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Period and cohort effects: consequences on spirometric lung function in Norway during the 20th century

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Take home message: Both period and cohort effects were observed in the study of lung function in Norwegian subjects during the 20th century. FEV₁ and FVC increased during this time as a result of cohort effects.

Abstract

Background and Aim: Several factors can influence measured lung function over time. The aim of this study was to investigate period and cohort effects on spirometric measures in a large general population sample in Norway during the 20th century, using GLI-2012 equations as a reference.

Methods: 36,466 subjects (born 1894–1969) from four cross-sectional surveys conducted between 1965 and 1999 were included, with harmonized data on smoking habits, respiratory symptoms, lung diseases, education, and spirometry. Changes in FEV₁ and FVC z-scores in healthy subjects across surveys were explored to investigate period effects. Linear mixed-effects models of FEV₁ and FVC z-scores on birth cohort, with survey as random effect, were used to investigate cohort effects, both in subjects of the total population and in healthy ones.

Results: Relatively higher FEV₁ and FVC z-scores in healthy subjects were found in the first survey (1965–1970) compared to the more recent ones (1988–1999), suggesting period effects. FEV₁ and FVC z-scores increased significantly with birth cohort from 1894 to 1935, after adjustment for covariates. A more stable trend of FEV₁ and FVC z-scores with birth cohort was evidenced for subjects born more recently (1945–1969).

Conclusions: An increase of lung function with year of birth was observed in Norwegian subjects during the first half of the 20th century. The impact of period effects on lung function decreased from 1965 to 1999.

Introduction

The measurement of lung function is fundamental for the diagnosis and management of several respiratory diseases. Numerous studies have described trends in prevalence of chronic respiratory diseases worldwide and in Norway in different periods of time [1-6], but changes in lung function over the past century have not been fully elucidated.

Different factors may influence lung function across periods of time. These factors can be characterized as period and cohort effects. Period effects are changes dependent on the time of measurement and affect all ages and cohorts within that time of measurement simultaneously [7]. Cohort effects are changes related to different exposures that characterize populations from the same period of birth [7].

Improvements in spirometry methodology may contribute to the variability of lung function measured at different points in time as period effects. Temporal changes in smoking habits, nutrition, socio-economic status, and environmental exposures, on the other hand, may affect lung function as cohort effects.

Secular trends in spirometric data during the 20th century have been described previously in different populations [8-12], however most of the studies explored only cohort and not period effects.

The Norwegian Population Survey Initiative on Respiratory Health in Adults (NPSIR) is a project focusing on the study of chronic inflammatory respiratory diseases and their determinants in Norwegian adults [13]. In total, random population samples of about 178,000 subjects in the counties of Oslo, Hordaland and Rogaland were invited in seven cross-sectional surveys, conducted at different time points – the first was conducted in 1965.

We hypothesized that in the Norwegian population during the 20th century measures of lung function have changed both in relation to year of measurement (period effects) and year of

birth (cohort effects). We therefore aimed to investigate the presence of both changes in over 35,000 subjects born 1894–1969 participating in four surveys of NPSIR, using spirometric measures and Global Lung Function Initiative (GLI-2012) equations as reference.

Methods

Study population

The study population consists of pooled data from four cross-sectional surveys that are part of NPSIR: the Bergen Chronic Respiratory Disease Survey (BCRDS, 1965–1970), the Pneumoconiosis Survey of Western Norway (PSWON, 1988–1990), the Hordaland County Respiratory Health Survey (HCRHS, 1996–1997) and the Bronchodilatation Survey of the Hordaland Health Study (BD-HUSK, 1998–1999). The characteristics of the four surveys have previously been described in detail [13] and are summarized in supplementary Table S1. The study was approved by the Committee on Medical Research Ethics (2017/1679), The Norwegian Data Inspectorate (07/00414) and The Norwegian Directorate of Health (07/948).

Questionnaires

All surveys used standardized questionnaires including information on smoking habits, respiratory symptoms and lung diseases. The first survey used an interview questionnaire, while the following surveys used self-administered questionnaires. Smoking status was categorized as never, former or current. Smokers were defined as subjects smoking cigarettes, pipe, cigars or a combination of them. Pack-years were calculated as the number of packs of cigarettes smoked daily multiplied by years of smoking. For hand-rolled cigarettes the equivalence 1 g tobacco = 1 cigarette was used. The respiratory symptoms selected for the

analysis were: breathlessness walking uphill and/or climbing two flights of stairs, attacks of breathlessness, morning cough and chronic cough. Information regarding the presence of lung diseases (asthma, bronchitis, emphysema, chronic obstructive pulmonary disease) was also collected.

