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POPULATION STUDY ARTICLE

Socioeconomic circumstances and lung function growth from early adolescence to early adulthood

Vânia Rocha[1], Milton Severo[1,2], Elisabete Ramos[1,2], Helena Falcão[3], Silvia Stringhini[4,5] and Sílvia Fraga[1,2]

BACKGROUND: A reduced lung function in early adulthood is associated with respiratory and non-respiratory diseases and is a long-term predictor of mortality. This study investigated the association between early socioeconomic circumstances (SEC) and lung function growth trajectories from early adolescence until early adulthood.
METHODS: We analysed data from the EPITeen population-based study, including adolescents born in 1990. Study waves occurred at 13, 17 and 21 years of age. Information on sociodemographic, behavioural and health factors, anthropometry and spirometry was collected. Early-life SEC were assessed using maternal education and paternal occupational position. The forced expiratory volume in the first second (FEV_1) growth trajectories were drawn considering sex-and-height interactions over an 8-year period. Our sample included 2022 participants with complete information for the relevant variables.
RESULTS: Participants from most disadvantaged SEC presented lower FEV_1 at early adolescence compared to high-SEC counterparts, but differences seem to diminish with height growth. The effect of paternal occupational position in lung function growth trajectories was moderated by height, thus individuals from fathers with less advantaged occupational position had lower FEV_1 at early adolescence, but they had a faster FEV_1 growth over time.
CONCLUSIONS: Individuals from most disadvantaged SEC presented lower lung function at early adolescence compared to high-SEC counterparts; nevertheless, a catch-up growth was observed.

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IMPACT:

- Lower socioeconomic circumstances were previously associated with reduced lung function and a higher risk of respiratory diseases in adults. Fewer studies analysed the effects of early-life socioeconomic circumstances in lung function growth during adolescence.
- Disadvantaged socioeconomic circumstances were associated with lower lung function in early adolescence. However, social differences diminished over adolescence, suggesting a catch-up growth of lung function among those from lower socioeconomic circumstances.
- An improved understanding of the mechanism underlying lung function catch-up (or the absence of catch-up) might support interventions to narrow social inequalities in respiratory health and should be further investigated.

INTRODUCTION

Lung function development and growth starts in uterus and continues through childhood and adolescence until early adulthood, when the maximal lung function is attained.[1,2] A low lung function in early adulthood is known to be associated with the development of several respiratory and non-respiratory diseases and is a long-term predictor of mortality.[3,4]

Previous studies showed that adults from the lowest socioeconomic groups are more likely to have poorer lung function, accelerated lung function decline over time and a higher risk of respiratory diseases.[5–7] However, it has been suggested that social inequalities in lung function might emerge already at early ages,[8] as children from lower socioeconomic circumstances (SEC) showed a reduced lung function in comparison with those from higher SEC.[8,9] And this evidence is consistent using different socioeconomic indicators, such as parental occupation, education and income.[8,9]

The period from adolescence to early adulthood has been considered a critical time for future respiratory health for several reasons. First, this is a period of rapid lung growth in which lungs are very susceptible to adverse influences, such as indoor and outdoor pollution, tobacco smoke, physical inactivity and poor nutrition, and all of these factors tend to be socially patterned.[7,10,11] In addition, it is becoming evident that inequalities in health are typically established early in life,[12] arising mostly from health-risk behaviours usually established from early

[1]EPIUnit, Instituto de Saúde Pública, Universidade do Porto, Porto, Portugal; [2]Departamento de Ciências da Saúde Pública e Forenses e Educação Médica, Faculdade de Medicina, Universidade do Porto, Porto, Portugal; [3]Centro Hospitalar Universitário do Porto, Porto, Portugal; [4]Institute of Social and Preventive Medicine, Lausanne University Hospital, Lausanne, Switzerland and [5]Population Epidemiology Unit, Primary Care Division, Geneva University Hospitals, Geneva, Switzerland
Correspondence: Sílvia Fraga (silvia.fraga@ispup.up.pt)
These authors jointly supervised this work: Silvia Stringhini, Sílvia Fraga.

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adolescence till adulthood. Nevertheless, few studies have focussed on social differences in lung function during adolescence and early adulthood, and most of the existing studies had cross-sectional designs and included small samples of adolescents and young adults.[13–15]

The association between socioeconomic status and lung function is also partially explained by height differences,[16,17] but height growth seems to be influenced by the social factors since early ages.[18,19] On the other hand, growth trajectories defined by weight and height are commonly used to describe growth and development, which are fundamental indicators of prenatal or childhood development.[20] Lung function growth trajectories may also provide fundamental indicators of prenatal or childhood development as well as an array of potential determinants of adult health outcomes. Specifically, by analysing patterns of lung function development over time will contribute to detect specific lung function trajectories with a higher risk of progression to respiratory disease in adulthood.[21] Thus, we hypothesised that adolescents from lower SEC might present less favourable lung function trajectories compared to those from high SEC, which therefore may compromise their wellbeing and contribute to the onset of adverse health outcomes later in life. An improved understanding of how early SEC impacts lung function growth over adolescence would contribute to provide evidence that may support public health policies and interventions to invest in respiratory health since early ages. Thus the current study aimed to investigate the association between early-life SEC and lung function growth from early adolescence until early adulthood using a Portuguese population-based cohort, the EPITeen study.

