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Socioeconomic position and mortality risk of smoking: evidence from the English Longitudinal Study of Ageing (ELSA)

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Background: It is not clear whether the harm associated with smoking differs by socioeconomic status. This study tests the hypothesis that smoking confers a greater mortality risk for individuals in low socioeconomic groups, using a cohort of 18 479 adults drawn from the English Longitudinal Study of Ageing. **Methods:-** Additive hazards models were used to estimate the absolute smoking-related risk of death due to lung cancer or Chronic Obstructive Pulmonary Disease (COPD). Smoking was measured using a continuous index that incorporated the duration of smoking, intensity of smoking and the time since cessation. Attributable death rates were reported for different levels of education, occupational class, income and wealth. **Results:** Smoking was associated with higher absolute mortality risk in lower socioeconomic groups for all four socioeconomic indicators. For example, smoking 20 cigarettes per day for 40 years was associated with 898 (95% CI 738, 1058) deaths due to lung cancer or COPD per 100 000 person-years among participants in the bottom income tertile, compared to 327 (95% CI 209, 445) among participants in the top tertile. **Conclusions:** Smoking is associated with greater absolute mortality risk for individuals in lower socioeconomic groups. This suggests greater public health benefits of smoking prevention or cessation in these groups.

Introduction

Smoking is more common in low socioeconomic groups in almost all high-income countries. In the UK in 2013, for example, 14% of adults in managerial and professional occupations smoked, compared to 29% in routine and manual occupations.[1] Smoking-related diseases such as lung cancer are also more common in low socioeconomic groups.[2]

Many studies show that differences in smoking behaviour only partially explain inequalities in smoking-related diseases such as lung cancer.[2–4] It has been suggested that the harms of smoking differ by socioeconomic status, but this interaction has received little attention. In a literature search we found 13 studies that tested the interaction between socioeconomic status and smoking (details of the search are included in Supplementary Material A), but these produced conflicting results. Four found a statistically significant interaction, with low socioeconomic status associated with increased risks of smoking.[5–8] For example, a cross-sectional study in Canada found that the difference in health outcomes between smokers and non-smokers was greatest for low income participants.[5] Eight found no evidence of an interaction.[9–16] For example, a cohort study in Belgium found that the all-cause mortality rate ratios comparing smokers to non-smokers did not differ by level of education.[10] Finally, one cross-sectional study[17] observed that the difference in health between smokers and non-smokers was greater for those in high status occupations than among manual workers. The author suggested that the effects of multiple risk factors in low socioeconomic groups do not always accumulate, limiting the risks specifically attributable to smoking. This is now commonly known as the 'Blaxter hypothesis'.

These studies compare the relative risk of smoking across socioeconomic groups, which may hide differences in absolute risk because the baseline risk of smoking-related diseases is higher in low socioeconomic groups.[4] The literature has three further limitations. First, studies commonly use simple measures of smoking exposure (such as classifying subjects as current, ex- or never-smokers), overlooking socioeconomic differences in total smoking history. For example, smokers in low socioeconomic groups start younger and smoke more cigarettes per day.[18] Second, most studies use general health outcomes such as all-cause mortality, meaning that the interaction between smoking and socioeconomic status may be confounded by other risk factors for general poor health. Third, several of the studies use cross-sectional designs, and the results may be biased by selection if some non-smokers quit due to worsening health.

This study uses data from the English Longitudinal Study of Ageing to test the hypothesis that smoking confers greater absolute risk of mortality in low socioeconomic groups. This may help explain the steep social gradients in smoking-related diseases. The study also aims to use a more complete measure of smoking exposure and use a smoking-specific outcome.

Methods

Data source

The data source was the English Longitudinal Study of Ageing (ELSA), which includes participants in the Health Survey for England's 1998, 1999 and 2001 rounds born before 1953. The sampling and research methodologies are described elsewhere.[19] All independent variables were taken from the Health Survey for England data, except for wealth, which was taken from the ELSA follow-up survey conducted in 2002. The interview date was used as the study baseline. Linked mortality data including the month, year and underlying cause of death were provided to ELSA by the UK's Office of National Statistics, with complete follow-up to April 2013.