Education

Education data were retrieved from the registers of Statistics Norway, which provided the highest attained education for each decade for each subject based on national census data in 1970, 1980, 1990 and 2001 [14, 15]. Data were converted into number of years of education and grouped in three categories (compulsory education <11 years, medium level = 11–13 years, university level = 14–20+ years).

Lung function

Pre-bronchodilator spirometry with measurement of absolute values of Forced Expiratory Volume in the first second (FEV₁) and Forced Vital Capacity (FVC) was performed in all surveys. A Vitalograph wedge bellows dry spirometer (P-model or S-model) was used in BCRDS, PSWON and BD-HUSK, and a Gould 2100 mass flow anemometer was used in HCRHS. Spirometry was performed according to the guidelines valid at the time of the survey in PSWON (year 1988–1990), HCRHS (year 1996–1997) and BD-HUSK (year 1998–1999) [16, 17]. At the time of the first survey (BCRDS, year 1965–1970) no international recommendations were available, and the best results of two acceptable maneuvers were collected [18]. Measurements were recorded at body temperature and pressure saturated conditions (BTPS) in all surveys, except for BCRDS, where they were recorded at ambient temperature pressure saturated conditions (ATPS) and converted to BTPS by a correction

factor. Z-scores, a measure of how many standard deviations the value is from its predicted, were calculated for FEV₁ and FVC using GLI-2012 reference equations [19].

Harmonization

Individual-level data were harmonized across surveys. Subjects who participated in more than one survey were only included in their first survey. Missing values were <1% for smoking status and <2% for education and symptoms/lung diseases. All other variables were complete. Missing values were not imputed.

Healthy subgroup

A selected subgroup of healthy individuals was identified to further analyze lung function in subjects who are traditionally selected for the development of reference equations. Subjects were defined 'healthy' if satisfying the following criteria: never smokers, no obstructive lung diseases, no breathlessness walking uphill and/or climbing two flights of stairs, no attacks of breathlessness, no morning cough and no chronic cough.

Statistical analysis

Population characteristics were described using measures of central tendency or distribution, as appropriate. To investigate the presence of period effects we examined the distribution of mean FEV₁ and FVC z-scores in healthy subjects across surveys. Linear mixed-effects models of FEV₁ and FVC z-scores on year of birth were used to investigate the presence of cohort effects. Year of birth was categorized into ten-year birth cohorts in order to explore potential non-linear trends. Analyses were conducted stratified by sex. The following covariates were selected *a priori*: smoking status, pack-years, education, lung diseases and respiratory symptoms. Age and height were accounted for through the use of z-scores.

Survey was included as random intercept effect to account for potential differences in lung function among surveys due to period effects. The models were developed in the total population and results were presented for both subjects of the total population and healthy ones. In order to explore the potential contribution of height to the changes in lung function, we also developed models of height on birth cohort, adjusted for age, separately by sex. All analyses were conducted using Stata 17 (StataCorp LLC, Texas, USA).

Results

Characteristics of the study population

The participation rates of the original surveys were 84% for BCRDS, 68% for PSWON, 75% for HCRHS, and 69% for BDHUSK. The final dataset after harmonization of the four original cohorts consisted of 36,466 subjects (Table 1). 30,531 (84%) subjects were males, of which 26,092 originated from the PSWON survey. Males were on average younger than females (mean age 40.4 vs 52.3). The year of birth of participants ranged from 1894 to 1969, and the study period ranged from 1965 to 1999. Among males, the number of current smokers was very high in the first survey and declined markedly over time, while variation in female smoking habits were more modest. The percentage of subjects with medium- and high-level education increased over time in both sexes. The variability of lung function reflected population demographics, with higher values in younger subjects and in males compared to females. Depending on the survey, 26–47% of subjects reported at least one respiratory symptom and 5–27% presence of lung diseases, with higher values in the two more recent examinations (Table S2).

In total, 8,042 subjects (22% of the original population) met criteria for inclusion in the healthy subgroup (Table 2).

Lung function and different surveys: period effects

Figure 1 and Figure 2 illustrate the distribution of mean FEV₁ and FVC z-scores in healthy subjects across surveys. FEV₁ z-scores were close to zero in the three more recent surveys (1988–1999), but higher in the first one (1965–1970), especially in males, suggesting the presence of period effects. A similar trend was observed for FVC, though less evident.