METHODS

Study design and sample

Data were collected as part of the EPITeen study—Epidemiological Health Investigation of Teenagers—in Porto aiming to understand how behaviours and habits acquired in adolescence will impact adult health. This is a population-based cohort that recruited adolescents born in 1990 enrolled at public and private schools of Porto, Portugal.[22,23] No exclusion criteria were predefined. The aim of this cohort was to understand how behaviours and habits acquired in adolescence will impact adult health. In the first wave, which occurred in 2003/2004 academic year when adolescents were 13 years of age, a total of 2786 eligible participants were identified and 2159 (77.5%) agreed to participate in the study. In the second wave (2007/2008) when participants were 17 years of age, 2499 adolescents were evaluated. Of these, 1716 participants recruited from wave 1 were re-evaluated while 783 new adolescents were enrolled in the cohort for the first time. The third wave occurred when participants were 21 years of age. While the first two waves took place at schools, in the third wave all participants were invited to visit our Department and a total of 1764 participants were re-evaluated.

In all the study waves, information was collected through self-administered questionnaires and face-to-face interviews, including sociodemographic characteristics, history of disease and behavioural factors. A physical examination comprising anthropometry and spirometry was also performed, using standardised procedures performed by a team of trained health professionals.

The present analysis includes 2022 participants with valid spirometry in at least two study waves and with complete information for all the relevant variables.

The included and excluded participants were not different considering anthropometry and health behaviours, but those excluded were more likely to have mothers of low education and fathers from most disadvantaged occupational position (Table S1, in supplementary material). In addition, the participants who entered the cohort at 17 years of age were not significantly different from those who were assessed at this age, considering their lung function and socioeconomic characteristics (i.e. maternal education and paternal occupational position). We compared the mean forced expiratory volume in the first second (FEV_1) at baseline between included vs. excluded participants within the socioeconomic groups (Table S2, in supplementary material) and no significant differences were observed.

This study was approved by the Ethics Committee of the Hospital S. João, the Ethics Committee of the Institute of Public Health and by the Portuguese data protection authority. Written informed consent was obtained from parents and adolescents at 13 and 17 years and from young adults at 21 years of age.

Early-life SEC

Early-life SEC were characterised using maternal education and paternal occupational position reported by parents. Maternal education was chosen because it is one of the most used social indicators to assess the impact of SEC on children and adolescents' lung health outcomes as it may reflect maternal care during childhood and adolescence.[8] Paternal occupational position has been considered an important indicator of both social standing and material resources.[24] It has implications on children health by ensuring health-care services access, namely, private medical care, and also participation in extra-school physical activity, with potential implications on lung health.[24,25] Maternal education was self-reported by the parents and was recorded as the number of completed years of formal schooling and classified into three categories according to the International Standard Classification of Education (ISCED): low, ≤6 years (ISCED 0–1); intermediate, 7–9 years (ISCED 2); and high, ≥10 years (ISCED 4–6), following usually Portuguese study cycles. The paternal occupational position was also self-reported by the parents, classified into major professional groups, according to the National Classification of Occupations—version 2010[26] and then grouped into three categories: less advantaged, intermediate, and more advantaged (detailed information are available in Text S1 in supplementary material). Thus individuals of parents with low education and less advantaged occupations were classified as belonging to "most disadvantage SEC" in comparison to those of parents with high education and more advantaged occupations classified as the high-SEC counterparts. Those individuals of parents with intermediate education and intermediate occupations were also compared to high-SEC counterparts, which is the reference category.

Lung function

Lung function was assessed with participants standing, using a nose clip and a disposable mouthpiece, following the American Thoracic Society/European Respiratory Society (ATS/ERS) guidelines. Since we assessed healthy adolescents, we performed all spirometry tests in standing position. A portable, battery-operated, ultrasound transit-time-based spirometer (Microlab 3500®) was used. Participants performed at least three forced expiratory manoeuvres and the highest technically satisfactory readings were analysed. The FEV_1 was recorded in litres. All spirometry tests were checked by a medical doctor specialised in respiratory problems, which followed the ATS and the ERS quality criteria.[27] The FEV_1 was chosen to characterise adolescents' lung function since it reflects airway flow obstruction and lung volume, while forced vital capacity (FVC) is more associated with only lung volume.[28] In addition, this indicator is the most widely reported index of respiratory function in children and adolescents and the best understood indicator in the medical literature.[2,8] As we found significant interactions of sex and height with early SEC, we opted to use absolute values of FEV_1 and FVC in our statistical models, since we would not be able to consider these interactions if we used the percentage predictive values. Nevertheless, to define lung function growth trajectories the main effects and the interaction effects considering sex and height were computed.

