Life-course socioeconomic disadvantage and lung function: a multicohort study of 70 496 individuals

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This multicohort study of 70 496 individuals from four European countries shows that life-course socioeconomic disadvantage is associated with a lower lung function and is an important predictor of years of lung function loss during adulthood and older ages https://bit.ly/3huxpOX

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ABSTRACT

Background: Lung function is an important predictor of health and a marker of physical functioning at older ages. This study aimed to quantify the years of lung function lost according to disadvantaged socioeconomic conditions across the life-course.

Methods: This multicohort study used harmonised individual-level data from six European cohorts with information on life-course socioeconomic disadvantage and lung function assessed by forced expiratory volume in 1 s (FEV_1) and forced vital capacity (FVC). 70 496 participants (51% female) aged 18–93 years were included. Socioeconomic disadvantage was measured in early life (low paternal occupational position), early adulthood (low educational level) and adulthood (low occupational position). Risk factors for poor lung function (*e.g.* smoking, obesity, sedentary behaviour, cardiovascular and respiratory diseases) were included as potential mediators. The years of lung function lost due to socioeconomic disadvantage were computed at each life stage.

Results: Socioeconomic disadvantage during the life-course was associated with a lower FEV_1. By the age of 45 years, individuals experiencing disadvantaged socioeconomic conditions had lost 4–5 years of healthy lung function *versus* their more advantaged counterparts (low educational level −4.36 (95% CI −7.33– −2.37) for males and −5.14 (−10.32–−2.71) for females; low occupational position −5.62 (−7.98–−4.90) for males and −4.32 (−13.31–−2.27) for females), after accounting for the risk factors for lung function. By the ages of 65 years and 85 years, the years of lung function lost due to socioeconomic disadvantage decreased by 2–4 years, depending on the socioeconomic indicator. Sensitivity analysis using FVC yielded similar results to those using FEV_1.

Conclusion: Life-course socioeconomic disadvantage is associated with lower lung function and predicts a significant number of years of lung function loss in adulthood and at older ages.

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Introduction

Lung function is a significant predictor of health and an important marker of physical functioning at older ages [1, 2]. Evidence from three large cohort studies showed that individuals with low lung function in early adulthood had a higher incidence of respiratory, cardiovascular and metabolic diseases; a higher number of comorbidities; and higher premature mortality by all causes [3].

Exposure to socioeconomic disadvantage in childhood or adulthood is associated with reduced lung function and a higher prevalence of respiratory diseases during adulthood and older ages [4–8]. However, less is known about the effects of socioeconomic disadvantage on lung function at each stage of the life-course [8–10] or the extent to which exposure to socioeconomic disadvantage reduces life-years of healthy lung function. It also remains unclear whether socioeconomic disadvantage is directly associated with reduced lung function or has an indirect impact, *via* other risk factors [11, 12]. For example, individuals from disadvantaged socioeconomic conditions have a higher prevalence of early respiratory tract infections, preterm birth and poor nutrition [13]; risk behaviours such as smoking and physical inactivity [14, 15]; and more exposure to indoor and outdoor pollution [16] and damaging occupational conditions [17], which also contribute to reduced lung function [18, 19].

Prior evidence showed that socioeconomic conditions over the life-course may help to predict outcomes of mobility, disability and functioning [20–22], but the extent to which disadvantaged socioeconomic conditions may affect lung function still needs to be understood. Lung function could potentially be considered a summary measure of overall functioning at older ages because of its links with cognitive and physical functioning [1, 2]. Therefore, it is of critical importance to identify its risk factors from a life-course perspective.

In this study, we aimed to quantify the years of lung function lost according to socioeconomic disadvantage at three distinct stages: childhood, early adulthood and adulthood, by sequentially controlling for time-ordered socioeconomic status and risk factors for poor lung function. In addition, we aimed to establish the life stages in which disadvantaged conditions may have more adverse effects on lung function by analysing harmonised individual-level data from six European cohort studies.

Methods

Study design and participants

This study is part of the European Commission's Horizon 2020 consortium, the Lifepath project. Details about the project are available elsewhere [23]. In the present analysis, we included six studies, including five population-based cohorts (the CoLaus|PsyCoLaus, CONSTANCES, the English Longitudinal Study of Ageing (ELSA), EPIPorto and the National Child Development Study (NCDS)) and one occupational-based cohort (the Whitehall II study) from four European countries (United Kingdom, France, Switzerland and Portugal). Detailed information on each cohort study is available in supplementary text S1.

Our analyses included 70 496 males and females aged 18–93 years with complete information on exposure (socioeconomic status measured by paternal occupational position, participant educational level and participant occupational position) and outcome (lung function measured by spirometry).

Data on lung function were collected between 2002 and 2017 across the cohort studies included. Detailed information on lung function measurements is available in supplementary table S1. The relevant local or national ethics committees approved each study, and all participants gave written informed consent to participate.

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Life-course socioeconomic disadvantage

Life-course socioeconomic disadvantage was assessed with multiple indicators at three life stages: childhood with low paternal occupational position; early adulthood with low participant educational level; and adulthood with low occupational position. The father's occupational position was chosen as a better surrogate of household socioeconomic conditions than the mother's occupational position, because prior evidence showed that the effects of father's occupational position on an individual's health exceeds that of the mother's [24]. Meanwhile, participants' own occupation may be a good indicator of social networks, work-based stress, control and autonomy [25]. Education reflects the material, intellectual resources of the family of origin, having the potential to capture the long-term influences of circumstances in both early life and young adulthood on adult health [25].