Lung function and year of birth: cohort effects

FEV₁ and FVC z-scores increased with subsequent birth cohorts from 1894 to 1969, both in males and females, after adjustment for smoking habits, education, lung diseases and respiratory symptoms (Table 3 and 4). The pattern was however non-linear, with a marked increase for birth cohorts from 1894 to 1935, followed by a more stable trend thereafter (1945–1969).

Figure 3 and Figure 4 illustrate the estimated changes of FEV₁ and FVC z-scores with birth cohort in healthy subjects. Compared to predictions from the GLI-2012 equations, both males and females born approximately between 1894 and 1935 showed lower lung function values, with a rising trend over time. FEV₁ and FVC z-scores of subjects born after 1935 were instead higher than GLI-predicted, without major changes depending on year of birth.

Corresponding graphs for the total population showed relatively lower lung function values, but the overall pattern was very similar (Figure S1 and S2).

Figure S3 illustrates the estimated changes of height according to birth cohort in the total population, for 45-year-old males and females. Both sexes showed a significant increase in height, especially until 1945, reflecting quite closely the spirometric measures.

Discussion

We have found that during the 20th century, lung function in Norwegian general population samples increased with year of birth, both for males and females, after adjustment for several covariates. Our data also showed the presence of period effects in relation to the first survey included in our study, but not the more recent ones.

The presence of cohort effects in lung function has been reported previously. Xu et al. showed an increase in height-adjusted FEV₁ from older to younger birth cohorts in general population subjects born in the Netherlands between 1911 and 1949 [8]. Similarly, Glindmeyer et al. reported an increase in height-specific vital capacity (VC) in a literature review of studies published between 1846 and 1975 [9]. Lak et al. also found that Swedish 75-year-olds born in 1930 had higher peak expiratory flow (PEF) than 75-year-olds born 1901-1902, after adjustment for several confounders [10]. More recently, Allinson et al. showed a height-independent increase of FEV₁ and FVC with year of birth, analyzing data from ten cross-sectional European population-based studies of subjects born between 1884 and 1996 [11].

Our results agree in general with these observations, showing an increase in mean lung function in Norwegian subjects born between 1894 and 1969. The increase of FEV₁ and FVC was particularly evident for subjects born in the first part of the century, with only minor changes thereafter. The interpretation of these findings is, however, related to the reference equations used. Subjects born in the early 1900s are likely not very represented in the

recently developed GLI-2012 equations. It was therefore possible to observe cohort effects in this particular subgroup. On the contrary, the absence of major cohort effects for subjects born approximately after 1935, might in part reflect a better fit of our sample with the GLI population in terms of years of birth. As GLI-2012 equations are derived from collated data, the same age might correspond to different years of birth. Cohort effects, therefore, if present, might have been included in the resulting equations.

While we cannot exclude the presence of some cohort effects in subjects born after 1935, it is also possible that the increase in lung function has indeed slowed in more recent years. This has also been suggested previously [11], where the authors, despite estimating homogeneous lung function changes with year of birth, observed that the increase appeared smaller among more recent birth cohorts. Moreover, they suggested that the cohort effects evidenced could lead one to progressively underestimate normal European lung function measured with GLI-2012 equations. Our results would agree with an underestimation of normal lung function for Norwegian subjects born approximately after 1935, but would show uncertainty as to whether this is determined by persistent cohort effects.

The FEV₁ and FVC z-scores of healthy subjects born after 1935 in our sample are in line with a previous study investigating the fit of the GLI-2012 reference equations in the Norwegian population, showing slightly above-predicted values in Norwegian subjects, especially for females [20]. In that study, Norwegian adolescents showed better fit with GLI-2012 equations than adults. This might somewhat support the hypothesis of slowing cohort effects. As expected, FEV₁ and FVC z-scores in our study were lower when examining changes in the total population, but the general birth cohort pattern was substantially unchanged.

As height is an important determinant of lung function, its significant increase is likely to largely explain the rising trend of FEV₁ and FVC in our study. Smoking habits, education, prevalence of lung diseases and respiratory symptoms, also proved to be significant contributors in our models. Other factors were, however, unexplored in our data, such as changes in childhood infections, healthcare quality, occupational and environmental exposures or nutrition. Future studies should also take such variables into consideration.

The use of relative lung function values limited the possibility to optimally investigate the contribution of height to the changes in spirometric measures in our study. We have however separately explored the trends of height with birth cohort and observed that its increase closely reflected the increase in FEV₁ and FVC in the first part of the century. In more recent birth cohorts the trend of lung function was slightly more flattened than the trend of height. As previously mentioned, this likely reflects that in subjects born 1935–1969 the effect of height is mostly accounted for in the prediction equations. On the contrary, subjects born 1894–1935 are on average shorter, for a given age, than those included in the GLI population. This allowed a better visualization of the increase in lung function attributable to height in this category.