Covariates
Weight and height were obtained at each evaluation, with the participant in light indoor clothes and without shoes. Weight was measured in kilograms, to the nearest tenth, using a digital scale (Tanita®) and height was measured in centimetres, to the nearest tenth, using a portable stadiometer, according to standardised procedures. The length and weight at birth were reported by parents considering the registries made by health professionals on the child health book.

The presence of a medical diagnosis of allergy, asthma and rhinitis was self-reported by the parents at 13 and 17 years of age. Participants with asthma were not excluded, but as a sensitivity analysis we performed the same analysis with asthmatics excluded.

Physical activity at 13 and 17 years of age were classified according to the number of times per week that participants played sports beyond school activities. If they did not report at least 20 min of physical activity out of school, they were considered as physically inactive.

Smoking behaviour at 13 and 17 years of age was self-reported and classified into two categories: ever smokers, i.e. daily, occasional or past smokers, or no smokers. Participants' second-hand smoke exposure at 13 and 17 years of age was ascertained by asking participants if at least one of their parents is a smoker.

Statistical analysis
Participants' characteristics such as anthropometrics, behavioural factors and respiratory diseases were described as means and standard deviation (SD) and counts and proportions (%). Differences in these characteristics by SEC were evaluated using one-way analysis of variance and chi-square test, as appropriate.

To draw the FEV_1 growth trajectories, first we tested several models using different covariates, such as age, linear height, quadratic height and cubic height with the respective interactions (Table S3, in supplementary material). The relation between FEV_1 and the quadratic height was the most appropriate and showed the lower values of Bayesian Information Criterion and Akaike Information Criterion, representing the best goodness of fit in relation to the other tested models. Thus, if the quadratic term was positive, the velocity of FEV_1 growth increases with the increase of height; if negative, the velocity of FEV_1 growth decreases with the decrease of height; and if the quadratic term was zero, the velocity of FEV_1 growth does not increase or decrease with an increase or decrease in height. We choose to draw the FEV_1 growth trajectories by height instead of age, since lung function is strongly associated with height[29] and height showed to be socially patterned during the whole period of the study, as can be seen in Table S4 (supplementary material). Thus, while age represents the chronological evolution, height may be a better surrogate of the biological maturation and might be more relevant to study growth over time.[30] This was also confirmed by a previous study showing that adjustment of weight-for-height fits the data better than weight-for-age and that fractional polynomials perform better in comparison to conventional analyses.[31] Thus, height may be a better reflection of body stature and growth than age, which means that two adolescents with same age may have a very different height and therefore distinct lung function values.

Afterwards, we used a mixed-effects model with a random intercept to draw the FEV_1 trajectories by height and sex, for a mean period of eight (SD = 0.5) years. First, we computed the residuals' normality plots for final models of maternal education and paternal occupational position. Visual inspection of these plots confirmed the normality of residuals. Then we fitted a model in boys and girls separately using the equation described in Text S2 (in supplementary material), since their lung function growth showed to be different over time. The height variable was standardised for the mean average height from all measures in the cohort (height minus grand average of height).

To test the effect of socioeconomic indicators in FEV_1 growth trajectories, we computed mixed-effects models and the respective height interactions were expressed as beta-coefficients (B) and 95% confidence intervals (95% CIs). These results were computed for each 10 cm of height change and the dependent variable was FEV_1 growth by height, and the independent variables were maternal education and paternal occupational position. We tested three models: model 0 accounting for height and sex; model 1 included model 0 further adjusted for second-hand exposure to smoke and physical inactivity; and model 2 included model 1 further adjusted for asthma, allergy and rhinitis. As supplementary analysis, we computed lung function trajectories using FVC. We conducted a parallel analysis using the inverse probability weighting to ascertain the possible impact of the excluded participants on the robustness of the results. We also tested the association of behavioural factors and respiratory diseases with FEV_1, using linear regression analysis, expressed as B and 95% CI (Table S5, supplementary material). Then we tested the effect of socioeconomic indicators in FEV_1 growth trajectories without the respective height interactions (Table S6, supplementary material). Finally, to test whether the results were robust regardless of the socioeconomic indicators used, we also replicated the analyses using paternal education and maternal occupational position (Table S7, supplementary material). Analyses were performed using IBM SPSS 21.0 and R 2.14.1 ("nlme" package). The level of significance considered was $\alpha = 0.05$.

RESULTS

At early adolescence, girls and boys from mothers with low education showed significantly lower FEV_1 (girls: 2.9 vs. 3.0 l, $p = 0.011$; boys: 3.1 vs. 3.2 l, $p = 0.020$) compared with those from mothers with high education. Similar findings were found when using paternal occupational position. Also, girls and boys from less advantaged SEC presented a significantly lower height, a higher prevalence of physical inactivity and a lower prevalence of medically diagnosed rhinitis (Table 1).

