Determinants of inequalities in life expectancy: an international comparative study of eight risk factors

Johan P Mackenbach, José Rubio Valverde, Matthias Bopp, Henrik Brønnum-Hansen, Patrick Deboosere, Ramune Kalediene, Katalin Kovács, Mall Leinsalu, Pekka Martikainen, Gwenn Menvielle, Enrique Regidor, Wilma J Nusselder

Summary

Background Socioeconomic inequalities in longevity have been found in all European countries. We aimed to assess which determinants make the largest contribution to these inequalities.

Methods We did an international comparative study of inequalities in risk factors for shorter life expectancy in Europe. We collected register-based mortality data and survey-based risk factor data from 15 European countries. We calculated partial life expectancies between the ages of 35 years and 80 years by education and gender and determined the effect on mortality of changing the prevalence of eight risk factors—father with a manual occupation, low income, few social contacts, smoking, high alcohol consumption, high bodyweight, low physical exercise, and low fruit and vegetable consumption—among people with a low level of education to that among people with a high level of education (upward levelling scenario), using population attributable fractions.

Findings In all countries, a substantial gap existed in partial life expectancy between people with low and high levels of education, of 2·3–8·2 years among men and 0·6–4·5 years among women. The risk factors contributing most to the gap in life expectancy were smoking (19·8% among men and 18·9% among women), low income (9·7% and 13·4%), and high bodyweight (7·7% and 11·7%), but large differences existed between countries in the contribution of risk factors. Sensitivity analyses using the prevalence of risk factors in the most favourable country (best practice scenario) showed that the potential for reducing the gap might be considerably smaller. The results were also sensitive to varying assumptions about the mortality risks associated with each risk factor.

Interpretation Smoking, low income, and high bodyweight are quantitatively important entry points for policies to reduce educational inequalities in life expectancy in most European countries, but priorities differ between countries. A substantial reduction of inequalities in life expectancy requires policy actions on a broad range of health determinants.

Funding European Commission and Network for Studies on Pensions, Aging, and Retirement.

Lancet Public Health 2019; 4: e529–37

See **Comment** page e487

Department of Public Health, Erasmus MC, University Medical Center Rotterdam, Rotterdam, Netherlands (Prof J P Mackenbach PhD, J Rubio Valverde MSc, W J Nusselder PhD); **Epidemiology, Biostatistics and Prevention Institute, University of Zürich, Zürich, Switzerland** (M Bopp PhD); **Department of Public Health, Faculty of Health Sciences, University of Copenhagen, Copenhagen, Denmark** (H Brønnum-Hansen PhD); **Department of Sociology, Vrije Universiteit Brussel, Brussels, Belgium** (Prof P Deboosere PhD); **Lithuanian University of Health Sciences, Kaunas, Lithuania** (Prof R Kalediene PhD); **Hungarian Demographic Research Institute, Budapest, Hungary** (K Kovács PhD); **Stockholm Centre for Health and Social Change, Södertörn University, Stockholm, Sweden** (M Leinsalu PhD); **Department of Epidemiology and Biostatistics, National Institute for Health Development, Tallinn, Estonia** (M Leinsalu); **Department of Sociology, University of Helsinki, Helsnki, Finland** (Prof P Martikainen PhD); **INSERM, Sorbonne Universités, Institut Pierre Louis d'Epidémiologie et de Santé Publique, Paris, France** (G Menvielle PhD); **Department of Public Health & Maternal and Child Health, Faculty of Medicine, Universidad Complutense de Madrid, Madrid, Spain** (E Regidor PhD); **and CIBER Epidemiología y Salud Pública, Madrid, Spain** (E Regidor)

Correspondence to:
Prof Johan P Mackenbach, Department of Public Health, Erasmus MC, University Medical Center Rotterdam, Rotterdam, Netherlands
j.mackenbach@erasmusmc.nl

See **Online** for appendix

Introduction

Inequality in mortality between socioeconomic groups is highly persistent and translates into substantial inequality in life expectancy.[1] Explanatory research has identified many factors contributing to inequalities in mortality, including childhood conditions, material living conditions, psychosocial factors, and behavioural risk factors.[2]

We aimed to determine the contribution of a broad range of risk factors, which have previously been shown to be differentially distributed between people with lower and higher levels of education, to inequalities in life expectancy in 15 European countries.

Methods

Data sources

We did an international comparative study of risk factors for shorter life expectancy in Europe. We collected and harmonised register-based mortality data from 15 European countries between 2010 and 2016: Finland, Sweden, Norway, Denmark, England and Wales, Netherlands, Belgium, Austria, Switzerland, France, Spain, Hungary, Poland, Lithuania, and Estonia. These data covered 2010–14, with the exceptions of Sweden (2005–08), Norway (2006–09), and France (2004–07). Most data covered complete national populations, with the exceptions of England and Wales and France, for which nationally representative 1% samples of the population were available, and the Netherlands, where available data covered 65% of the population. Most data were from a longitudinal mortality follow-up after a census, with the exceptions of the Netherlands (follow-up of a mix of registry data and labour force surveys) and Hungary and Poland (cross-sectional unlinked studies). More details on the data sources for mortality are shown in the appendix (p 2).

We aimed to collect survey data on as many risk factors for mortality as possible. Risk factors were selected if a reliable estimate of their relative risk of mortality is available in the literature and estimates of their prevalence by level of education in the 15 countries are available from internationally harmonised surveys. Eight risk factors that

Research in context

Evidence before this study

Socioeconomic inequalities in mortality are a major challenge for public health policy in all European countries. Although many studies have determined the contribution of specific risk factors to inequalities in mortality within specific countries, comparative studies that have quantified the role of different risk factors in a range of countries are almost non-existent. Our consortium has created a harmonised database of inequalities in mortality in a range of countries in Europe, and we have previously published a study on the contribution of six risk factors to educational inequalities in mortality in 21 European countries and a study on the contribution of three risk factors to educational inequalities in life expectancy in five European countries, both in the early 2000s.