Both paternal occupational position and participant occupational position were retrospectively assessed using information on the last known occupational title at study enrolment and were pre-defined and harmonised between the study cohorts [20]. The European Socioeconomic Classification (ESEC) system [26], which includes nine categories, was used to code participants' paternal occupational position and their own occupational position. The tenth category included people who never worked or were unemployed long-term, and these people were excluded from the analysis. ESEC occupational classes 1–3 were considered high professions (including higher-level professionals and managers, higher-level clerical, services and sales workers); ESEC classes 4–6 as intermediate professions (including small employers and self-employed, farmers, lower-level supervisors and technicians); and ESEC classes 7–9 as low professions (including lower-level clerical, services and sales workers; skilled workers; and semiskilled and unskilled workers). Participants' educational level was measured as completed years of schooling, categorised as high (including tertiary education or post-secondary); intermediate (higher secondary school); and low (including primary or lower secondary school).

Lung function

Lung function was assessed using spirometry performed according to American Thoracic Society (ATS) and European Respiratory Society (ERS) criteria [27]. In all cohorts, at least three reproducible and acceptable forced manoeuvres were performed; the highest technically satisfactory readings of forced expiratory volume in 1 s (FEV_1) and forced vital capacity (FVC) (mL) were collected. A single measure of FEV_1 and FVC were analysed from one wave of each cohort included (CoLaus wave 2, 2014–2017; CONSTANCES wave 1, 2012–2017; ELSA wave 6, 2012–2013; EPIPorto wave 2, 2014–2015; NCDS wave 8, 2002–2003; Whitehall II wave 11, 2012–2013). To harmonise spirometry values and allow comparisons between the cohorts, some exclusion criteria to FEV_1 and FVC were defined [27]. Thus, participants with incomplete information, whose tests ended in the first second, or with a volume in the first second higher than the total volume were excluded from the analysis. Further details on the spirometry procedures and exclusions are available in supplementary table S1. All the FEV_1 and FVC values used in the analyses were age- and height-adjusted and stratified by sex using the statistical method described here. Analyses were not stratified by race/ethnicity because almost all participants were white (99.3%).

Sociodemographic information, health risk factors and disease history

Sex, age and marital status were self-reported, and marital status was further categorised as married or living in common law *versus* single, divorced or widow.

Health risk factors, such as body mass index (BMI), smoking and sedentary behaviour, which are known to be associated with both socioeconomic disadvantage and lung function, were considered as covariates. Risk factor measurements that were closest to the lung function assessment were used. If data were unavailable at the same wave, we completed information from the preceding evaluation. Height and weight were measured using standard procedures. BMI was then calculated as weight (kg) divided by height (m^2) and categorised as underweight (<18.5 $kg \cdot m^{-2}$), normal weight (18.5 to <25 $kg \cdot m^{-2}$), overweight (25 to <30 $kg \cdot m^{-2}$), or obese (⩾30 $kg \cdot m^{-2}$), according to World Health Organization classification. Self-reported smoking was categorised as smokers, former smokers (*i.e.* participants who had not smoked for ⩾6 months) or never-smokers. Smoking intensity was collected as the number of cigarettes per day (continuous variable) and further categorised in 1–19 and ⩾20 cigarettes per day for all cohorts, excepting NCDS, which did not have this information available. Although physical activity was measured with different questions in each study, a dichotomised variable indicating the presence or absence of sedentary behaviour was harmonised. In all cohorts, the prevalence of cardiovascular disease was ascertained by using a harmonised variable referring to the medical diagnosis or self-reported diagnosis of angina and/or heart attack and/or coronary artery disease and/or myocardial infarction, with the exception of Whitehall II (information on stroke and coronary heart disease) and NCDS (information on medicines for cardiovascular disease). The prevalence of respiratory disease was ascertained using the prevalence of self-reported asthma, chronic bronchitis, emphysema or chronic lung disease for all cohorts with the exception of ELSA, in which respiratory diseases were medically diagnosed. The NCDS only had information on medicines for respiratory disease.

Statistical analysis

Analyses were performed separately for males and females and all analyses accounted for cohort effects.

Association between socioeconomic disadvantage and lung function

Generalised linear models were used to investigate the relationship between socioeconomic disadvantage and lung function using FEV_1. The minimally adjusted model was adjusted for age and height. The fully adjusted model assessing paternal occupational position as exposure was adjusted for age, height, health risk factors (smoking, sedentary behaviour and BMI) and history of disease (respiratory and cardiovascular). The fully adjusted model assessing educational level as exposure was adjusted for age, height, paternal occupational position, health risk factors and history of disease. The fully adjusted model assessing occupational position as exposure was adjusted for age, height, paternal occupational position, educational level, health risk factors and history of disease. These analyses allow us to evaluate the total effect of socioeconomic disadvantage on lung function and the variables included in fully adjusted models were considered mediators in the association of socioeconomic disadvantage with lung function, since they stand in the midst of the causal chain from socioeconomic disadvantage to lung function. Therefore, as we assessed total effects rather than direct effects, we did not perform mediation analysis and adjustments were sequentially performed considering the chronology of events over the life-course.

Lung function and age

A generalised additive mixed model using a mgvc 4 algorithm was used to estimate FEV_1, with age and height as fixed-effect predictors and cohort as a random effect at the intercept and age slope. We computed 95% confidence intervals from the uncertainty of the estimated smoothing function. The lung function decline by year was also estimated for each age group: 18–24 years; 25–44 years; 45–64 years; ⩾65 years. The age groups were based on the lung function periods of growth and decline. From 18 to 25 years, lung function might slightly increase until the maximal lung function attainment. From 25 to 45 years, the maximal lung function has already been attained and individuals are in the plateau phase when merely small fluctuations in lung function indices occur. After this period, they enter in the decline phase during adulthood, characterised by a smooth decrease in lung function over time. After 65 years, the decline phase is more accentuated due to the physiological ageing of the lungs.