With regard to the factors explaining changes in physical characteristics of the Norwegian population during the 20th century, many of these are probably related to economic growth. As discussed by Bore [21], economic factors can affect height via access to nutrients, work intensity, and access to health services. Their study reported that between 1907 and 1977 the gross domestic product (GDP) per capita in Norway increased by nearly seven times [21]. The Norwegian state has gradually introduced universal healthcare, free education, sick leave payment, maternity and paternity leave along other welfare benefits. Numerous other changes

occurred in the Norwegian society over the course of the century, such as a rapid increase of the total population (from 2.2 million to about 4.5 million), general improvement in living conditions, transition from a predominantly agricultural to a predominantly industrial society, significant decline of mortality due to infections such as tuberculosis and dramatic reduction of infant mortality [22].

Our study examined data for subjects born until 1970, but several factors have changed since then. The average height of Norwegian military recruits has not increased much after 1975 [23]. In contrast, from 1973 to today rates of daily smoking in Norway have declined substantially, both for males and females [24]. We thus need new studies of subjects born more recently to see how lung function trends have evolved. Immigration has also increased in the last decades in Norway, particularly from Eastern Europe and Asia, with immigrants and Norwegian-born to immigrant parents constituting respectively 13.8% and 3% of the total population in 2017, while corresponding figures in 1997 were 4.5% and <1% [25]. The effect of multi-ethnicity on normal lung function in Norway should also be a topic of further research.

When considering the variability of FEV₁ and FVC between surveys, our results also suggest the presence of period effects. In case of perfect agreement with the selected reference equations, mean z-scores of a healthy sample should be 0, with SD 1 [26]. In our study, FEV₁ and FVC z-scores of healthy subjects had values close to zero in the three more recent surveys, but positive in the first one.

It is possible that our findings may be explained by the different spirometry quality criteria used in the different surveys. As increasingly stringent reproducibility criteria were applied

over the study time (no fixed criteria, ECCS 1983 [16] and ATS 1994 [17]), this might have resulted in a relative overestimation of values in our earliest survey where fewer measurements were excluded. The different measurement conditions (ATPS vs BTPS) of the first survey might represent another explanation, as well as differences in the models of spirometry equipment.

The participation rate of the various surveys (clinical examination) also declined over time, in line with literature reports [27]. This might also have contributed to the observed period effects. Finally, it is possible that some of the differences in lung function between surveys might also reflect cohort effects, i.e., the different distribution of years of birth in the various surveys might have determined a different degree of fit of the GLI-2012 equations.

Quanjer et al. investigated period effects in a collated dataset of over 40,000 white healthy subjects and found no significant correlation between year of measurement and FEV₁ or FVC z-scores [12]. The apparent contrast with our findings might be explained by the periods of time in which the studies were performed. The data of their study were collected between 1978 and 2009, while our study was slightly earlier (1965–1999). When considering only the latest examinations (1988–1999), our results also do not show significant period effects.

Quanjer et al. also explored the z-scores distribution of 30 different centers, while our population was more homogeneous. It is possible that certain minor trends in their study might have been obscured by the heterogeneity of the populations.

Period effects were also explored in some previous studies with inconsistent conclusions [8, 28-31]. While one study showed an increase in FEV₁ in subsequent survey periods from 1965 to 1990 [8], others reported changes in lung function between surveys more similar to our

findings [28-31]. All these studies were, however, performed on longitudinal data, which limits the comparability with our results.

The interpretation of lung function measurements in clinical practice relies on comparison with reference values derived from samples of healthy individuals. Several studies have explored them in Norway in the past [32-34]. Recently, multi-ethnic all-age reference equations have been developed, with the aim to allow more generalizable predictions across populations and promote the standardization of the interpretation of lung function tests worldwide [19]. Period and cohort effects might affect reference standards, especially if reference populations are built over a large period of time. This might result in increased variation that should be considered when interpreting lung function results. Equations should be periodically reviewed and updated to minimize the impact of secular trends.

Our study has several strengths. We have examined both period and cohort effects in a large number of individuals that were randomly selected from the general population, with a very wide range in years of examination and years of birth. The geographical area of our study population was well-defined. Our analyses were adjusted for a large number of covariates and also performed in a healthy sub-sample. All the surveys were initiated and conducted by investigators affiliated with the same institution, which ensured uniformity in data collection and management.