Study variables

The dependent variable was survival in months from the date of interview. If the underlying cause of death was lung cancer or COPD, the cause was considered 'smoking related'. These diseases have a high degree of specificity, allowing us to examine specific smoking-related risk, although it is recognised that smoking also contributes to many other conditions.

Participants' smoking history was summarised using the comprehensive smoking index (CSI).[20] This measure was chosen because it includes the duration of smoking, intensity of smoking (cigarettes per day) and time since cessation, which are important determinants of smoking-related risk and may vary by socioeconomic status.[18] It also reflects the non-linear relationship between these variables and smoking-related risk.[21] The formula is:

$$\mathrm{CSI} = \left(1 - 0.5^{\frac{\text{years of smoking}}{\text{half-life}}}\right) \times \left(0.5^{\frac{\text{years since quit}}{\text{half-life}}}\right) \times \ln(\text{intensity} + 1)$$

A 'half-life' of 25 years was determined by testing a range of values and maximising model fit.[20] The recommended formula also included a 'lag term', as harm does not reduce immediately after cessation. However, this did not improve model fit and was excluded. The range of CSI was 0 (for never-smokers) to 3.7 (for an individual who reported smoking 80 per day for 66 years). CSI was included as a continuous measure in survival models. For reporting baseline characteristics, it was aggregated into never smokers and tertiles for ever-smokers.

Education was collapsed into those with (1) A-levels or higher; around 13 or more years of education, (2) qualifications below A-level; typically around 11 years of education, (3) no formal qualifications, (4) other qualifications.

Occupation of the 'household reference person' (the person who owns or rents the participant's home or has the highest income) was based on the UK Office for National Statistic's 'Social Class based on Occupation'[22] and was collapsed into those with (1) non-manual, including professional, managerial and technical and skilled non-manual occupations; levels I, II and IIIN (2) skilled manual; level IIIM and (3) semi- and unskilled manual occupations; levels IV and V.

Income was based on equivalised gross household income, with tertiles calculated for each survey year. Income was adjusted for the number, age and relationships of people in the household, using the McClements equivalence score.[23]

Total non-pension household wealth tertiles included financial wealth (savings and investments), the value of any home and other property (less mortgage), the value of any business assets and physical wealth such as artwork and jewellery, net of debt.

Age at last birthday was used in survival models. For reporting baseline characteristics, it was aggregated into 10-year bands.

To determine passive smoking, participants were asked 'does anyone smoke inside this house/flat on most days?' Those who responded 'yes' were recorded as passive smokers.

Missing data

The ELSA sample included 18 651 adults. Fifty-six cases had missing data for their smoking status (current, ex- or never smoker), cigarettes currently smoked per day, passive smoking status or education level achieved. One case appeared to have an incorrect date of death. Smoking exposure could not be calculated for 56 ex-smokers who reported less than one year of smoking and 59 individuals who described themselves as current smokers yet reported smoking zero cigarettes per day. These cases were excluded, leaving 18 479 (99% of the original sample).

Income data were not available for 3,346 (18%) and occupation data were not available for 435 (2%). The age of smoking initiation was not available for 1,171 (including 14% of ex-smokers and <1% of current smokers). The number of cigarettes previously smoked per day was not available for 1,157 ex-smokers (14%). These cases were retained. Multiple imputed complete datasets ($m = 20$) were generated from age, sex, CSI and all socioeconomic variables, using the Amelia II package.[24] For additive hazards models, the results were combined using Rubin's Rule. Descriptive analyses used 'missing' categories rather than multiple imputation.

Wealth data were collected for a sub-sample of 10 922 participants who responded to a follow-up ELSA survey in 2002. These data were analysed using the interview date in 2002 as the baseline.