Years of lung function lost

The number of years of lung function lost was computed from the mixed-model predictions of FEV_1 along with age. The mixed model of FEV_1 included a random cohort effect at the intercept and age slope. Fixed effects included age, age squared (age^2), height and the socioeconomic factor under study in the minimally adjusted models. The fully adjusted models included age, age^2, height, the socioeconomic indicators as previously described, smoking, sedentary behaviour, BMI, respiratory and cardiovascular disease and an interaction term between age and socioeconomic factor. The structure of the models was determined through likelihood ratio tests. Confidence intervals for years of lung function lost were determined through 5000 bootstrap samples, applying a model-based parametric bootstrap method. For all examined factors, we computed the years of lung function lost associated with the exposure by predicting the chronological age of the unexposed group (high socioeconomic status) equivalent to the FEV_1 at 45, 65 or 85 years in the exposed group (intermediate or low socioeconomic status). This method allows years of lung function lost by a given age to be retrospectively calculated, as opposed to the classic years of life lost prospectively calculated.

Supplementary analyses

As supplementary analyses, we repeated the generalised linear models and computed the number of years of lung function lost using the FVC. Moreover, because smoking is one of the main predictors of reduced lung function, we repeated the linear regression analyses on the association of socioeconomic disadvantage and FEV_1, stratifying results by smoking status. In addition, we stratified results by smoking intensity (number of cigarettes per day) using a subsample of our data (n=14 403), since we did not have this information for all participants. Finally, we performed a multiple imputation model using chained equations to check whether results were similar using the total sample (n=96 600) in contrast to using only participants with complete exposure and outcome information (n=70 496). This technique allows imputing missing information for several variables at a time through an iterative process (the chained equations). 15 completed datasets were generated, and results were combined to produce estimates with standard errors that should correctly reflect the variability of data. We imputed data for the exposure (the three socioeconomic indicators) and covariates (smoking, sedentary behaviour, BMI and respiratory and cardiovascular disease. The outcome measure was not imputed. Analyses were performed using STATA (version 15.0; StataCorp, College Station, TX, USA) and R (R Foundation, Vienna, Austria).

Results

Out of 96 600 eligible participants from the six cohort studies, 70 496 participants were included in this study (supplementary figure S1). We found statistically significant differences between included and excluded participants, with those included being older (48.8 *versus* 47.8 years, p<0.001) and more likely to have high educational level (52.2% *versus* 38.4%, p<0.001) and high occupational position (31.7% *versus* 25.9%, p<0.001) (supplementary table S2).

The mean±SD age of included participants was 48.8±12.4 years and 50.5% were female (table 1). The mean±SD FEV_1 values were 3501.9±524.1 and 2788.1±511.5 mL and FVC values were 4446.8±626.1 and 3480.4±602.5 mL in males and females, respectively. Most participants had a low paternal occupational position (43.7%), a high own educational level (52.2%) and an intermediate own occupational position (35.3%). About half of the participants were never-smokers (45.9%) and presented normal weight (52.4%).

TABLE 1 Characteristics of the participants included by sex

	Males	Females	Total
Subjects	34 843	35 653	70 496
Demographics, anthropometrics			
Age years	49.2±12.2	48.4±12.5	48.8±12.4
Age groups years			
18–44	11 242 (32.3)	12 569 (35.3)	23 881 (33.8)
45–64	19 055 (54.7)	18 825 (52.8)	37 880 (53.7)
⩾65	4546 (13.0)	4259 (11.9)	8805 (12.5)
Race/ethnicity			
White	34 527 (99.2)	35 396 (99.3)	69 923 (99.3)
Non-white	289 (0.8)	237 (0.7)	526 (0.7)
Height cm	175.9±6.8	162.7±6.4	169.1±9.2
Weight kg	80.5±13.2	65.7±13.9	73.0±15.5
Lung function mL			
FEV_1	3501.9±524.1	2788.1±511.5	3140.9±628.9
FVC	4446.8±626.1	3480.4±602.5	3958.1±781.5
Socioeconomic status			
Paternal occupational position (ESEC class)			
High (1–3)	6285 (18.0)	6989 (19.6)	13 274 (18.8)
Intermediate (4–6)	12 899 (37.0)	13 515 (37.9)	26 414 (37.5)
Low (7–9)	15 659 (44.9)	15 149 (42.5)	30 808 (43.7)
Participants' educational level			
High (tertiary school)	17 345 (49.8)	19 446 (54.5)	36 791 (52.2)
Intermediate (higher secondary school)	10 945 (31.4)	9448 (26.5)	20 393 (28.9)
Low (primary/lower secondary school)	6553 (18.8)	6759 (19.0)	13 312 (18.9)
Participants' occupational position (ESEC class)			
High (1–3)	14 072 (40.4)	8269 (23.2)	22 341 (31.7)
Intermediate (4–6)	10 986 (31.5)	13 875 (38.9)	24 861 (35.3)
Low (7–9)	9785 (28.1)	13 509 (37.9)	23 294 (33.0)
Health risk factors			
Smoking			
Never	13 994 (41.4)	17 395 (50.4)	31 389 (45.9)
Former	13 635 (40.3)	10 836 (31.4)	24 471 (35.8)
Current	6172 (18.3)	6297 (18.2)	12 469 (18.2)
Sedentary behaviour	8919 (26.5)	9069 (26.3)	17 988 (26.4)
BMI			
Under-/normal weight	15 065 (43.4)	21 732 (61.2)	36 707 (52.4)
Overweight/obese	19 621 (56.6)	13 773 (38.8)	33 394 (47.6)
Disease history			
Cardiovascular disease	1681 (4.8)	831 (2.3)	2512 (3.6)
Respiratory disease	4668 (13.5)	4703 (13.2)	9371 (13.3)

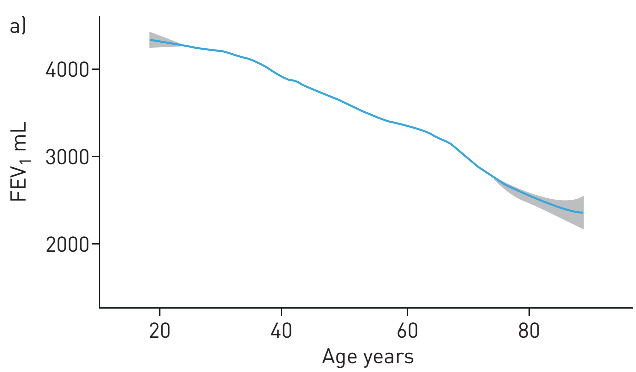
Data are presented as n, mean±SD or n (%). FEV_1: forced expiratory volume in 1 s, age- and height-adjusted; FVC: forced vital capacity, age- and height-adjusted; ESEC: European Socioeconomic Classification; BMI: body mass index.

