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Original article

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, 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

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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:

$$tLE\_50_{2009} - tLE\_50_{1950} = [(R_{2009} - R_{1950}) \times (L_M - 50)] + [(L_{2009} - L_{1950}) \times R_M]$$

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]:

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

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 $SAF = p(RR - 1)/(p(RR - 1) + 1)$. 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 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