Figures 1 and 2 depict the effects of maternal education and paternal occupational position in FEV_1 growth trajectories considering sex-and-height interactions. Both girls and boys from mothers with low education and fathers with less advantaged occupational position presented lower lung function at early adolescence but these differences diminish with the height growth.

Table 2 shows a quadratic effect between height and FEV_1, and this effect was moderated by sex. Boys showed a significantly higher FEV_1 of 0.14 l (95% CI: 0.09; 0.20) for the mean height when compared with girls, and this difference was even higher with the height growth over time (sex–height interaction = 0.28 l, 95% CI: 0.21; 0.32).

The effect of maternal education on FEV_1 was not moderated by height ($B = 0.05$, 95% CI: −0.00; 0.09 for intermediate education; $B = 0.00$, 95% CI: −0.05; 0.06 for low education; Table 2). Thus, individuals from mothers with intermediate education had a higher FEV_1 growth of 0.07 l (95% CI: 0.01; 0.13) than those from mothers with high education (Table S6, in supplementary material). In contrast, the effect of paternal occupational position in lung function growth trajectories was moderated by height ($B = 0.05$, 95% CI: 0.00; 0.10 for low paternal occupation position), supporting that, although participants from fathers with less advantaged occupational position had lower FEV_1 at early adolescence, they presented a faster FEV_1 growth over the period of adolescence (Table 2). These effects remained statistically significant after adjustment for second-hand exposure to smoke, physical inactivity, asthma, allergy and rhinitis medical diagnosis (models 1 and 2).

Table 1. Baseline characteristics of the participants by maternal education and paternal occupational position, among girls ($n = 2022$).

	Maternal education				Paternal occupational position			
	High	Intermediate	Low	p^a	More advantaged	Intermediate	Less advantaged	p^a
Girls (n = 1044)								
Baseline lung function								
FEV_1 (l), mean (SD)	2.95 (0.41)	2.96 (0.41)	2.86 (0.42)	0.011	2.97 (0.41)	2.89 (0.35)	2.89 (0.45)	0.029
Anthropometry, mean (SD)								
Birth length (cm)	49.41 (2.51)	48.92 (2.30)	48.83 (2.83)	0.013	49.32 (2.64)	49.07 (2.21)	48.88 (2.49)	0.140
Birth weight (kg)	3.31 (0.51)	3.27 (0.48)	3.26 (0.55)	0.524	3.31 (0.49)	3.27 (0.52)	3.27 (0.53)	0.662
Height (cm)	162.13 (5.65)	160.75 (6.34)	160.13 (6.06)	<0.001	162.29 (5.63)	160.60 (6.35)	160.48 (6.14)	<0.001
Weight (kg)	57.10 (8.54)	58.23 (10.53)	57.15 (9.56)	0.347	57.11 (8.48)	57.95 (9.88)	57.54 (10.22)	0.545
Behavioural factors, *n* (%)								
Ever smoking	213 (44.5)	91 (48.7)	164 (43.5)	0.495	202 (45.9)	90 (41.3)	126 (45.8)	0.491
Physical inactivity	114 (24.1)	45 (24.1)	156 (41.7)	<0.001	113 (26.0)	72 (33.3)	94 (34.3)	0.032
Second-hand smoke exposure[b]	242 (50.6)	73 (39.0)	133 (36.2)	<0.001	230 (52.5)	76 (35.2)	104 (38.1)	<0.001
Respiratory diseases, *n* (%)								
Asthma	57 (12.1)	21 (11.2)	44 (11.8)	0.958	52 (12.0)	26 (11.9)	34 (12.4)	0.983
Allergy	151 (31.9)	57 (30.5)	104 (27.8)	0.430	142 (32.7)	62 (28.4)	75 (27.4)	0.264
Rhinitis	80 (17.1)	22 (15.9)	36 (9.9)	0.010	74 (17.2)	22 (10.4)	32 (12.2)	0.036
Boys (n = 978)								
Baseline lung function								
FEV_1 (l), mean (SD)	3.23 (0.57)	3.14 (0.62)	3.10 (0.58)	0.020	3.24 (0.59)	3.20 (0.59)	3.10 (0.53)	0.050
Anthropometry, mean (SD)								
Birth length (cm)	50.11 (2.19)	49.88 (2.12)	49.61 (2.73)	0.053	50.16 (2.17)	49.84 (2.35)	49.85 (2.56)	0.230
Birth weight (kg)	3.42 (0.49)	3.41 (0.50)	3.42 (0.53)	0.986	3.44 (0.49)	3.40 (0.54)	3.45 (0.45)	0.642
Height (cm)	173.99 (6.30)	172.99 (6.70)	173.64 (6.12)	0.207	174.34 (6.45)	173.09 (6.51)	173.53 (6.00)	0.047
Weight (kg)	67.62 (10.73)	67.87 (12.59)	67.38 (11.00)	0.901	68.06 (11.31)	67.57 (11.34)	67.55 (11.15)	0.806
Behavioural factors, *n* (%)								
Ever smoking	214 (42.0)	65 (38.0)	135 (45.6)	0.270	191 (44.0)	88 (40.9)	87 (39.7)	0.529
Physical inactivity	50 (9.8)	28 (16.5)	49 (16.8)	0.006	41 (9.5)	27 (12.7)	31 (14.4)	0.151
Second-hand smoke exposure[b]	243 (48.2)	77 (45.6)	129 (44.5)	0.570	200 (46.6)	101 (47.2)	93 (43.7)	0.720
Respiratory diseases, *n* (%)								
Asthma	72 (14.3)	21 (12.4)	29 (10.2)	0.258	58 (13.5)	27 (12.7)	23 (10.7)	0.614
Allergy	141 (28.0)	39 (23.1)	52 (18.4)	0.009	114 (26.5)	56 (26.4)	45 (21.0)	0.281
Rhinitis	69 (14.0)	17 (10.4)	15 (5.3)	0.001	62 (14.8)	20 (9.8)	12 (5.6)	0.002