The prevalence of sedentary behaviour was 26.4%, cardiovascular disease was 3.6% and respiratory disease was 13.3% (table 1). Detailed information on the characteristics of participants by sex and cohort is available in the supplementary material (supplementary table S3).

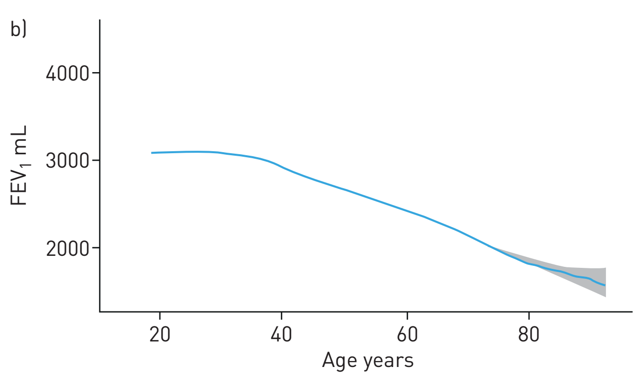
Figure 1 shows the age-related decline in FEV_1 in both males and females using the generalised additive mixed model. An increased decline with age was observed; more accentuated among males than females.

Participants with intermediate or low paternal occupational position, own educational level and own occupational position had a lower FEV_1 *versus* higher socioeconomic counterparts (minimally adjusted models) (table 2). In fully adjusted models, these associations attenuated, but remained significant considering paternal occupational position (males, intermediate −147.3 mL, 95% CI −163.0−−131.6 mL; low −167.4 mL, 95% CI −182.8−−152.0 mL; and females, intermediate −153.1 mL, 95% CI −167.9−−138.4 mL; low −175.4 mL, 95% CI −190.0−−160.8 mL) and own educational level (males, intermediate −164.6 mL, 95% CI −177.5−−151.7 mL; low −210.6 mL, 95% CI −226.5−−194.7 mL; and females, intermediate −208.6, 95% CI −221.3−−196.0 mL; low −333.6 mL, 95% CI −348.6−−318.6 mL) (table 2). Sensitivity analysis using FVC yielded similar results to those using FEV_1 (supplementary table S4).

Figures 2–4 show the years of lost function by the ages of 45 years, 65 years and 85 years according to intermediate or low socioeconomic conditions using the three socioeconomic indicators. By 45 years, compared with individuals with high socioeconomic status, the years of lung function lost were −4.36 (95% CI −7.33−−2.37) and −5.14 (95% CI −10.32−−2.71) in males and females, respectively, of low educational level and −5.62 (95% CI −7.98−−4.90) and −4.32 (95% CI −13.31−−2.27) in males and females, respectively, of low occupational position (figure 2, fully adjusted models). These findings suggest a difference of 4–5 years in lost lung function, meaning that, overall, a 45-year-old male or female who experienced socioeconomic disadvantage had the same lung function as a 49- to 50-year-old male or female who had experienced more favourable socioeconomic conditions, independently of the socioeconomic indicator used. By 65 years, the years of lost function due to disadvantaged socioeconomic conditions diminished in males and females, respectively, to −2.78 (95% CI −4.37−−1.64) and −1.40 (95% CI −2.53−−0.45) for low educational level and to −4.30 (95% CI −5.35−−3.37) and −4.32 (95% CI −13.31−−2.27) for low occupational position (figure 3, fully adjusted models). By 85 years, a reduction in the years of lost function was also observed, compared with by 45 years. This reduction was more pronounced among females, with differences observed only for low occupational position (−1.29, 95% CI



Age groups years	Decline per year mL
18–24	−11.6±2.4
25–44	−25.1±11.1
45–64	−25.4±6.8
≥65	−36.2±17.3



Age groups years	Decline per year mL
18–24	2.8±1.0
25–44	−15.1±9.7
45–64	−24.2±6.0
≥65	−27.2±8.6

FIGURE 1 Age- and height-adjusted forced expiratory volume in 1 s (FEV_1) as a function of age in a) males and b) females, along with lung function decline by year for the different age groups, using cross-sectional data. Data are presented as mean±SD.

−2.55−−0.44), while in males differences were observed for low educational level (−1.85, 95% CI −3.86−−0.49) and low occupational position (−3.52, 95% CI −4.53−−2.39) (figure 4, fully adjusted models). The sensitivity analysis computing the years of lung function lost using FVC by 45, 65 and 85 years showed similar trends, with a slightly higher magnitude of differences between individuals with low *versus* high socioeconomic status (supplementary table S5).

The association of socioeconomic disadvantage with lung function was independent of smoking status, since it was also observed in participants who never smoked (supplementary table S6). Yet, the greater number of cigarettes smoked per day, the lower FEV_1 among low socioeconomic status participants (supplementary table S7). The sensitivity analysis using the total sample yielded results similar to those found in our main analyses (supplementary table S8).

Discussion

In this multicohort study using individual-level data of 70 496 individuals from six European cohort studies, socioeconomic disadvantage from childhood to adulthood was associated with lower lung function and predicts a significant number of years of lung function loss during adulthood and older ages.