Added value of this study

This study represents an update for the early 2010s, as well as an improvement on our previous studies, by using the more intuitive outcome measure life expectancy for analyses of a wide range of risk factors, by including only national instead of partly regional data, by including an indicator of childhood conditions, by including better estimates of relative risks, and by adding a series of sensitivity analyses.

Implications of all the available evidence

The three most quantitatively important entry points for policies to reduce educational inequalities in life expectancy in most European countries are smoking, low income, and high bodyweight. However, because the relative contribution of individual risk factors differs between countries, policy makers should tailor strategies to the situation prevailing in their target population. Furthermore, because action on single risk factors will have only a small effect, forceful policy actions on a broad front of health determinants will be necessary to substantially reduce inequalities in life expectancy.

are differentially distributed between people with low and high levels of education met these criteria. Many other candidates, such as unemployment and housing conditions, were excluded, because we could not find reliable estimates of relative risks for the exposure categories measured in the surveys. Additionally, because the definition of the risk factor had to be identical for relative risks and prevalence data, risk factor categories often had to be merged into two or three levels only.

The eight risk factors included were father with a manual occupation as an indicator of the conditions in which adults had grown up,[3] low income as an indicator of current material living conditions,[4] few social contacts as an indicator of psychosocial conditions,[5] and smoking,[6] high alcohol consumption,[7] high bodyweight,[8] low physical activity,[9] and low fruit and vegetable consumption[10] as indicators of inequalities in behavioural risk factors (appendix p 4). These risk factors cover different but overlapping explanatory perspectives. Behavioural risk factors can be conceptualised as being downstream in the causal pathway between level of education and mortality, whereas father with a manual occupation and low income partly determine why people with low and high levels of education have different health-related behaviours and should, therefore, be seen as more upstream.[11] Furthermore, father with a manual occupation partly determines a person's educational achievement[12] and, in contrast to the other risk factors, should not be seen as a possible mediator of the effect of education on mortality, but as a factor capturing the persistent effect of childhood conditions on the risks of mortality in later life.

We extracted data on the prevalence of all risk factors (February, 2017), except low income, from the European Social Survey (ESS), which was designed to collect harmonised data on risk factors for morbidity and mortality in its seventh round fielded in 2014 and 2015.[13] We applied restricted cubic spline models to smooth the gender-specific and education-specific prevalence of each risk factor across age groups. For low income, we used the EU Statistics on Income and Living Conditions Survey, which has more detailed income questions than ESS. More details on the survey data used in our analyses can be found in the appendix (p 3).

Socioeconomic position was indicated by highest level of completed education: low, mid, high corresponding to International Standard Classification of Education 1997 categories 0–2, 3–4, and 5–6. We focused on educational inequalities (instead of occupational inequalities, for example), primarily because comparable mortality and survey data by educational attainment were available for many more European countries than data by other indicators of socioeconomic position. Education is also the most stable measure of socioeconomic position, because it is normally completed early in adulthood, avoiding most of the problems of reverse causation.[14] The analyses were restricted to ages 35–79 years because education becomes less reliable as an indicator of socioeconomic position at greater ages.

Data analysis

After dividing mortality data into 5-year age groups, we calculated partial life expectancies between ages of 35 years and 80 years for each country by educational level and gender. For descriptive purposes, we also calculated age-adjusted prevalence ratios for each risk factor by educational level and gender using high-level education as a reference category.

To determine the contribution of risk factors to inequalities in partial life expectancy, we used a method

based on population attributable fractions, which estimates the effect of counterfactual distributions of the risk factors on the magnitude of social inequalities in mortality.[15] The relative risks for mortality used in the population attributable fraction calculations were taken from systematic reviews, meta-analyses, or pooled analyses, taking care to select relative risks adjusted for confounding. As potential confounders we considered age and gender, any of the other eight risk factors not on the causal pathway between one risk factor and mortality, and adult socioeconomic position. An overview of these relative risks and their sources is given in the appendix (p 4). The estimates of the contribution of risk factors were based on a counterfactual scenario, in which we assumed that exposure to a risk factor among men and women with low-level education would be reduced to the amount among men and women with high-level education within each country (upward levelling).

To test the robustness of our findings, we did several sensitivity analyses. The upward levelling scenario assumes that reducing exposure in groups with lower-level education to that of groups with higher-level education is feasible. Therefore, we also estimated the effect of a counterfactual scenario, in which differences in exposure between low-level and high-level education were reduced to the amount in the country with the lowest overall prevalence of the high-risk category and the smallest inequalities in prevalence between low-level and high-level education (best practice). In cases of doubt (ie, when these two criteria were in conflict), the best practice country was chosen by trial-and-error, in which we determined which of several counterfactual scenarios reduced inequalities the most (appendix pp 6–11).

For some risk factors, the relative risks for mortality were uncertain. The main uncertainties relate to father with a manual occupation (whether an adjustment for adult socioeconomic position is appropriate can be debated), low income (whether there is a causal effect of low income on mortality, and if so what the level of increased risk is, is uncertain),[16] and high bodyweight (some studies have produced lower relative risks than the ones used in our main analysis).[17] Therefore, we also estimated upward levelling scenarios with increased or decreased relative risks for these risk factors (appendix p 4).