Statistical analysis

Baseline characteristics of study participants were reported by age, sex, all socioeconomic indicators, current smoking status, CSI and passive smoking status. Mortality rates were directly age-adjusted using ten-year age bands and the study population as the reference. Population attributable fractions were calculated for the proportion of smoking-related deaths that could be attributed to smoking, to check how closely the outcome event was related to smoking.

Additive hazards models[7,25] were used to estimate the number of additional deaths per 100 000 person-years associated with the independent variables. This approach allowed us to compare the absolute risks of smoking and the numbers of deaths that could be avoided by preventing smoking in different socioeconomic groups.

Three models were fitted for each socioeconomic indicator. The dependent variable was the time in months until death due to lung cancer or COPD, with cases censored if they died due to other causes. The first model estimated the additional deaths associated with the socioeconomic indicator, adjusting for age, sex and passive smoking to allow reasonable comparisons between socioeconomic groups. The second model was also adjusted for smoking (using CSI). The third model included an interaction term between CSI and socioeconomic status and reported the effect of CSI for each socioeconomic level. *P*-values were reported from tests of the difference between the socioeconomic-specific effects of CSI. Models were not adjusted for environmental factors, health

Table 1 Baseline characteristics and mortality rates

			Age-adjusted mortality rate per 100 000 person-years		
	Level	***n* (%)**	**Lung cancer or COPD**	**Other causes**	**All causes**
Age[a]	45–49	1481 (8)	47	290	337
	50–59	6279 (34)	107	533	641
	60–69	5017 (27)	279	1492	1772
	70–79	3899 (21)	542	4261	4803
	80+	1803 (10)	594	8830	9424
Sex	Female	10 177 (55)	210	2038	2248
	Male	8302 (45)	408	2864	3271
Education[b]	A-level	4482 (24)	173	2032	2205
	GCSE	3573 (19)	253	2221	2474
	None	8962 (48)	358	2561	2919
	Other	1462 (8)	266	2251	2517
Occupation	Non-manual	9037 (49)	209	2220	2429
	Skilled manual	5165 (28)	364	2645	3010
	Manual	3842 (21)	380	2474	2855
	Missing	435 (2)	310	2031	2341
Income	>£22k	5039 (27)	227	2244	2471
	£12k–£22k	5053 (27)	299	2495	2794
	<£12k	5041 (27)	390	2711	3101
	Missing	3346 (18)	229	2000	2228
Wealth[c]	>£202k	3640 (20)	188	1860	2047
	£76k–£202k	3634 (20)	197	2125	2322
	<£76k	3648 (20)	511	2947	3459
	Missing	7557 (41)	-	-	-
Smoking	Never	6827 (37)	60	1999	2059
	Ex	8030 (43)	310	2438	2748
	Current	3622 (20)	795	3046	3842
CSI	Never-smoker	6827 (37)	60	1999	2059
	<0.8	3415 (18)	159	2234	2394
	0.8–1.6	3516 (19)	430	2706	3136
	1.6–3.7	3516 (19)	917	3083	4000
	Missing	1205 (7)	110	2111	2221
Passive smoking	No	13 429 (73)	190	2196	2386
	Yes	5050 (27)	637	2964	3600
All		18479	261	1997	2258

a: Crude rates are shown for age groups.
b: ‘A-level’ means A-level or higher (including higher education); ‘GCSE’ means GCSE or equivalent (e.g. O-level).
c: Wealth data was collected in a follow-up survey in 2002. Missing data is non-respondents to the follow-up survey. Rates are calculated from 2002 and are not reported for participants with missing data because death between the baseline survey (conducted in 1998, 1999 or 2001) and follow-up survey is a reason for non-response.

behaviours, comorbidities and other factors associated with socioeconomic status that may cause a differential impact, as these variables are plausibly on the causal pathway between socioeconomic status and the interaction effect between smoking and mortality. The analyses were repeated using mortality due to causes other than lung cancer or COPD and all-cause mortality as the events of interest. Kolmogorov–Smirnov and Cramer–von Mises tests were used to evaluate the assumption of time-invariance.[26] There was evidence that the effect of age varied over follow-up. Age was therefore included as a time-varying regressor. The results report socioeconomic-specific effects of CSI from the third model, with results from all models reported in Supplementary Material B. As a sensitivity analysis, we re-ran the additive hazards models excluding all participants with CSI greater than 2.5 (equivalent to 40 cigarettes per day for 40 years), as smoking indices may perform poorly at extreme values.