Our study has also several limitations. First, we estimated period and cohort effects only as relative lung function changes, and not absolute ones. We explored the study of cohort effects in terms of absolute lung function, but the collinearity between age and year of birth in our models precluded accurate estimates. Age-period-cohort analysis might have represented an

alternative methodological solution, but this approach was not suitable given the non-continuous nature of our period data. Second, the different spirometry methodologies adopted in the surveys represent a limitation for the analysis of cohort effects, which however could not have been avoided given the nature of the study. The differences in lung function attributable to period effects were, however, accounted for in the cohort effects analysis by including survey as a random (intercept) effect. This also explains the apparently contradictory finding for which period and cohort effects differ in direction. Third, while we adjusted our cohort effects models for period effects, our period effects analysis was only descriptive and not adjusted for cohort ones. Fourth, the harmonization of qualitative variables, e.g., subjectively reported respiratory symptoms and lung diseases, was sub-optimal due to a sometimes imperfect correspondence between the questionnaire items in the various surveys. Finally, we lacked detailed information regarding occupational exposures and possibly other confounders.

Another issue that deserves to be mentioned is that the number of males in the study was higher than females. All analyses were performed in strata by sex, in order to address this limitation. The close agreement in both period and cohort effects between males and females, in our opinion suggests that the findings are robust and not influenced by the size of the populations. Additionally, the distribution in terms of birth cohorts of the male population was not homogeneous, due to the majority of the subjects originating from a single large survey. We have considered the possibility that this might have affected the cohort effects results. We believe that the similarity of the pattern with females, which instead had a more homogeneous birth cohort distribution, reasonably excludes this possibility.

With regard to the periods of data collection, the years of measurement of the study presented a gap between 1970 and 1988. This did not allow us to investigate with continuity the impact of period effects from 1965 to 1999 (i.e. to explore whether the changes in lung function after the first survey were more or less gradual). Despite the gap in data collection, years of birth were continuously represented from 1894 to 1969, both for males and females. We therefore do not think that the cohort effects conclusions are affected by the non-continuous data collection.

Although the participation rate of the surveys can be considered quite high, as in any survey there is a risk of non-participation bias. Moreover, the geographical area of our study was limited to Western Norway. A previous study has shown however only minor differences between spirometric values of healthy reference samples collected in different areas of Norway, one of which is included in the population of this study [20]. This indirectly supports a certain generalizability of the findings. Nonetheless, validation studies would be very important.

In conclusion, our study showed that FEV₁ and FVC have increased in Norwegian males and females in the first half of the 20th century, as a result of cohort effects. Period effects seemed to have decreased from 1965 to 1999, likely reflecting more comparable methodology. Future studies in more recent generations would be useful to determine if secular trends in lung function persist.

Conflicts of interest

L. Cestelli has nothing to disclose. A. Johannessen has nothing to disclose. K. Stavem reports fees from UCB Pharma and MSD, outside the submitted work. A. Gulsvik has nothing to disclose. R. Nielsen reports funding from AstraZeneca, outside the submitted work.

TABLE 1. Characteristics and spirometry values of participants in the study population, stratified by sex and by survey.