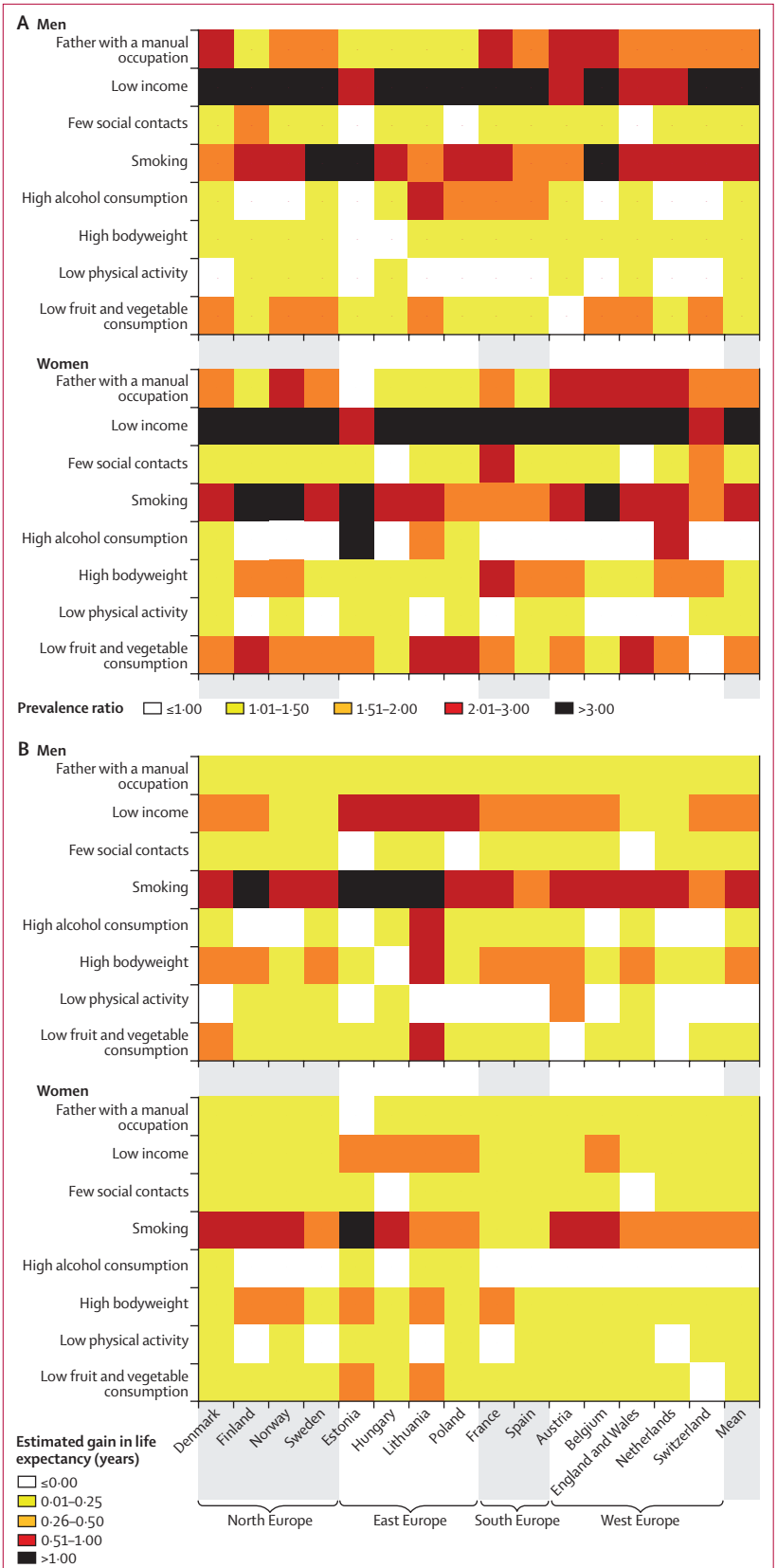
Our analyses rely on survey data for the prevalence of risk factors. Although all risk factors might be prone to misreporting, surveys tend to underestimate alcohol consumption, because heavy drinkers are underrepresented in surveys, and because survey respondents tend to underreport the amount of alcohol consumed.[7] Therefore, in a third set of sensitivity analyses, we used a correction procedure developed by Rehm and colleagues[18] that adjusts survey-based estimates upwards on the basis of recorded alcohol sales.

For all analyses we also produced a European mean, which was calculated as a population-weighted average of

	Partial life expectancy, years			Gap* between low level and high level (95% CI)
	Low-level education	Mid-level education	High-level education	
Men				
North				
Denmark	37·5	40·0	41·7	4·2 (4·1–4·3)
Finland	37·4	39·3	41·5	4·1 (4·0–4·2)
Norway	37·9	40·2	41·8	3·9 (3·4–4·3)
Sweden	39·3	40·5	41·9	2·6 (2·5–2·7)
East				
Estonia	32·8	36·6	40·1	7·3 (7·0–7·6)
Hungary	33·8	38·3	40·1	6·3 (6·2–6·4)
Lithuania	31·2	35·2	39·4	8·2 (8·0–8·4)
Poland	34·2	38·2	40·7	6·5 (6·5–6·5)
South				
France	37·6	39·5	41·3	3·7 (3·3–4·1)
Spain	39·2	40·4	41·3	2·1 (2·0–2·1)
West				
Austria	38·3	39·8	41·8	3·5 (3·4–3·6)
Belgium	38·5	39·8	41·2	2·7 (2·6–2·8)
England and Wales	39·4	41·5	42·1	2·7 (2·4–3·0)
Netherlands	39·7	40·9	42·0	2·3 (2·2–2·6)
Switzerland	39·1	41·0	42·3	3·2 (3·0–3·3)
Europe mean†	37·8	39·9	41·3	3·6 (3·4–3·7)
Women				
North				
Denmark	40·0	41·8	42·6	2·6 (2·6–2·7)
Finland	40·6	42·2	43·0	2·4 (2·3–2·5)
Norway	40·6	42·1	42·9	2·2 (1·9–2·5)
Sweden	41·1	42·0	42·8	1·8 (1·7–1·8)
East				
Estonia	38·7	41·4	42·6	3·9 (3·6–4·2)
Hungary	39·0	41·3	41·9	2·9 (2·8–2·9)
Lithuania	37·8	40·9	42·3	4·5 (4·2–4·7)
Poland	39·8	41·5	42·5	2·7 (2·7–2·7)
South				
France	41·5	42·3	43·1	1·6 (1·3–1·9)
Spain	42·4	42·7	42·9	0·6 (0·5–0·6)
West				
Austria	41·5	42·2	42·8	1·3 (1·2–1·5)
Belgium	41·2	41·9	42·6	1·4 (1·3–1·5)
England and Wales	41·0	42·4	42·7	1·7 (1·4–1·9)
Netherlands	41·3	42·2	42·7	1·4 (1·3–1·6)
Switzerland	41·9	42·9	43·1	1·2 (1·1–1·3)
Europe mean†	41·0	42·1	42·7	1·7 (1·5–1·8)