The EPIteen cohort study 2003–2013, Porto, Portugal.
[a]*p* value for one-way ANOVA in the case of mean (SD) and chi-square test for *n* (%).
[b]Second-hand exposure to smoke was computed using maternal or paternal smoking; percentages should be read in column.

Supplementary analysis

The results for FVC trajectories by SEC showed similar results to the ones using FEV_1 (Fig. S1 in supplementary material).

The inverse probability weighting yielded similar results to the ones presented in our main analyses (data not shown). In addition, the results were not substantively different when asthma patients were excluded from the calculations.

Table S5 (in supplementary material) shows the association of behavioural factors and respiratory diseases with lung function, stratified by sex. Physically inactive girls presented a lower FEV_1 of −0.06 l (−0.10; −0.01) than their physically active counterparts. In boys, those with a medical diagnosis of asthma or allergy showed a lower FEV_1 of −0.26 l (95% CI: −0.36; −0.17) and −0.11 l (95% CI: −0.18;−0.03), respectively, compared with healthy counterparts. Table S7 (in supplementary material) shows that results were similar if we use paternal education and maternal occupational position as the early-life socioeconomic indicators, which means that our results were robust regardless of the socioeconomic indicator used.

DISCUSSION

This study shows that individuals from most disadvantaged SEC present a lower lung function at early adolescence compared to high-SEC counterparts, nevertheless social differences seem to diminish during the growth period, mostly due to a height growth.

Height was shown to be associated with lung function,[32–34] in which taller individuals presented higher lung volumes.[35] This is due to the fact that larger lungs are associated with more respiratory bronchioles and wider airway diameters.[36] Moreover, higher lung function was found among boys compared with girls at the same height, and differences in lung function between boys and girls also increase with the height growth over time.[2,32,37]

We also observed that participants from low maternal education and less advantaged paternal occupational position showed shorter height at ages 13, 17 and 21 years, corroborating previous studies suggesting that height is socially patterned since childhood.[18,19] It is, therefore, plausible that part of the socioeconomic differences in lung function are explained by differences in height.[16,38] Nevertheless, we also found differences in