	BCRDS	PSWON	HCRHS	BD-HUSK	Total
Survey years	1965–1970	1988–1990	1996–1997	1998–1999	1965–1999
Birth years	1894–1943	1944–1958	1914–1969	1925–1951*	1894–1969
No. of subjects	5616	26092	1993	2765	36466
Males	2524 (45)	26092 (100)	814 (41)	1101 (40)	30531 (84)
Age, years	47.3 (13.9)	38.2 (4.3)	50.5 (16.0)	68.3 (9.3)	40.4 (9.0)
Height, cm	174.6 (6.6)	178.8 (6.3)	177.5 (6.9)	175.7 (6.6)	178.3 (6.5)
Smoking status					
No smoker	392 (16)	8133 (31)	267 (33)	247 (23)	9039 (30)
Ex-smoker	461 (18)	6395 (25)	274 (34)	640 (59)	7770 (26)
Current smoker	1671 (66)	11488 (44)	273 (34)	206 (19)	13638 (45)
Pack-years	13.8 (13.8)	16.1 (9.4)	17.4 (14.7)	20.9 (18.1)	16.1 (10.6)
Education					
< 11 years	982 (41)	3476 (14)	158 (20)	229 (21)	4845 (16)
11-13 years	1110 (47)	15450 (60)	459 (57)	550 (50)	17569 (59)
14-20+ years	292 (12)	6785 (26)	189 (23)	311 (29)	7577 (25)
FEV ₁ , L	3.88 (1.05)	4.28 (0.62)	3.68 (0.95)	2.90 (0.74)	4.18 (0.74)
FEV ₁ , z-score	0.08 (1.34)	-0.08 (0.96)	-0.37 (1.10)	-0.55 (1.10)	-0.09 (1.02)
FVC, L	4.90 (1.12)	5.40 (0.76)	4.73 (1.06)	3.87 (0.82)	5.29 (0.87)
FVC, z-score	0.13 (1.14)	0.04 (0.90)	-0.26 (0.95)	-0.52 (0.97)	0.02 (0.93)
Females	3092 (55)	-	1179 (59)	1664 (60)	5935 (16)
Age, years	48.3 (14.0)	-	50.6 (15.0)	60.8 (12.2)	52.3 (14.8)
Height, cm	161.2 (6.0)	-	164.7 (6.2)	163.3 (6.3)	162.5 (6.3)
Smoking status					
No smoker	1925 (62)	-	533 (45)	782 (48)	3240 (55)
Ex-smoker	144 (5)	-	274 (23)	454 (28)	872 (15)
Current smoker	1023 (33)	-	372 (32)	396 (24)	1791 (30)
Pack-years	6.6 (6.2)	-	11.9 (10.1)	13.3 (11.0)	9.9 (9.4)
Education					
< 11 years	1717 (58)	-	264 (23)	438 (27)	2419 (42)
11-13 years	1062 (36)	-	649 (56)	862 (53)	2573 (44)
14-20+ years	198 (7)	-	253 (22)	339 (21)	790 (14)
FEV ₁ , L	2.78 (0.73)	-	2.74 (0.67)	2.36 (0.60)	2.66 (0.71)
FEV ₁ , z-score	0.10 (1.29)	-	-0.20 (1.04)	-0.37 (1.06)	-0.09 (1.20)
FVC, L	3.38 (0.79)	-	3.43 (0.76)	3.00 (0.69)	3.28 (0.78)
FVC, z-score	-0.02 (1.13)	-	-0.16 (0.93)	-0.38 (0.92)	-0.15 (1.05)

Variables are presented as mean (SD) or number (%) as appropriate.

BCRDS= Bergen Chronic Respiratory Disease Survey, PSWON= Pneumoconiosis Survey of Western Norway, HCRHS= Hordaland County Respiratory Health Survey, BD-HUSK= Bronchodilatation Survey of the Hordaland Health Study, FEV₁= Forced Expiratory Volume in the first second, FVC= Forced Vital Capacity. Z-scores calculated according to GLI-2012 equations. * Two birth cohorts: 1925–1927 and 1950–1951.

TABLE 2. Characteristics and spirometry values of participants in the healthy subgroup, stratified by sex and by survey.

	BCRDS	PSWON	HCRHS	BD-HUSK	Total
Survey years	1965–1970	1988–1990	1996–1997	1998–1999	1965–1999
Birth years	1894–1943	1944–1958	1914–1969	1925–1951*	1894–1969
No. of subjects [†]	1438 (26)	5674 (22)	409 (21)	521 (19)	8042 (22)
Males	328 (23)	5674 (100)	154 (38)	136 (26)	6292 (78)
Age, years	40.8 (14.4)	37.8 (4.4)	44.8 (14.9)	64.5 (11.5)	38.7 (7.3)
Height, cm	175.5 (6.6)	179.3 (6.3)	179.4 (6.8)	176.5 (6.5)	179.0 (6.4)
Education					
< 11 years	81 (26)	405 (7)	11 (7)	16 (12)	513 (8)
11-13 years	149 (47)	2922 (52)	77 (50)	60 (44)	3208 (52)
14-20+ years	87 (27)	2277 (41)	65 (42)	59 (44)	2488 (40)
FEV ₁ , L	4.43 (0.92)	4.42 (0.59)	4.14 (0.77)	3.38 (0.61)	4.39 (0.64)
FEV ₁ , z-score	0.71 (1.11)	0.11 (0.92)	-0.01 (0.88)	0.06 (0.91)	0.14 (0.94)
FVC, L	5.35 (1.04)	5.50 (0.76)	5.18 (0.94)	4.32 (0.77)	5.46 (0.80)
FVC, z-score	0.48 (1.00)	0.12 (0.89)	-0.03 (0.81)	-0.09 (0.84)	0.13 (0.90)
Females	1110 (77)	-	255 (62)	385 (74)	1750 (22)
Age, years	47.6 (14.1)	-	50.7 (15.2)	61.7 (12.3)	51.1 (15.0)
Height, cm	161.5 (6.1)	-	164.8 (6.2)	163.0 (6.3)	162.3 (6.3)
Education					
< 11 years	559 (52)	-	48 (19)	89 (23)	696 (41)
11-13 years	420 (39)	-	118 (47)	194 (51)	732 (43)
14-20+ years	101 (9)	-	86 (34)	98 (26)	285 (17)
FEV ₁ , L	2.91 (0.68)	-	2.87 (0.64)	2.47 (0.55)	2.81 (0.67)
FEV ₁ , z-score	0.39 (1.16)	-	0.14 (0.90)	0.01 (0.91)	0.27 (1.09)
FVC, L	3.50 (0.73)	-	3.55 (0.76)	3.09 (0.65)	3.42 (0.74)
FVC, z-score	0.19 (1.03)	-	0.10 (0.84)	-0.11 (0.83)	0.11 (0.97)