*Difference between low-level and high-level education. †Population-weighted mean of all European countries in the analysis.

Table 1: **Educational inequalities in partial life expectancy between 35 years and 80 years of age**



the values obtained for each of the 15 countries. All 95% CIs were determined with bootstrapping (1000 samples).

Analyses were done using Stata version 13.

Role of the funding source

The funder of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding author had full access to all the data and final responsibility to submit for publication.

Results

Life expectancy was shorter among the people with low levels of education than those with high levels of education in all countries, but life expectancy and gaps differed between countries (table 1). Men with a high-level education had a partial life expectancy that varied between 39·4 years in Lithuania and 42·3 years in Switzerland, whereas men with low-level education had a partial life expectancy that varied between 31·2 years in Lithuania and 39·7 years in the Netherlands (table 1). The gap in life expectancy varied between 2·1 years (95% CI 2·0–2·1) in Spain and 8·2 years (8·0–8·4) in Lithuania (table 1). Among women, partial life expectancies were longer and gaps smaller than among men, but the pattern of variation between countries was similar, with gaps in life expectancy ranging from 0·6 years (0·5–0·6) in Spain to 4·5 years (4·2–4·7) in Lithuania (table 1).

Most risk factors were more prevalent among people with a low level of education than among those with a high level of education, with some exceptions—eg, high alcohol consumption among women (figure A; appendix pp 6–11). The largest inequalities were found for low income and smoking (figure A).

The only risk factor for which upward levelling raised life expectancy among men with low education levels (and, thus, reduced the gap in life expectancy between low-level and high-level education) by more than 1 year was smoking. Increases in life expectancy of 0·5–1 year occurred for smoking in 13 countries for men and seven for women and in four countries for low income for men (figure B). Among women, the largest effects were also found for these two risk factors, but they tended to be smaller than among men (figure B). High bodyweight had the next greatest effect, with upward

Figure: **Educational inequalities in prevalence of risk factors and effect of upward levelling scenario on life expectancy of people with low-level education**

(A) Educational inequalities in prevalence of risk factors. Prevalence ratio of more than one indicates a greater prevalence in the low-level education group. (B) Estimated gain in partial life expectancy in the low-level education group in an upward levelling scenario. The effects shown are in number of years gained (ie, absolute effects); therefore, they also indicate the effect of upward levelling on the gap in partial life expectancy between low-level and high-level education groups. Mean is the population-weighted average of all European countries in the analysis.

	North Europe				East Europe				South Europe		West Europe					Europe mean*
	Denmark	Finland	Norway	Sweden	Estonia	Hungary	Lithuania	Poland	France	Spain	Austria	Belgium	England and Wales	Netherlands	Switerland	
Men																
Father with a manual occupation	−4·4%	−2·5%	−3·5%	−4·2%	−1·8%	−2·0%	−1·4%	−1·0%	−5·4%	−5·3%	−4·5%	−6·4%	−4·1%	−4·1%	−3·1%	−3·5%
Low income	−6·1%	−9·3%	−5·9%	−6·6%	−7·3%	−12·1%	−10·7%	−11·4%	−8·3%	−11·4%	−8·7%	−11·6%	−8·3%	−9·2%	−10·6%	−9·7%
Few social contacts	−0·2%	−2·8%	−0·8%	−1·2%	0·8%	−0·6%	−0·4%	1·2%	−1·7%	−0·9%	−1·2%	−0·5%	0·3%	−0·9%	−0·8%	−0·3%
Smoking	−15·9%	−26·7%	−24·9%	−24·8%	−29·3%	−32·1%	−18·3%	−12·7%	−23·0%	−16·6%	−18·9%	−33·2%	−20·6%	−23·4%	−8·9%	−19·8%
High alcohol consumption	−1·7%	1·8%	0·5%	−0·6%	1·0%	−1·1%	−7·1%	−0·9%	−2·8%	−3·5%	−1·4%	2·8%	−0·9%	0·0%	0·6%	−1·4%
High bodyweight	−9·4%	−6·9%	−5·6%	−13·7%	−1·1%	1·4%	−7·3%	−3·0%	−10·2%	−14·6%	−11·2%	−5·9%	−9·6%	−8·7%	−7·8%	−7·6%
Low physical activity	3·2%	−3·4%	−0·6%	−4·4%	4·6%	−0·9%	6·3%	2·6%	1·7%	2·2%	−7·7%	3·3%	−4·1%	4·8%	5·5%	0·7%
Low fruit and vegetable consumption	−6·3%	−3·7%	−5·5%	−8·4%	−3·0%	−3·4%	−7·7%	−0·8%	−3·7%	−4·0%	0·9%	−6·1%	−7·1%	0·4%	−5·4%	−3·7%
Women																
Father with a manual occupation	−3·8%	−3·1%	−5·3%	−5·7%	0·7%	−3·7%	−0·7%	−0·3%	−4·6%	−6·1%	−9·1%	−8·3%	−7·4%	−7·0%	−5·5%	−4·5%
Low income	−7·1%	−9·1%	−10·4%	−8·3%	−8·4%	−16·0%	−10·1%	−15·5%	−13·6%	−19·1%	−14·4%	−17·4%	−11·3%	−13·1%	−15·2%	−13·4%
Few social contacts	−1·6%	−0·5%	−2·2%	−0·2%	−0·9%	0·5%	−0·6%	−0·1%	−4·3%	−4·6%	−3·3%	−2·3%	0·7%	−1·1%	−3·1%	−1·2%
Smoking	−19·2%	−33·2%	−35·5%	−20·0%	−27·1%	−27·7%	−6·5%	−15·5%	3·8%	−8·0%	−35·1%	−42·5%	−30·0%	−28·5%	−21·4%	−18·9%
High alcohol consumption	−0·1%	0·3%	0·4%	0·6%	−1·3%	1·1%	−0·6%	−0·3%	0·3%	0·8%	1·1%	0·6%	1·4%	0·3%	1·5%	0·5%
High bodyweight	−7·1%	−12·8%	−11·9%	−10·3%	−11·3%	−7·6%	−10·9%	−4·7%	−19·2%	−32·1%	−15·5%	−9·6%	−8·9%	−15·8%	−6·2%	−11·7%
Low physical activity	−2·6%	1·8%	−1·3%	0·4%	−1·3%	−0·5%	3·9%	−3·7%	2·0%	−3·9%	−11·2%	−1·5%	−6·9%	0·8%	−2·4%	−2·5%
Low fruit and vegetable consumption	−5·1%	−8·2%	−3·7%	−7·8%	−5·9%	−6·5%	−9·3%	−7·0%	−5·0%	−8·6%	−8·1%	−4·8%	−9·7%	−5·8%	0·2%	−7·0%