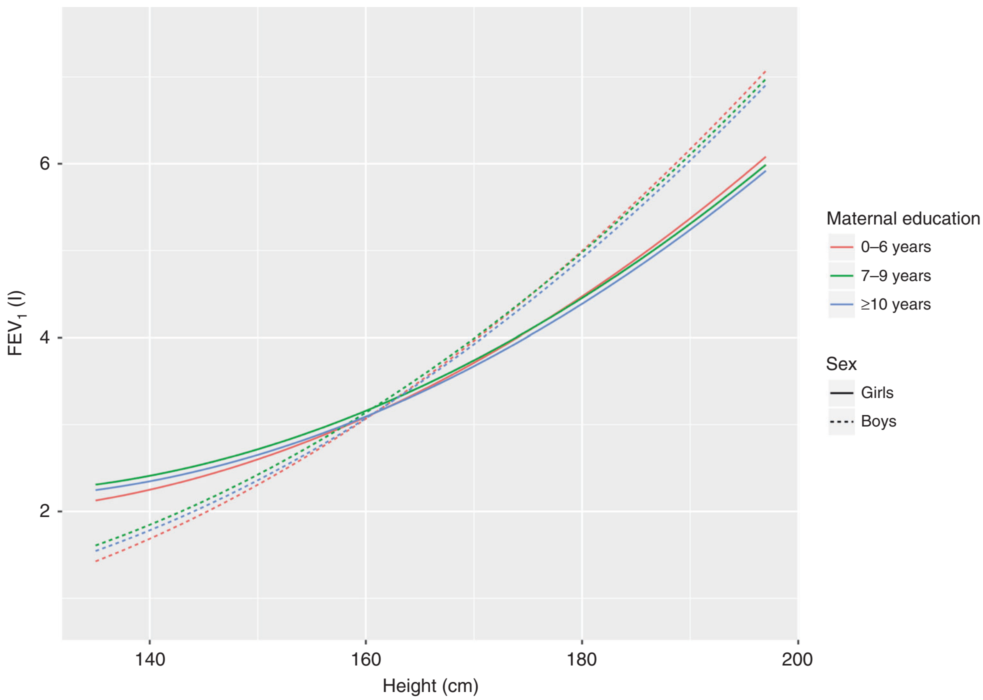

Fig. 1 The effect of maternal education in forced expiratory volume (FEV_1) growth trajectories, considering maternal education-height interaction, stratified by sex.

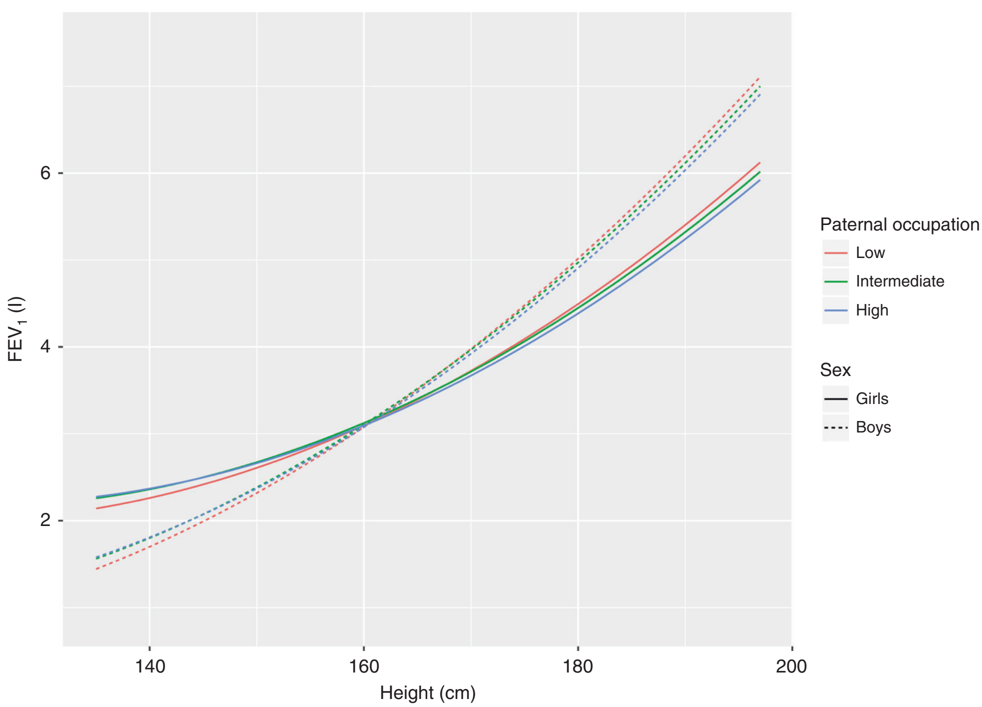

Fig. 2 The effect of paternal occupational position in forced expiratory volume (FEV_1) growth trajectories, considering paternal occupation-height interaction, stratified by sex.

lung function that were independent of height, meaning that height differences do not fully explain the lung function variability within the SEC groups.

A higher lung function among both girls and boys from fathers with more advantaged occupational position was also found, and this effect was moderated by the height growth. Although individuals from fathers with less advantaged occupational position presented lower lung function at early adolescence, they showed a faster increase of FEV_1 than those from fathers with more advantaged positions. This phenomenon of catch-up growth was previously observed for lung function in low-SEC individuals[39,40] and was described as a "release" from adversity, such as low SEC or maternal smoking, which may lead to an improved lung function later in life.[39] Prior studies hypothesised that the catch-up growth observed during childhood and adolescence might occur because the environmental factors

Table 2. Description of the effects of maternal education and paternal occupational position in FEV_1 growth trajectories from adolescence to early adulthood.