At 45 years of age, 4–5 years of healthy lung function was lost in both males and females according to socioeconomic disadvantage. These associations remained after controlling for health risk factors for respiratory health, including smoking, sedentary behaviour, obesity and cardiovascular and respiratory disease.

In addition, we found that socioeconomic differences diminished with age, but did not disappear. A difference of 2–3 years of healthy lung function was observed at 85 years of age between low *versus* high socioeconomic groups, depending on the socioeconomic indicator. These findings suggest a narrowing of the socioeconomic gradient in respiratory health at older ages, which is in line with evidence showing that in relative terms, social inequalities in health tend to narrow with advancing age [28]. Previous studies [5, 28] suggest that selective mortality may be the key mechanism to explain this effect. Thus, we could hypothesise that the narrowing of social inequalities at 65 and 85 years of age may be due to the earlier death of individuals in more disadvantaged socioeconomic conditions, leaving relatively robust high socioeconomic status survivors and reducing the gap between the more advantaged and disadvantaged groups in mortality [5, 28]. We observed that participants who reached older ages and were included in the 85-years analyses were more likely to have a higher educational level, which in part supports this theory.

TABLE 2 Serially adjusted association of life-course socioeconomic disadvantage with lung function by sex

	FEV_1 differences mL			
	Males		Females	
	Minimally adjusted model#	Fully adjusted model¶	Minimally adjusted model#	Fully adjusted model¶
Paternal occupational position				
High	Reference	Reference	Reference	Reference
Intermediate	−175.8 (−191.5−−160.2)	−147.3 (−163.0−−131.6)	−177.0 (−191.6−−162.4)	−153.1 (−167.9−−138.4)
Low	−206.3 (−221.5−−191.2)	−167.4 (−182.8−−152.0)	−215.1 (−229.4−−200.8)	−175.4 (−190.0−−160.8)
Participants' educational level				
High	Reference	Reference		
Intermediate	−214.6 (−226.8−−202.4)	−164.6 (−177.5−−151.7)	−241.7 (−253.7−−229.8)	−208.6 (−221.3−−196.0)
Low	−273.7 (−288.2−−259.2)	−210.6 (−226.5−−194.7)	−381.7 (−395.2−−368.2)	−333.6 (−348.6−−318.6)
Participants' occupational position				
High	Reference	Reference		
Intermediate	−83.0 (−96.5−−69.6)	−3.6 (−17.1−9.9)+	−127.7 (−141.5−−113.9)	33.3 (17.7−48.9)
Low	−96.4 (−109.4−−83.3)	60.3 (44.8−75.9)	−171.3 (−185.2−−157.5)	−28.4 (−42.3−−14.5)

Data are presented as β-coefficient of linear regression models (95% CI). FEV_1: forced expiratory volume in 1 s. #: adjusted for age and height; ¶: the model assessing paternal occupational position as exposure was adjusted for age, height, health risk factors (smoking, sedentary behaviour and body mass index) and history of disease (respiratory and cardiovascular); the model assessing educational level as exposure was adjusted for age, height, paternal occupational position, health risk factors and history of disease; and the model assessing occupational position as exposure was adjusted for age, height, paternal occupational position, educational level, health risk factors and history of disease; +: nonsignificant.

Another known explanation is the "universality of biological frailty" hypothesis [29], in which morbidity becomes compressed among more advantaged groups until late in life, and hence inequalities are reduced at older ages. This pattern of narrowing of health inequalities has mainly been observed in cross-sectional studies, which rely on comparing individuals at different ages [30], whereas longitudinal studies primarily