Gap is calculated as the percentage difference between the observed gap in partial life expectancy between 35 and 80 years of age and the gap in a counterfactual upward levelling scenario in which the prevalence of each risk factor among the low educated is the same as that among the high educated in the same country. *Population-weighted mean of all European countries in the analysis.

Table 2: **Change in gap in partial life expectancy according to upward levelling scenario, by gender, country, and risk factor**

	Main analysis*	Sensitivity analyses				
		Best practice scenario†	No correction father's occupation for adult education	Higher mortality relative risk for income	Lower mortality relative risk for obesity	Rehm et al[18] correction for alcohol consumption
Men						
Father with a manual occupation	–3·5%	–2·0%	–6·7%	..	..	..
Low income	–9·7%	0·0%	..	–15·5%	..	..
Few social contacts	–0·3%	–1·1%	..	..	..	..
Smoking	–19·8%	–2·7%	..	..	..	..
High alcohol consumption	–1·4%	–1·3%	..	..	..	–0·1%
High bodyweight	–7·6%	–3·4%	..	..	–2·7%	..
Low physical activity	0·7%	2·9%	..	..	..	..
Low fruit and vegetable consumption	–3·7%	–1·9%	..	..	..	..
Women						
Father with a manual occupation	–4·5%	–1·6%	–8·5%	..	..	..
Low income	–13·4%	–4·7%	..	–21·1%	..	..
Few social contacts	–1·2%	–2·0%	..	..	..	..
Smoking	–18·9%	–17·0%	..	..	..	..
High alcohol consumption	0·5%	0·2%	..	..	..	1·5%
High bodyweight	–11·7%	–3·6%	..	..	–4·2%	..
Low physical activity	–2·5%	–3·4%	..	..	..	..
Low fruit and vegetable consumption	–7·0%	–2·7%	..	..	..	..

Gap is calculated as the percentage difference between the observed gap in partial life expectancy between 35 and 80 years of age among the low and high educated. For values of relative risk used in sensitivity analyses, see appendix (p 4). *A scenario in which the prevalence of each risk factor among the low educated is the same as that among the high educated. †A counterfactual scenario in which the prevalence of each risk factor is the same as that in the country with the lowest average prevalence and the smallest inequalities between low and high educated.

***Table 3*: Change in gap in partial life expectancy: results of sensitivity analyses**

levelling resulting in an increase in partial life expectancy among women with a low-level education (and reduction of the gap in life expectancy between low-level and high-level education) of 0·5–1·0 years in eight countries among men and in five countries among women (figure B). The effects for the other risk factors were usually much smaller—ie, fewer than 0·25 years (figure B).

Among men, smoking was quantitatively important for the gap in life expectancy in all 15 countries, but more so in Estonia, Finland, Hungary, and Lithuania, whereas, among women, it contributed much less in France, Spain, and Switzerland. These differences can often be traced back to larger and smaller inequalities in smoking as shown in figure A. Among both men and women, low income contributed more to educational inequalities in life expectancy in central and eastern Europe than in most other countries, which can be traced back to differences between countries in the magnitude of educational inequalities in low income (figure A).

Contributions of risk factors can be compared between countries more easily when they are expressed as percentages of the gap in life expectancy in each country—ie, in relative instead of absolute terms (table 2). Smoking was the only risk factor that reduced the gap in life expectancy by more than 25% in some countries, both among men and women (table 2). The second and third largest contributors were low income and high bodyweight (table 2). As a weighted mean of all European countries, the contributions to the gap in life expectancy for smoking were 19·8% among men and 18·9% among women, whereas the contributions for low income were 9·7% and 13·4%, and those for overweight and obesity were 7·7% and 11·7% (table 2). However, large differences existed between countries in the relative contribution of risk factors. For example, among Belgian men, smoking (33·2%) clearly contributed more than high bodyweight (5·9%), but among Spanish men they were about equal (16·6% *vs* 14·6%; table 2). Among women, smoking contributed much less in France, Spain, and Switzerland than in the other European countries (table 2).