Maternal education	*B* (95% CI)	Paternal occupational position	*B* (95% CI)
Model 0		*Model 0*	
Sex (boys)	0.14 (0.09; 0.20)	Sex (boys)	0.14 (0.09; 0.20)
Height	0.59 (0.54; 0.64)	Height	0.59 (0.54; 0.64)
Height^2	0.09 (0.07; 0.11)	Height^2	0.07 (0.05; 0.09)
Education (high)	Ref.	Occupation (high)	Ref.
Education (intermediate)	0.07 (0.01; 0.13)	Occupation (intermediate)	0.04 (−0.02; 0.10)
Education (low)	0.02 (−0.04; 0.08)	Occupation (low)	0.03 (−0.03; 0.01)
Height × sex	0.28 (0.21; 0.34)	Height × sex	0.27 (0.22; 0.33)
Height × education (intermediate)	0.05 (−0.00; 0.09)	Height × occupation (intermediate)	0.02 (−0.03; 0.07)
Height × education (low)	0.00 (−0.05; 0.06)	Height × occupation (low)	0.05 (0.00; 0.10)
Model 1		*Model 1*	
Sex (boys)	0.14 (0.08; 0.20)	Sex (boys)	0.14 (0.08; 0.19)
Height	0.59 (0.54; 0.64)	Height	0.59 (0.54; 0.64)
Height^2	0.07 (0.05; 0.08)	Height^2	0.07 (0.05; 0.09)
Education (high)	Ref.	Occupation (high)	Ref.
Education (intermediate)	0.07 (0.00; 0.13)	Occupation (intermediate)	0.04 (−0.02; 0.10)
Education (low)	0.02 (−0.04; 0.08)	Occupation (low)	0.03 (−0.03; 0.09)
Height × sex	0.27 (0.22; 0.33)	Height × sex	0.27 (0.21; 0.32)
Height × education (intermediate)	0.00 (−0.05; 0.06)	Height × occupation (intermediate)	0.02 (−0.03; 0.07)
Height × education (low)	0.04 (−0.00; 0.09)	Height × occupation (low)	0.05 (0.00; 0.10)
Model 2		*Model 2*	
Sex (boys)	0.13 (0.08; 0.19)	Sex (boys)	0.14 (0.08; 0.20)
Height	0.59 (0.54; 0.64)	Height	0.59 (0.53; 0.64)
Height^2	0.07 (0.05; 0.09)	Height^2	0.07 (0.05; 0.09)
Education (high)	Ref.	Occupation (high)	Ref.
Education (intermediate)	0.07 (0.00; 0.13)	Occupation (intermediate)	0.04 (−0.02; 0.10)
Education (low)	0.02 (−0.03; 0.08)	Occupation (low)	0.04 (−0.02; 0.09)
Height × sex	0.27 (0.22; 0.32)	Height × sex	0.27 (0.22; 0.33)
Height × education (intermediate)	0.04 (−0.01; 0.09)	Height × occupation (intermediate)	0.02 (−0.03; 0.07)
Height × education (low)	−0.00 (−0.06; 0.05)	Height × occupation (low)	0.05 (0.00; 0.10)

The EPIteen cohort study 2003–2013, Porto, Portugal. Model 0: height and sex interaction adjusted; Model 1: Model 0 further adjusted for second-hand exposure to smoke and physical inactivity; Model 2: model 1 further adjusted for respiratory diseases (asthma, allergy, and rhinitis).
FEV_1 forced expiratory volume, *B (95% CI)* beta coefficient and 95% confidence interval, *Ref.* reference category.

limiting lung function growth early in life can change with time, for instance, by improvements in the living conditions and because the period of adolescence might be a window of opportunity for the catch-up growth to occur.[40–42] However, we cannot discard that the lung function differences narrowing on late adolescence may occur because adolescents from low SEC tend to be shorter and might have a late puberty, and therefore present a later catch-up growth. Indeed, previous studies have found that a later onset and steeper pubertal growth is associated with increased maximally attained lung volumes at later adolescence, by analysing longitudinal heights around the time of puberty.[41,43] A better understanding of the mechanism underlying the lung function catch-up (or the absence of catch-up) could be relevant to support interventions to narrow social inequalities in respiratory health. Yet, studies also reported that this catch-up growth at early ages might have negative implications in respiratory function during adulthood and older ages, such as a faster decline of lung function in later ages.[40–42] Therefore, further studies are needed to disentangle this mechanism.

This study also suggests that, unlike paternal occupation, maternal education influences lung function growth independently of height. We observed a significantly higher lung function growth among those of mothers with intermediate education, during the whole study period, but the lung growth in this group was quite close to that one found among individuals from the high education group at early adolescence. In fact, while the paternal occupational position might be a good indicator of the social networks and important material resources to access the health system and healthier lifestyles,[44] the maternal education seems to be more connected with the care for children and adolescents.[45,46] Literature suggested that maternal education may be highly correlated with children and adolescents health outcomes, showing that mothers with high education are more likely to promote healthier lifestyles, either by ensuring adequate nutritional intake, which influences lung growth, or by avoiding health risk factors (e.g. smoking during pregnancy or passive smoking, physical inactivity, among others)[47] with potential consequences in lung health.

As expected, the lung function differences found among the different socioeconomic groups are not clinically important at these ages, because our sample is constituted by healthy adolescents; however, these differences tend to increase with age and may be translated in later negative respiratory health consequences. Therefore, this study highlights that reducing social inequalities affecting lung function growth since early ages may have the potential to prevent future respiratory diseases.