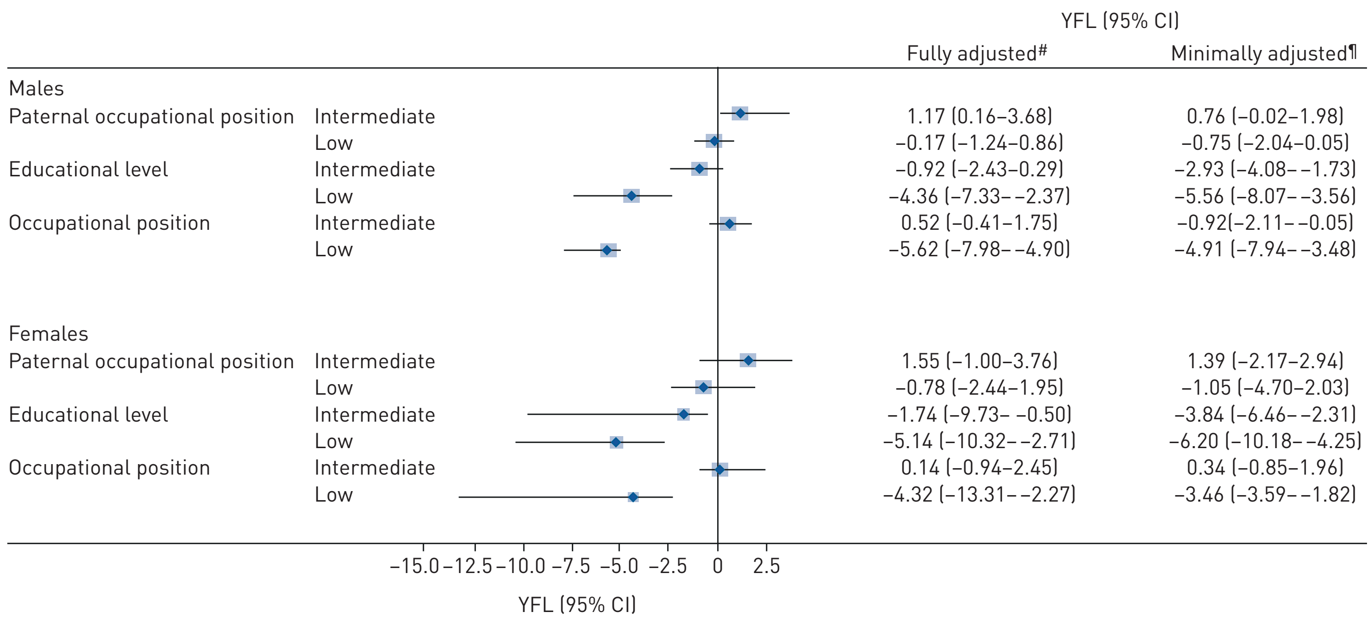


FIGURE 2 Years of function lost (YFL) by age 45 years due to intermediate or low socioeconomic conditions, based on cross-sectional data. The reference categories were high paternal occupational position, high educational level and high occupational position. #: the model assessing paternal occupational position as exposure was adjusted for age, height, health risk factors (smoking, sedentary behaviour and body mass index) and history of disease (respiratory and cardiovascular); the model assessing educational level as exposure was adjusted for age, height, paternal occupational position, health risk factors and history of disease; and the model assessing occupational position as exposure was adjusted for age, height, paternal occupational position, educational level, health risk factors and history of disease; ¶: adjusted for age and height.

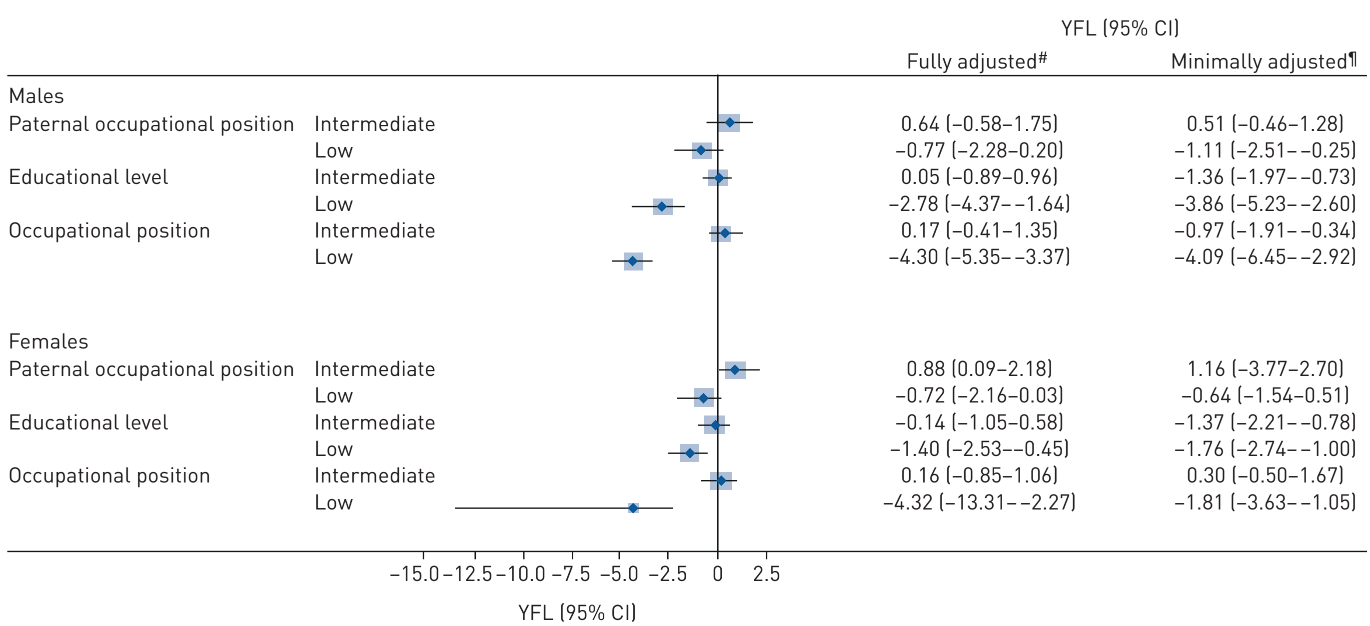
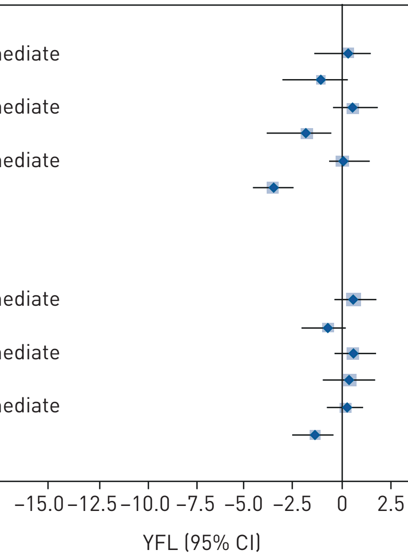


FIGURE 3 Years of function lost (YFL) by age 65 years due to intermediate or low socioeconomic conditions, based on cross-sectional data. The reference categories were high paternal occupational position, high educational level and high occupational position. #: the model assessing paternal occupational position as exposure was adjusted for age, height, health risk factors (smoking, sedentary behaviour and body mass index) and history of disease (respiratory and cardiovascular); the model assessing educational level as exposure was adjusted for age, height, paternal occupational position, health risk factors and history of disease; and the model assessing occupational position as exposure was adjusted for age, height, paternal occupational position, educational level, health risk factors and history of disease; ¶: adjusted for age and height.