When we replaced the upward levelling scenario with a more realistic best practice scenario, the contributions of most risk factors declined substantially (table 3). The selection of best practice countries and detailed results for this scenario are given in the appendix (pp 6–12). For example, among men the mean contribution of smoking went down from 19·8% in the upward levelling scenario to 2·7% in the best practice scenario (table 3); this is unsurprising, because no country has small inequalities in smoking (ie, a prevalence ratio of <1·5) between men with low and high levels of education, so upward levelling cannot have a large effect. Among men, low physical activity contributed more than smoking in the best practice scenario (table 3). However, among women the mean contribution of smoking in the best practice scenario (17·0%) was only slightly smaller than that in the upward levelling scenario (18·9%; table 3). Among women, the three risk factors that contributed most were still smoking, low income, and high bodyweight, although low physical activity became a greater contributor relative to the other risk factors (table 3).

Our findings are also sensitive to assumptions about the effect of risk factors on mortality. When we took higher relative risks for father with a manual occupation (removing the adjustment for adult education from the relative risk estimate) or for low income (taking a controversial higher estimate from the published literature; appendix p 4), we found larger contributions of both risk factors to the gap in life expectancy, and the contribution of high bodyweight was substantially reduced when we took lower relative risks (taking less plausible lower estimates from the literature).

When we corrected for under-reporting of alcohol consumption as described by Rehm and colleagues,[18] the contribution of high alcohol consumption to the gap in

life expectancy did not substantially change and remained much smaller than that of the other risk factors.

In general, the second and third sets of sensitivity analyses confirmed the findings of the main analysis for low income (large contribution) and high alcohol consumption (small contribution) and added some uncertainty to the findings for father with a manual occupation and high bodyweight (which might contribute more or less, respectively, than suggested by the main analysis).

Discussion

We found a substantial gap in partial life expectancy between people with low and high levels of education in all European countries. The risk factors contributing most to the gap in life expectancy were smoking, low income, and high bodyweight, but large differences existed between countries in the contribution of risk factors. Sensitivity analyses using a best practice scenario showed that the potential for reducing the gap might be considerably smaller, particularly for men.

In previous studies[19,20] we presented estimates of the contribution of six risk factors to educational inequalities in mortality and three risk factors to educational inequalities in life expectancy in a range of European countries in the early 2000s. This study represents an update and incorporates several improvements, such as use of national instead of regional data from Spain, inclusion of an indicator of childhood conditions, better estimates of relative risks, and addition of a series of sensitivity analyses.

Our study has several limitations. We relied on survey data with self-reported information on risk factors. A previous study[21] has shown that the magnitude of inequalities in smoking differs between surveys, probably due to differences in sampling procedures, non-response patterns, and survey questions, and the same might apply to other risk factors in our analysis. Inaccuracies in the measurement of risk factors, and the merging of risk factor categories, might have contributed to an underestimation of their contribution to inequalities in life expectancy in our study.

We did a dedicated sensitivity analysis for the risk factor that had the most evidence for misrepresentation in surveys (ie, alcohol consumption), but after adjustment its contribution to inequalities in life expectancy was still very small (table 3). These results contradict a previous study[22] that estimated the contribution of alcohol consumption to inequalities in mortality using alcohol-related causes of death, which suggest that its contribution is 10% or more in some European countries. One possible explanation is that our method assumes that the risk of mortality associated with heavy drinking is the same for low-level and high-level education, whereas it might be greater for people with low-level education—eg, because their pattern of drinking is more hazardous or because they benefit less from a supportive social network.[23] Further research is necessary.

The assumption that relative risks are the same for low-level and high-level education might also be unrealistic for other risk factors. Some studies have found that smokers with low levels of education have a greater likelihood of developing lung cancer than smokers with higher levels of education, perhaps due to differences in in smoking behaviour (eg, deeper inhalation of tobacco smoke or more carcinogenic types of tobacco smoked) or biological susceptibility,[24] implying that the contribution of smoking to inequalities in mortality might be larger than estimated using equal relative risks. However, findings of studies[25,26] that estimated the contribution of smoking by use of smoking-related causes of death have produced estimates similar to those made in this study. We also assumed that the relative risks for mortality were the same for men and women, for all age groups, and for all countries in the study.

We found it difficult to find reliable estimates of relative risks for our risk factors, particularly because they had to match the exposure categories available in European harmonised surveys, which made a more formal process of identifying relative risks unfeasible. We could not always rely on systematic reviews (appendix p 4), which might imply that our estimates are incorrect. Another, related problem is that the causal nature of the relationship captured in the relative risk estimates is often uncertain. Low income is an example of this problem; although we found an estimate (corresponding to the income measurements in EU Statistics on Income and Living Conditions Survey) from a high-quality longitudinal study with correction for confounders,[27] reviews[16,28] of quasi-experimental evidence for a causal relationship between income and mortality have not been able to conclude that the relationship is mainly causal.