Earlier studies have associated physical inactivity and second-hand exposure to smoke with a decreased lung growth and lower lung function from childhood to early adulthood,[48–51] but in our analysis, these factors did not contribute to explain the association between SEC and lung function. A possible justification might be the period of exposure that could not be enough for the effects to be established. Regarding physical inactivity, we found a higher prevalence in participants from low-SEC parents when compared with the high-SEC counterparts (Table 1), and physical inactivity was also associated with lower lung function especially among girls (Table S3, in supplementary material). Therefore, our findings emphasise the importance of promoting more active lifestyles since younger ages, mainly among adolescents from lower socioeconomic groups, as this period could be crucial to the establishment of healthy lifestyles with potential implications in short- and long-term lung function.[50,52] In addition, the diagnosis of respiratory diseases as asthma, allergy and rhinitis did not show any contribution to explaining the association between SEC and lung function. Nevertheless, we observed a higher prevalence of allergy and rhinitis among boys and girls from high-SEC parents, agreeing with previous literature.[53,54] First, this might suggest that high-SEC parents are more likely to attend health services and outpatient speciality care, leading to a higher prevalence of medical diagnosis; and second, it might illustrate the lower exposure to microbes and infections in children from more advantaged socioeconomic groups, which has been associated with an increase in the predisposition to respiratory conditions such as allergies and asthma, providing support for the hygiene hypothesis.[54,55] Nevertheless, these hypotheses deserve further investigation.

Strengths and limitations

The longitudinal perspective is the strong point of this investigation as it provides the lung function growth from early adolescence until early adulthood. We also used robust socioeconomic indicators, such as education and occupational position measured in both mothers and fathers. The use of spirometry in all the study waves is also an asset, as this pulmonary function test is one of the most used in population studies because it is simple, relatively inexpensive and quite informative.[27]

Some limitations should also be considered. The longitudinal design was associated with some differential losses of follow-up, mainly of individuals from parents from low SEC, which might have influenced our results. However, if we had included those participants, and following the trend found in this study, we could expect that the magnitude of association would be even larger. In addition, the collection of early life markers when adolescents were 13 years of age might have limited our results. Nevertheless, we do not expect major changes in the SEC from adolescents' birth until the 13 years of age because parents had completed the school before their children were born and most of them were already in the labour market. In addition, in Portugal between 1990 and 2003 the educational attainment had a strong influence on the occupational position held by parents, which might suggest some stability in the parents' SEC. The interpretation of pulmonary function test results requires considering age, sex, height and ethnic group; however, in our sample there is no ethnic variability to account for since almost all participants were Caucasian, therefore we did not expect that the social inequalities found in lung function were explained by ethnic differences. Additionally, in this analysis we were not able to fully account for second-hand exposure to smoke, since we only considered second-hand exposure to smoke through parents, nevertheless other environments that adolescents can attend, such as coffee shops and nightclubs among other places where their peers smoke, could also be a way of exposure to passive smoke. In addition, as second-hand exposure to smoke was measured based on the parents' smoking this could have led to some degree of misclassification. We believe that we are accounting for important factors that might influence the association between early-life SEC and lung function; however, there are other factors that may have a significant role in this association, for instance, nutrition and diet, exposure to pollution levels and maternal smoking during pregnancy that we were unable to include in our analysis. We also examined the contribution of other early factors to the association of SEC with lung function, namely, birth weight and birth length. In our analysis, birth weight did not contribute for this association but birth length was associated with the maternal education among girls. Nevertheless, as the direction of the association was the same as height we opted to adjust only for height to avoid over adjustment.

CONCLUSIONS

Our study shows that participants from most disadvantaged SEC presented a lower lung function at early adolescence compared to high-SEC counterparts; however, social differences seemed to diminish during the growth period, mostly due to height growth. A catch-up growth was also observed in low-SEC individuals, as they showed a faster increase of FEV_1. Nevertheless, the consequences of this catch-up growth in respiratory health over the life course need to be further investigated.

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AUTHOR CONTRIBUTIONS

V.R. performed the study conceptualisation, conducted data analysis and interpretation, and drafted the manuscript. M.S. conducted data analysis and interpretation and critically reviewed the manuscript. H.F. and E.R. contributed to data collection and critically reviewed the manuscript. S.S. and S.F. performed the study conceptualisation, contributed to data analysis and interpretation, and critically reviewed the manuscript for important intellectual content. All authors approved the final manuscript as submitted and agree to be accountable for all aspects of the work.

ADDITIONAL INFORMATION

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Ethics: This study was approved by the Ethics Committee of the Hospital S. João, the Ethics Committee of the Institute of Public Health and by the Portuguese data protection authority. Written informed consent was obtained from parents and adolescents at 13 and 17 years and from young adults at 21 years of age.

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