Variables are presented as mean (SD) or number (%) as appropriate.

BCRDS= Bergen Chronic Respiratory Disease Survey, PSWON= Pneumoconiosis Survey of Western Norway, HCRHS= Hordaland County Respiratory Health Survey, BD-HUSK= Bronchodilatation Survey of the Hordaland Health Study, FEV₁= Forced Expiratory Volume in the first second, FVC= Forced Vital Capacity.

Z-scores calculated according to GLI-2012 equations.

* Two birth cohorts: 1925–1927 and 1950–1951. [†] Percentage refers to the original population.

TABLE 3. Estimated changes of FEV₁ z-scores with birth cohort in the total population.

Birth cohort	Males				Females			
	n	Coef.	C.I.	p-value	n	Coef.	C.I.	p-value
1894–1904	469	-	-	-	640	-	-	-
1905–1914	517	-0.05	(-0.18, 0.08)	0.440	720	0.19	(0.06, 0.31)	<0.001
1915–1924	674	0.19	(0.07, 0.31)	<0.001	790	0.31	(0.19, 0.43)	<0.001
1925–1934	1,552	0.51	(0.39, 0.63)	<0.001	1,580	0.61	(0.49, 0.74)	<0.001
1935–1944	2,125	0.74	(0.61, 0.86)	<0.001	720	0.66	(0.53, 0.79)	<0.001
1945–1954	17,838	0.66	(0.54, 0.79)	<0.001	1,095	0.57	(0.42, 0.73)	<0.001
1955–1964	7,223	0.59	(0.46, 0.72)	<0.001	250	0.48	(0.28, 0.68)	<0.001
1965–1969	133	0.59	(0.37, 0.80)	<0.001	140	0.55	(0.32, 0.79)	<0.001

Linear mixed-effect models with random effects at the survey level, adjusted for smoking status, pack-years, education, lung diseases and respiratory symptoms. Birth cohort reference category= 1894–1904. Z-scores calculated according to GLI-2012 equations. C.I. 95%.

TABLE 4. Estimated changes of FVC z-scores with birth cohort in the total population.

Birth cohort	Males				Females			
	n	Coef.	C.I.	p-value	n	Coef.	C.I.	p-value
1894–1904	469	-	-	-	640	-	-	-
1905–1914	517	0.00	(-0.12, 0.12)	0.990	720	0.13	(0.02, 0.24)	0.020
1915–1924	674	0.14	(0.03, 0.26)	0.010	790	0.28	(0.18, 0.39)	< 0.001
1925–1934	1,552	0.43	(0.32, 0.54)	< 0.001	1,580	0.54	(0.43, 0.66)	< 0.001
1935–1944	2,125	0.61	(0.50, 0.73)	< 0.001	720	0.53	(0.41, 0.65)	< 0.001
1945–1954	17,838	0.60	(0.48, 0.72)	< 0.001	1,095	0.50	(0.36, 0.64)	< 0.001
1955–1964	7,223	0.61	(0.49, 0.73)	< 0.001	250	0.50	(0.32, 0.68)	< 0.001
1965–1969	133	0.70	(0.50, 0.90)	< 0.001	140	0.64	(0.43, 0.85)	< 0.001

Linear mixed-effect models with random effects at the survey level, adjusted for smoking status, pack-years, education, lung diseases and respiratory symptoms. Birth cohort reference category= 1894–1904. Z-scores calculated according to GLI-2012 equations. C.I. 95%.