Another limitation is that we could not include a lag time between risk factor exposure and mortality, because we did not have survey data for points in time preceding the measurement of mortality. Therefore, we might have underestimated or overestimated the contribution of certain risk factors to present-day mortality inequalities in cases where prevalence of the risk factor has substantially changed over time. For example, we know that in countries in which the smoking epidemic has advanced furthest, such as England and Wales, inequalities in smoking behaviour were smaller in the past,[29] implying that in such cases we might have overestimated the current contribution of smoking to inequalities in mortality (and that our estimates may more accurately represent the future contribution of smoking).[30]

We only studied risk factors individually, because available methods for combining them assume mutual independence,[31] which would not be guaranteed in our case, because downstream risk factors, such as smoking or high bodyweight, might partly be determined by more

upstream ones, such as low income or father with a manual occupation, and might also be determined by each other (as in the case of low physical activity leading to high bodyweight). Without more detailed analyses considering interconnections between risk factors, prediction of what the combined effects will be is difficult.[15]

Our study highlights both similarities and differences between European countries. Smoking, low income, and high bodyweight contribute most to inequalities in mortality in most European countries, but they contribute more in some countries than in others, suggesting that it is advisable for policy makers to tailor strategies to the situation prevailing in their target population. For example, in northern Europe smoking is clearly a more quantitatively important policy target than low income or high bodyweight for policies to reduce the educational gap in life expectancy, but the same is not true for Switzerland, where low income is relatively more important, or Spain, where high bodyweight is relatively more important. Studies of the relative contribution of risk factors to inequalities in self-assessed health[32] and activity limitations[33] in a range of European countries have reached similar conclusions.

Differences in the social patterning of risk factors between European countries are a result of both spontaneous trends and policies. For example, differences between countries with inequalities in smoking partly reflect differences in the progression of the smoking epidemic,[29] and inequalities in obesity might similarly reflect differences in diffusion of the obesity epidemic. However, differences between countries in social and health policies also have a role, such as income inequalities that are larger in countries with less progressive income taxation and less generous social security arrangements.[34] Nevertheless, these patterns can probably be affected by policy. For example, equity-oriented tobacco control policies that combine increased taxes with smoking cessation support services targeted to disadvantaged smokers can reduce inequalities in smoking,[35] and countries that have large income inequalities can reduce them by more progressive income taxation policies and more generous social security arrangements.

Although our study helps to identify entry points for policy, it also shows that the scope for reducing inequalities in life expectancy by targeting each of the studied risk factors separately is narrow, because most risk factors make small contributions. Even when their contribution is substantial, such as in the case of smoking, low income, and high bodyweight, the results of best practice scenarios suggest that the potential for reduction of inequalities might be smaller, because no European countries have truly small risk factor inequalities. Substantial reductions will only be possible with policies that simultaneously address many different health determinants.

Contributors

JPM conceptualised the study and wrote the first and final drafts of the paper. JRV and WJN harmonised the data, did the analyses, and reviewed the paper. MB, HB-H, PD, RK, KK, ML, PM, GM, and ER prepared data for their country and reviewed the paper. All authors approved the final version.

Declaration of interests

We declare no competing interests.

Acknowledgments

This study was done as part of the LIFEPATH project, which has received financial support from the European Commission (Horizon 2020 grant number 633666), and as part of the project "Longer life, longer in good health, working longer? Implications of educational differences for the pension system", which has received financial support from Network for Studies on Pensions, Aging and Retirement. Data were partly collected as part of the DEMETRIQ project, which also received support from the European Commission (grant numbers FP7-CP-FP and 278511). The permission of the Office for National Statistics (ONS) to use the Longitudinal Study is gratefully acknowledged, as is the help provided by staff of the Centre for Longitudinal Study Information & User Support (CeLSIUS). CeLSIUS is supported by the ESRC Census of Population Programme (award reference ES/K000365/1). The authors alone are responsible for the interpretation of the data. This work contains statistical data from ONS, which is Crown Copyright. The use of the ONS statistical data in this work does not imply the endorsement of the ONS in relation to the interpretation or analysis of the statistical data. This work uses research datasets, which might not exactly reproduce National Statistics aggregates. The mortality data for Switzerland were obtained from the Swiss National Cohort, which is based on mortality and census data provided by the Federal Statistical Office and supported by the Swiss National Science Foundation (grant numbers 3347CO-108806, 33CS30_134273, and 33CS30_148415). For the European Survey, we used Data file edition 2·1, Norwegian Centre for Research Data, Norway—data archive and distributor of ESS data for ESS ERIC. PM was funded by the Academy of Finland and MINDMAP, a European Commission HORIZON 2020 research and innovation action grant 667661.

References

1 Murtin F, Mackenbach JP, Jasilionis D, Mira d'Ercole M. Inequalities in longevity by education in OECD countries: insights from new OECD estimates. Paris: OECD Publishing, 2017.
2 Commission on Social Determinants of Health. Closing the gap in a generation. Health equity through the social determinants of health. Geneva: World Health Organization, 2008.
3 Galobardes B, Lynch JW, Davey Smith G. Childhood socioeconomic circumstances and cause-specific mortality in adulthood: systematic review and interpretation. *Epidemiol Rev* 2004; **26:** 7–21.
4 Aldabe B, Anderson R, Lyly-Yrjänäinen M, et al. Contribution of material, occupational, and psychosocial factors in the explanation of social inequalities in health in 28 countries in Europe. *J Epidemiol Community Health* 2010; **65:** 1123–31.
5 Stansfeld SA. Social support and social cohesion. In: Marmot M, Wilkinson RG, eds. Social determinants of health, 2 edn. Oxford: Oxford University Press, 2006. 148–71.
6 Hiscock R, Bauld L, Amos A, Fidler JA, Munafò M. Socioeconomic status and smoking: a review. *Ann NY Acad Sci* 2012; **1248:** 107–23.
7 Devaux M, Sassi F. Alcohol consumption and harmful drinking: trends and social disparities across OECD countries. Paris: OECD Publishing, 2015.
8 Roskam AJ, Kunst AE, Van Oyen H, et al. Comparative appraisal of educational inequalities in overweight and obesity among adults in 19 European countries. *Int J Epidemiol* 2010; **39:** 392–404.
9 Beenackers MA, Kamphuis CBM, Giskes K, et al. Socioeconomic inequalities in occupational, leisure-time, and transport related physical activity among European adults: a systematic review. *Int J Behav Nutr Phys Act* 2012; **9:** 116.
10 De Irala-Estévez J, Groth M, Johansson L, Oltersdorf U, Prättälä R, Martínez-González MA. A systematic review of socio-economic differences in food habits in Europe: consumption of fruit and vegetables. *Eur J Clin Nutr* 2000; **54:** 706–14.
11 Marmot MG. Understanding social inequalities in health. *Perspect Biol Med* 2003; **46:** S9–23.