As a second sensitivity analysis, we fitted Cox’s proportional hazards models to assess whether multiplicative and additive models produce different results. The results of the Cox models are shown in Supplementary Material C.

All analyses and production of graphics were carried out using R version 3.3.1.

Results

The analysis included 18 479 adults and 223 641 years of follow-up (mean = 12.1 years). Table 1 shows the baseline characteristics of the sample and the age-adjusted mortality rates. Older people, men, those of lower socioeconomic status and smokers had higher rates of our measure of smoking-related mortality (i.e. death due to lung cancer or COPD), consistent with other research.

There were 5,050 deaths, of which 310 were due to lung cancer and 274 to COPD. 92% of deaths due to lung cancer or COPD were in current or ex-smokers. Given the prevalence of ever-smoking in this study, the proportion of deaths due to lung cancer or COPD attributable to smoking can be estimated at 80% (95% CI 73%, 85%). This compares to 20% (95% CI 17%, 23%) of deaths due to all causes.

After adjusting for age, sex and passive smoking, lower socioeconomic groups had higher rates of smoking-related

Table 2 Deaths per 100 000 person-years associated with a one-unit increase in the Comprehensive Smoking Index, stratified by socioeconomic status (95% CIs)[b]

		Cause of death		
		Lung cancer or COPD	**Other**	**All**
Education[a]	A-level	152 (89, 215)	206 (54, 359)	358 (192, 525)
	GCSE	258 (172, 344)*	361 (189, 534)	619 (426, 812)*
	None	383 (322, 445)***	293 (153, 432)	675 (519, 831)**
	Other	357 (220, 494)**	223 (-68, 514)	579 (269, 889)
Occupation	Non-manual	241 (184, 297)	377 (248, 507)	618 (479, 757)
	Skilled manual	366 (295, 436)**	178 (27, 328)	542 (378, 707)
	Manual	363 (273, 453)*	268 (74, 462)	630 (413, 847)
Income	>£22k	160 (102, 218)	175 (33, 317)	335 (181, 488)
	£12k–£22k	314 (244, 383)***	360 (204, 516)	673 (502, 845)**
	<£12k	440 (362, 519)***	317 (141, 494)	756 (564, 948)**
Wealth	>£202k	217 (121, 312)	251 (54, 449)	468 (249, 686)
	£76k–£202k	215 (128, 302)	283 (87, 480)	498 (286, 710)
	<£76k	446 (338, 554)***	264 (25, 503)	709 (445, 973)

a: 'A-level' means A-level or higher (including higher education); 'GCSE' means GCSE or equivalent (e.g. O-level).
b: Adjusted for age, sex and passive smoking.
*: $P < 0.05$.
**: $P < 0.01$.
***: $P < 0.001$.
P-values test the difference between each value and the value for the highest socioeconomic group (e.g. 'GCSE' vs. 'A-level').