		YFL (95% CI) Fully adjusted#	YFL (95% CI) Minimally adjusted¶
Males			
Paternal occupational position	Intermediate	0.35 (−1.36–1.55)	0.31 (−1.17–1.42)
	Low	−1.09 (−2.99–0.28)	−1.41 (−3.05–−0.28)
Educational level	Intermediate	0.60 (−0.49–1.78)	−0.44 (−1.47–0.23)
	Low	−1.85 (−3.86–−0.49)	−2.84 (−4.20–−1.04)
Occupational position	Intermediate	−0.02 (−0.60–1.22)	−1.00 (−2.20–−0.30)
	Low	−3.52 (−4.53–−2.39)	−3.60 (−5.55–−2.33)
Females			
Paternal occupational position	Intermediate	0.62 (−0.36–1.70)	−0.36 (−1.75–0.59)
	Low	−0.68 (−1.98–0.18)	−0.90 (−2.52–0.45)
Educational level	Intermediate	0.61 (−0.41–1.65)	−0.18 (−1.05–0.56)
	Low	0.44 (−1.00–1.62)	0.47 (−0.14–1.53)
Occupational position	Intermediate	0.17 (−0.83–1.10)	0.29 (−0.84–1.58)
	Low	−1.29 (−2.55–−0.44)	−1.04 (−2.31–0.13)

FIGURE 4 Years of function lost (YFL) by age 85 years due to intermediate or low socioeconomic conditions, based on cross-sectional data. The reference categories were high paternal occupational position, high educational level and high occupational position. #: the model assessing paternal occupational position as exposure was adjusted for age, height, health risk factors (smoking, sedentary behaviour and body mass index) and history of disease (respiratory and cardiovascular); the model assessing educational level as exposure was adjusted for age, height, paternal occupational position, health risk factors and history of disease; and the model assessing occupational position as exposure was adjusted for age, height, paternal occupational position, educational level, health risk factors and history of disease; ¶: adjusted for age and height.

report a widening in the social gradient in health with advancing age, as a result of the accumulated effects of social disadvantage over time [31, 32]. The only previous study that we found specifically on social inequalities and lung function presented cross-sectional evidence that socioeconomic disparities in lung function increase with age, especially for males [33]. In contrast, the study by Benzeval *et al.* [30] using longitudinal data from three European cohort studies found that inequalities are more pronounced at middle age and then narrow after the age of 65 years, which is in line with our observations. The effects of narrowing or widening of health inequalities may be complicated by cohort effects, because differences may widen with age, but increase with younger cohorts, producing an artefactual appearance of convergence if age is modelled without adjustment for cohort [34]. Nevertheless, in our study, all analyses accounted for cohort effects to minimise this artefact. Moreover, we performed regression analyses separately for each cohort study and then conducted a meta-analysis of the lung function differences using the three socioeconomic indicators (data not shown), which yielded similar results to those presented in table 2. Thus, the weight of evidence seems to suggest that inequalities in health tend to be more evident at middle age and then narrow at older ages [28, 30, 31, 35], supporting our findings.

Furthermore, we observed that the narrowing of the socioeconomic gradient in lung function was more pronounced among females than males. This could be explained by sex differences in life expectancy, because females tend to live longer than males [36], and naturally will be more susceptible to the narrowing of the social gradient. Yet, other studies on socioeconomic inequalities on lung function suggested that both boys and men [37, 38] are more sensitive to socioeconomic inequalities in health. Indeed, a systematic review aimed at disentangling women's apparent relative immunity to the socioeconomic gradient in health concluded that the gradient appears stronger for males than for females for all health outcomes, except cardiovascular disease [39]. More studies are needed to clarify whether there are sex differences in survival bias or males are indeed more susceptible to socioeconomic inequalities affecting their health.

We found that early-life socioeconomic disadvantage (*i.e.* measured in childhood and early adulthood) was associated with lower lung function, independent of adult-life disadvantage, health risk factors (smoking, sedentary behaviour and BMI) and cardiovascular and respiratory diseases. These findings agree with previous literature suggesting that some exposures at a specific period in the life-course, namely at early ages when lungs are growing, may influence the anatomical structure and physiological function of the lungs and will eventually result in disease [40, 41]. In addition, the effects of adult-life disadvantage on lung function seemed to be almost fully explained by the socioeconomic conditions that individuals were exposed to during early ages, namely their fathers' paternal occupational position and the educational level attained in early adulthood. These findings support the hypothesis that early life may be particularly important, having the potential to shape and influence the life-course socioeconomic trajectories of individuals during adulthood and then influence later respiratory health outcomes [42]. In our study, we used occupational position as the single indicator of disadvantaged socioeconomic conditions in early life. Other important factors, and in particular material disadvantage, housing conditions or overcrowding in early life, could not be examined, as this information was not available widely across cohorts. Given the strong influence of those factors on lung function [43, 44], our results for years of functioning lost due to disadvantaged socioeconomic conditions may be underestimated. Yet, the results of this study using paternal occupational position as an individual-level indicator agree with some studies [43, 44] looking at the association of material socioeconomic disadvantage in early life (measured by housing quality, overcrowding and residential area deprivation in addition to paternal occupational position) and lung function in adulthood and older ages.

Other pathways should also be considered. For instance, cigarette smoking is a primary predictor of low lung function and is more prevalent among disadvantaged socioeconomic groups [45]. Thus, it may explain the social gradient in lung function [5]. Nevertheless, our findings showed that after accounting for smoking status, the effects of socioeconomic disadvantage on lung function attenuated, but remained significant, suggesting that these effects were independent of smoking status. In addition, we performed a sensitivity analysis stratifying results by smoking, which showed that the effects of socioeconomic disadvantage on lung function were significant among never-smokers, former smokers and current smokers. This suggests that although smoking is an important factor for lung function in our study, it is not the determinant factor, because participants of low socioeconomic status who never smoked also had reduced lung function, as described previously [5, 12]. We also observed that the greater number of cigarettes smoked per day, the lower FEV_1 among low socioeconomic status participants, reinforcing the dose-effect of smoking intensity on lung function. Yet, more detailed information on smoking would strengthen our results because we were not able to characterise passive exposure to smoking during early life or smoking intensity for all participants, factors that have been previously associated with reduced lung function [46, 47]. Obesity and the presence of sedentary behaviour may also be important for the social patterning of lung function, but the results of this study were independent of these factors, as shown in other studies [5, 8]. Thus, acting on socioeconomic conditions from early ages onwards [48] might have positive effects on lung function, but also on the health-risk factors for lung function over the life-course, namely smoking, obesity and sedentary behaviour.