12 Breen R, Jonsson JO. Inequality of opportunity in comparative perspective: recent research on educational attainment and social mobility. *Annu Rev Sociol* 2005; **31:** 223–43.

13 Huijts T, Stornes P, Eikemo TA, Bambra C. The social and behavioural determinants of health in Europe: findings from the European Social Survey (2014) special module on the social determinants of health. *Eur J Public Health* 2017; **27** (suppl 1)**:** 55–62.

14 Daly MC, Duncan GJ, McDonough P, Williams DR. Optimal indicators of socioeconomic status for health research. *Am J Public Health* 2002; **92:** 1151–57.

15 Hoffmann R, Eikemo TA, Kulhánová I, et al. The potential impact of a social redistribution of specific risk factors on socioeconomic inequalities in mortality: illustration of a method based on population attributable fractions. *J Epidemiol Community Health* 2013; **67:** 56–62.

16 O'Donnell O, Van Doorslaer E, Van Ourti T. Health and inequality. In: Atkinson AB, Bourguignon FJ, eds. Handbook of income distribution, vol 2. Amsterdam: Elsevier, 2015. 1419–533.

17 Stringhini S, Carmeli C, Jokela M, et al. Socioeconomic status and the 25×25 risk factors as determinants of premature mortality: a multicohort study and meta-analysis of 1·7 million men and women. *Lancet* 2017; **389:** 1229–37.

18 Rehm J, Kehoe T, Gmel G, Stinson F, Grant B, Gmel G. Statistical modeling of volume of alcohol exposure for epidemiological studies of population health: the US example. *Popul Health Metr* 2010; **8:** 3.

19 Eikemo TA, Hoffmann R, Kulik MC, et al. How can inequalities in mortality be reduced? A quantitative analysis of 6 risk factors in 21 European populations. *PLoS One* 2014; **9:** e110952.

20 Mäki NE, Martikainen PT, Eikemo T, et al. The potential for reducing differences in life expectancy between educational groups in five European countries: the effects of obesity, physical inactivity and smoking. *J Epidemiol Community Health* 2014; **68:** 635–40.

21 Kulik MC, Eikemo TA, Regidor E, Menvielle G, Mackenbach JP. Does the pattern of educational inequalities in smoking in Western Europe depend on the choice of survey? *Int J Public Health* 2014; **59:** 587–97.

22 Mackenbach JP, Kulhanova I, Bopp M, et al. Inequalities in alcohol-related mortality in 17 European countries: a retrospective analysis of mortality registers. *PLoS Med* 2015; **12:** e1001909.

23 Katikireddi SV, Whitley E, Lewsey J, Gray L, Leyland AH. Socioeconomic status as an effect modifier of alcohol consumption and harm: analysis of linked cohort data. *Lancet Public Health* 2017; **2:** e267–76.

24 Rod NH, Lange T, Andersen I, Marott JL, Diderichsen F. Additive interaction in survival analysis: use of the additive hazards model. *Epidemiology* 2012; **23:** 733–37.

25 Gregoraci G, van Lenthe FJ, Artnik B, et al. Changes in the contribution of smoking to socio-economic inequalities in mortality in 13 European countries. *Tob Control* 2017; **26:** 260–68.

26 Kulik MC, Menvielle G, Eikemo TA, et al. Educational inequalities in three smoking-related causes of death in 18 European populations. *Nicotine Tob Res* 2014; **16:** 507–18.

27 Martikainen P, Mäkelä P, Koskinen S, Valkonen T. Income differences in mortality: a register-based follow-up study of three million men and women. *Int J Epidemiol* 2001; **30:** 1397–405.

28 Cooper K, Stewart K. Does money in adulthood affect adult outcomes? York: Joseph Rowntree Foundation, 2015.

29 Giskes K, Kunst AE, Benach J, et al. Trends in smoking behaviour between 1985 and 2000 in nine European countries by education. *J Epidemiol Community Health* 2005; **59:** 395–401.

30 Kulik MC, Hoffmann R, Judge K, et al. Smoking and the potential for reduction of inequalities in mortality in Europe. *Eur J Epidemiol* 2013; **28:** 959–71.

31 Murray CJ, Ezzati M, Lopez AD, Rodgers A, Vander Hoorn S. Comparative quantification of health risks: conceptual framework and methodological issues. *Popul Health Metrics* 2003; **1:** 1.

32 Balaj M, McNamara CL, Eikemo TA, Bambra C. The social determinants of inequalities in self-reported health in Europe: findings from the European social survey (2014) special module on the social determinants of health. *Eur J Public Health* 2017; **27** (suppl 1)**:** 107–14.

33 Pérez-Hernández B, Rubio Valverde J, Nusselder WJ, Mackenbach JP. Socioeconomic inequalities in disability in 19 European countries: the contribution of behavioral, work-related and living conditions. submitted for publication. *Eur J Publ Health* 2019; **29:** 640–47

34 OECD. Divided we stand: why inequality keeps rising. Paris: OECD Publishing, 2011.

35 Brown T, Platt S, Amos A. Equity impact of population-level interventions and policies to reduce smoking in adults: a systematic review. *Drug Alcohol Depend* 2014; **138:** 7–16.