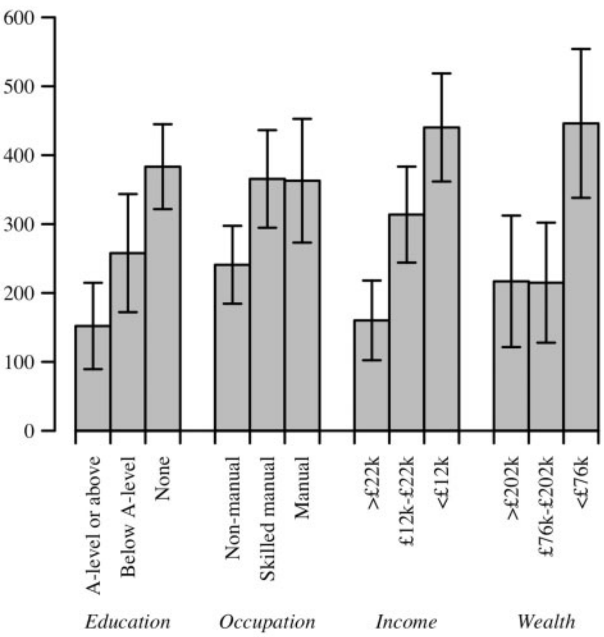

Figure 1 Deaths due to lung cancer or COPD per 100 000 person-years associated with a one-unit increase in the Comprehensive Smoking Index, with 95% CIs

mortality. For example, the rate of smoking-related mortality in participants with less than £76 000 of wealth was estimated to be 248 (95% CI 165, 330) per 100 000 person-years higher than in participants with more than £202 000 of wealth. Adjusting for smoking only partially explained this gradient for all socioeconomic indicators (results of models without interaction terms are shown in Supplementary Material B). We then included an interaction term between CSI and socioeconomic group to test whether the association between smoking and mortality varied across these groups, finding that the effect of smoking was greater in lower socioeconomic groups (see table 2; figure 1). For example, a one-unit increase in CSI was associated with an increase in smoking-related mortality of 160 (95% CI 102, 218) per 100 000 person-years among participants in the top income tertile, compared to 440 (95% CI 362, 519) among participants in the bottom tertile. To illustrate this, smoking 20 cigarettes per day for 40 years (CSI = 2.0) was associated with 327 (95% CI 209, 445) smoking-related deaths per 100 000 person-years in the top income tertile and 898 (95% CI 738, 1058) in the bottom tertile. While increases in smoking were also associated with increases in the rate of mortality due to other causes, the effects did not differ significantly between socioeconomic groups. In the sensitivity analysis excluding participants with CSI greater than 2.5, the point estimates for the number of deaths per 100 000 person-years attributable to a one-unit increase in CSI reduced by 15% or less. There was no apparent relationship between the change and socioeconomic level, and no changes in the gradients or significance of results.

Discussion

This study investigated socioeconomic differences in the relationship between smoking and mortality. The results show that substantially more deaths due to lung cancer or COPD can be attributed to smoking in low socioeconomic groups, even after accounting for the higher rates of smoking in these groups.

The mechanisms behind this finding were not explored in the present study. Risk factors associated with socioeconomic status, such as diet, physical activity, air pollution and exposure to asbestos, may interact with smoking,[27–29] and future research could investigate which pathways lead to greater absolute risk in smokers of low socioeconomic status.

Many studies have shown that smoking-related diseases have a steep social gradient[30] that is only partially explained by smoking behaviour;[3,4] findings that are consistent with the results of this study. The finding that smoking is associated with more deaths due to lung cancer or COPD in low socioeconomic groups appears to contrast with the majority of existing studies, which did not find evidence of effect modification.[9–16] However, these studies used multiplicative regression models that test for differences in relative risk. The analysis in the present study using Cox's proportional hazards models (shown in Supplementary Material C, which also discusses the differences between absolute and relative risk) showed that hazard ratios associated with smoking were similar across socioeconomic groups. Large differences in the absolute risk of smoking are therefore consistent with similar relative risks (or even a reversed gradient in relative risks), due to differing baseline mortality rates across socioeconomic groups. A study comparing mortality rates of manual and non-manual workers in Scotland[16] found that the absolute difference between smokers and non-smokers was similar in the two groups. This study looked at all-cause mortality and a wider definition of 'smoking-related mortality' than lung cancer and COPD, including cardiovascular disease, respiratory infections and some non-respiratory cancers. These results may therefore be consistent with the lack of difference in attributable deaths found for all-causes and 'other causes' of death when comparing occupational classes in the present study. Differences in the social gradients in smoking-related risk for other causes of death may be an area for further research.

