levels continued to rise up to around 1980, and began to decline thereafter. 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 (Figure 2) was in line with the acceleration of rectangularization in all-cause mortality (Figure 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 Figure 3). Among men, the Spearman correlation between the trends in lifetime smoking prevalence and the trends in rectangularity were 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 non-smoking-related mortality than for all-cause mortality (Figure 1; Supplementary figure 1), especially among men. For non-smoking-related mortality no sudden acceleration in rectangularization occurred among men in most of the countries around 1980. Among women, the accelerations in rectangularization for non-smoking-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 non-smoking-related mortality, the contribution of rectangularization (LEAR) to the overall gain in tLE₅₀ between 1959 and 2009 was consistently less than 50%, which indicates that longevity extension contributed more of the years gained (Figure 4). But among men, LEAR was lower for non-smoking-related mortality (around 30%) than for all-cause mortality (around 40%). Among women, LEAR was almost the same for all-cause and non-smoking-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 non-smoking-related mortality. Among men, the contribution of rectangularization to the increase in life expectancy was less for non-smoking-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 & Lopez (2003)(28) estimated that in 2000 smoking caused 2.43 million deaths in adults aged 30 and over in industrialized countries, a figure which represents 19% of total adult mortality. Among people aged 30-69, 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 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 sizeable difference between all-cause and non-smoking 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 non-smoking-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 non-smoking-related mortality trends among women than among men from 1980 onwards, observed as well in other countries, are most likely the result of behavioural 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. (34)). The crucial assumptions of the Peto-Lopez method are: (i) the use of similar relative risks 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 (2012)(35) resulted in a higher increase in trimmed life expectancy for non-smoking-related mortality, but our conclusions were not affected.

Out of the many indicators which could be used to study the rectangularization of the survival curve or the compression of mortality (40)(11), we chose to assess rectangularization using the approach by Rousson & Paccaud (2010) (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 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. Since 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 non-linear trends in rectangularization, need to be considered when predicting future mortality.

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Figures

Figure 1 - Trends in rectangularity (R) and longevity (L) for all-cause mortality (grey) and non-smoking-related-mortality (black), for five selected countries, 1950-2009, by country and sex; the dotted line represents a two-segment regression line for all-cause mortality.

DK = Denmark; IT = Italy, NL = the Netherlands, SE = Sweden, UK = the United Kingdom; m = males; f = females

Figure 2 – Estimated age- and sex-standardized lifetime smoking prevalence (% exposed to smoking), 1950-2009, by country and sex

DK = Denmark; FI = Finland, FR = France, DE = West Germany, IT = Italy, NL = the Netherlands, NO = Norway, SE = Sweden, CH = Switzerland, UK = the United Kingdom; m = males; f = females

Figure 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 (m), triangles to females (f))

Figure 4 –Contribution of rectangularization to the overall gain in trimmed life expectancy at age 50 (tLE₅₀) between 1956 and 2009* for the different countries, for all-cause mortality and non-smoking-related mortality, by sex

*due to missing data in West Germany before 1956

DK = Denmark; FI = Finland, FR = France, DE = West Germany, IT = Italy, NL = the Netherlands, NO = Norway, SE = Sweden, CH = Switzerland, UK = the United Kingdom

Supplementary Figures

Supplementary Figure 1 - Trends in all-cause mortality (blue for men; red for women) and non-smoking-related-mortality (black), by country and sex, 1950-2009; the dotted line represents a two-segment regression line for all-cause mortality.

a) Trimmed life expectancy at age 50 (tLE₅₀), b) Rectangularity (R), c) Longevity (L)

DK = Denmark; FI = Finland, FR = France, DE = West Germany, IT = Italy, NL = the Netherlands, NO = Norway, SE = Sweden, CH = Switzerland, UK = the United Kingdom; m = males; f = females

Supplementary Figure 2 – Correlation of 10-year trends in age-standardized lifetime smoking prevalence (excluding trends calculated over years in which the lifetime smoking prevalence was under 10%) with 10-year trends in rectangularity (R) and longevity (L), over the different periods and countries, by sex (blue circles refer to males (m), red triangles to females (f))

all-cause mortality (males)

all-cause mortality (females)

non-smoking-related mortality (males)

non-smoking-related mortality (females)