The strongest association between socioeconomic disadvantage and lower lung function were observed by educational level. Prior studies [5, 49] sought to explain this association by adjusting for smoking status, physical activity and body composition; however, as in our study, the effects of educational level on lung function seem largely independent of these factors. This evidence suggests that a low educational level may be an important and consistent upstream risk factor for low lung function, but further research is needed to disentangle the precise mechanism(s) underlying this association. Thus, enhancing populations' educational level might help to improve respiratory health, but this hypothesis warrants further investigation. Conversely, the individuals' occupational position was the indicator associated with a higher number of years of lung function lost, mainly in males, which makes sense since, occupational position during adulthood will determine retirement pension at older ages.

The effects of socioeconomic disadvantage were observed on both FEV_1 and FVC indicators, yet the magnitude of the effects on FVC were slightly stronger than on FEV_1. FVC largely reflects lung volume, while FEV_1 is influenced by both airways flow obstruction and lung volume [6]. With advancing age, even healthy participants show a reduction in lung volume, and as our sample includes a large percentage of older adults, this might explain the slightly higher number of years of lung function lost associated to FVC. In addition, the differences between low *versus* high socioeconomic groups were in the range of 140–380 mL, which are higher that the values proposed (100–140 mL) as minimal clinically important differences by the ATS and ERS [50]. A difference >100 mL in FEV_1 might be considered clinically relevant based on clinical anchoring to end-points such as exacerbations, perception of dyspnoea and lung function decline [51]. Thus, our findings suggest that socioeconomic disadvantage since early ages might translate in clinically relevant consequences for respiratory health over the life-course.

Strengths and limitations

The strengths of this study are the use of harmonised individual-level data from six cohort studies with information on socioeconomic indicators in different stages of the life-course. In addition, the FEV_1 and FVC are reliable and robust health indicators to characterise lung function, with broader use in clinical and research fields, associated with several health outcomes [3].

Some limitations should also be considered. The harmonisation process requires standardising variables across cohorts, meaning that some cohort specificities may have been smoothed out or lost. The cohorts participating in the Lifepath consortium were from high-income countries, so our results might not be generalisable to other populations. Health-risk factors (smoking, BMI, sedentary behaviour) were self-reported, and thus subject to some degree of measurement error and social desirability. However, due to the longitudinal nature of the cohorts included, we were able to complete and compare information on lifestyle factors with information from the preceding evaluations, reducing missing data and improving the reliability and validity of information. Other factors, such as early-life respiratory tract infections, poor nutrition, pollution levels, low housing conditions and damaging occupational exposures might contribute to explain the relationship between life-course socioeconomic disadvantage and lung function, but we did not have that information for all included cohorts. These factors deserve to be explored by further studies. Cardiovascular disease was characterised using information on major cardiovascular disease (including angina and/or heart attack and/or coronary artery disease and/or myocardial infarction), which may lead to some degree of underestimation, since mild cardiovascular disease, such as arterial hypertension, some types of arrhythmias, and cardiomyopathies could not be considered. The use of chronological age to compare years of lung function between the socioeconomic groups might not directly reflect the individuals' functional and health characteristics, since such characteristics vary extensively by individuals. However, other more precise measure of biological age or functional capacity were not available for all the included cohorts. Our approach which uses chronological age to calculate differences in lung function at the ages of 45, 65 and 85 years remains a simple and direct way to compare individuals of the same age, translating in a clear message for health policy implications. The cohort studies included were subject to attrition and we had some differential exclusions, as described previously. For instance, individuals of disadvantaged socioeconomic status tend to die earlier, when compared with those from high socioeconomic status. Yet, the results of our sensitivity analysis using the total sample (supplementary table S8) showed that we might have underestimated the effects and, if those participants were included, the associations would be even more evident, mainly at 45 years of age. In addition, we cannot exclude the possibility of reverse causality, because poorer lung function in early ages may have prevented participants' educational attainment, with potential implications in occupational position. There is likely to be unmeasured confounding, measurement error and heterogeneity across cohorts regarding the socioeconomic variables. In addition, as lung age was calculated retrospectively, some misclassification might occur in fully adjusted models which considered predictors beyond age and height that can vary over the life-course (smoking, sedentary behaviour, BMI, respiratory and cardiovascular disease). Because our analyses relied on cross-sectional data, we cannot totally exclude reverse causality and thus infer a causal relationship between socioeconomic disadvantage and respiratory health. However, socioeconomic conditions in early life preceded respiratory health assessment, and our estimates indicate a potential effect of socioeconomic disadvantage on lung function at adulthood and older ages.

Conclusion

This study shows that socioeconomic disadvantage is associated with lower lung function across the life-course and predicts a significant number of years of lung function loss in adulthood and older ages. Social inequalities in lung function are particularly wide in middle age and seem to narrow with ageing. These findings suggest that actions to improve respiratory health over the life-course should consider the negative effects of adverse socioeconomic conditions from early ages onwards.

Author contributions: V. Rocha, S. Fraga and S. Stringhini conceived the study. V. Rocha wrote the first and successive drafts of the manuscript. C. Moreira, V. Rocha and C. Carmeli modelled and analysed the data. A. Lenoir, A. Steptoe, G. Giles, M. Goldberg, M. Zins, M. Kivimaki, P. Vineis, P. Vollenweider and H. Barros collected the data. All authors revised the manuscript for important intellectual content.

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