By using an outcome that is closely related to smoking (mortality due to lung cancer or COPD) and a smoking exposure variable that captures important elements of risk, this study overcomes some of the issues with existing studies. It is a study of older people, which means that a large proportion of participants' lifetime smoking is likely to be in the past. The mean duration of smoking was 42 years for current smokers, while mean follow-up was 12.1 years. This limits the risk of bias due to unmeasured smoking during follow-up and smoking cessation due to ill health. The study population also includes the vast majority of smoking-related deaths, with 99% of deaths due to COPD and 98% of deaths due to lung cancer in England and Wales occurring in people aged over 50.[31]

Smoking was based on self-report and a limited number of variables (duration of smoking, intensity of smoking and time since cessation). This simplifies smoking behaviours, which are likely to change over time. Recall may be inaccurate due to the difficulty of remembering the average number of cigarettes smoked or social desirability bias. Studies that compare biomarkers such as cotinine and exhaled carbon monoxide with self-report data have found that self-report data tend to underestimate prevalence of current smoking, but underreporting is not associated with socioeconomic status.[32] This suggests that social gradients in the effects of smoking are unlikely to be strongly affected by recall bias.

The study used cause-specific mortality data, which may be susceptible to misclassification. Death due to lung cancer is likely to be well defined and cancers are often histologically confirmed. Diagnosis of death due to COPD may have less certainty and misclassification may occur.[33] Analyses of cause-specific mortality may also be susceptible to bias from competing risks, for which we have not accounted. Other research suggests that smokers in lower socioeconomic groups are more likely to suffer premature death due to cardiovascular causes[34] and may be less likely to survive until they develop lung cancer or COPD. This scenario would mean that the observed differences in the risks of smoking are understated.

The Health Survey for England (from which the ELSA sample is drawn) may have selection bias due to non-response. The response rate is difficult to estimate because the study population is a subset of Health Survey for England participants. Response rates for the full Health Survey for England sample were 69, 70 and 67% in 1998, 1999 and 2001, respectively.[35] The results for wealth tertiles are subject to further drop-out, with a response rate of 59% in the follow-up survey from which wealth information was drawn. Bias may have affected the study if non-response was associated with both socioeconomic status and smoking-associated risk.

The results are likely to be applicable in settings with similar patterns of socioeconomic status as England, including other Western European countries, but may not be generalizable to low-income countries, where smoking patterns and socioeconomic conditions are different.

Conclusions

Some tobacco control policies, particularly individual or group-level smoking cessation interventions, appear more effective in higher socioeconomic groups.[36] Prevalence of smoking is reducing most rapidly in high socioeconomic groups, and smoking in high-income countries is increasingly associated with deprivation.[37] Using an additive approach, this study shows large inequalities in the absolute mortality risk of smoking. It suggests that smoking prevention and cessation in lower socioeconomic groups can lead to greater population health benefits than would be expected simply because of their higher smoking rates. This underlines the importance of strengthening population-based policies that are effective in low socioeconomic groups, thereby narrowing inequalities in smoking, including steadily increasing taxation.[38]

Supplementary data

Supplementary data are available at *EURPUB* online.

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Conflicts of interest: None declared.

Ethics approval and informed consent

Informed consent was obtained from all individual participants included in the English Longitudinal Study of Ageing, which was approved by the National Research Ethics Service (London Multicentre Research Ethics Committee MREC/01/2/91). This analysis was approved by the Ethics Committee of the London School of Hygiene and Tropical Medicine.

Key points

- Smoking is associated with greater absolute mortality risk for individuals in lower socioeconomic groups.
- The social gradient in risk is seen across multiple indicators of socioeconomic status.
- Smoking among people with low income or education is associated with three times the rate of death due to lung cancer or chronic obstructive pulmonary disease than smoking among people with high income or education.
- The public health benefits of smoking prevention are greatest in lower socioeconomic groups.

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