References

1. Soriano JB, Kendrick PJ, Paulson KR, et al. Prevalence and attributable health burden of chronic respiratory diseases, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017. *The Lancet Respiratory Medicine* 2020; 8(6): 585-596.
2. Janson C, Johannessen A, Franklin K, et al. Change in the prevalence asthma, rhinitis and respiratory symptom over a 20 year period: associations to year of birth, life style and sleep related symptoms. *BMC Pulm Med* 2018; 18(1): 152.
3. West EA, Strassmann A, Wang C, et al. Increase in Airway Obstruction between 1993 and 2012 in Switzerland. An Observational Study. *Ann Am Thorac Soc* 2020; 17(4): 457-465.
4. Gulsvik A. Prevalence and manifestations of obstructive lung disease in the city of Oslo. *Scand J Respir Dis* 1979; 60(5): 286-296.
5. Bakke PS, Baste V, Hanao R, et al. Prevalence of obstructive lung disease in a general population: relation to occupational title and exposure to some airborne agents. *Thorax* 1991; 46(12): 863-870.
6. Waatevik M, Skorge TD, Omenaas E, et al. Increased prevalence of chronic obstructive pulmonary disease in a general population. *Respir Med* 2013; 107(7): 1037-1045.
7. Blanchard RD, Bunker JB, Wachs M. Distinguishing aging, period and cohort effects in longitudinal studies of elderly populations. *Socio-Economic Planning Sciences* 1977; 11(3): 137-146.
8. Xu X, Laird N, Dockery DW, et al. Age, period, and cohort effects on pulmonary function in a 24-year longitudinal study. *Am J Epidemiol* 1995; 141(6): 554-566.

9. Glindmeyer HW, Diem JE, Jones RN, et al. Noncomparability of longitudinally and cross-sectionally determined annual change in spirometry. *Am Rev Respir Dis* 1982; 125(5): 544-548.
10. Lak VW, Skoog I, Guo X. Secular trends in lung function and its relation to survival in Swedish 75 year olds 1976-2006. *Age Ageing* 2012; 41(6): 735-740.
11. Allinson JP, Afzal S, Colak Y, et al. Changes in lung function in European adults born between 1884 and 1996 and implications for the diagnosis of lung disease: a cross-sectional analysis of ten population-based studies. *Lancet Respir Med* 2022; 10(1): 83-94.
12. Quanjer PH, Stocks J, Cole TJ, et al. Influence of secular trends and sample size on reference equations for lung function tests. *Eur Respir J* 2011; 37(3): 658-664.
13. Gulsvik A, Humerfelt S, Bakke PS, et al. Norwegian population surveys on respiratory health in adults: objectives, design, methods, quality controls and response rates. *Clin Respir J* 2008; 2 Suppl 1: 10-25.
14. The Norwegian Historical Data Centre. Documenting the Norwegian Census. [cited May 2022]; Available from: <https://rhd.uit.no/nhdc/census.html#modern>
15. Statistisk sentralbyrå - Statistics Norway. Norske folketellinger. [cited May 2022]; Available from: <https://www.ssb.no/a/folketellinger/>
16. Standardized lung function testing. Report working party. *Bull Eur Physiopathol Respir* 1983; 19 Suppl 5: 1-95.
17. ATS. Standardization of Spirometry, 1994 Update. American Thoracic Society. *Am J Respir Crit Care Med* 1995; 152(3): 1107-1136.
18. Rose GA, Blackburn H. Cardiovascular survey methods. *Monogr Ser World Health Organ* 1968; 56: 1-188.

19. Quanjer PH, Stanojevic S, Cole TJ, et al. Multi-ethnic reference values for spirometry for the 3-95-yr age range: the global lung function 2012 equations. *Eur Respir J* 2012; 40(6): 1324-1343.
20. Langhammer A, Johannessen A, Holmen TL, et al. Global Lung Function Initiative 2012 reference equations for spirometry in the Norwegian population. *Eur Respir J* 2016; 48(6): 1602-1611.
21. Bore RR. Norske rekrutter har skutt i været. i *På liv og død, Statistiske analyser, Statistisk sentralbyrå* 2007; 94: 136-152.
22. Nordhagen R, Grøholt EK, Irgens L, et al. Folkehelse i Norge 1814–2014. *Folkehelse rapporten 2014* 2014; 4: 16-26.
23. Statistisk sentralbyrå - Statistics Norway. Vernepliktige etter høyde. Table 4.22. [cited May 2022]; Available from: <https://www.ssb.no/a/histstat/tabeller/4-22.html>
24. FHI - Norwegian Institute of Public Health. Utbredelse av røyking i Norge. [cited May 2022]; Available from: <https://www.fhi.no/nettpub/tobakkinorge/bruk-av-tobakk/utbredelse-av-royking-i-norge/>
25. Sandnes T. Innvandrere i Norge 2017. Statistisk sentralbyrå, 2017.
26. Quanjer PH, Stanojevic S. Do the Global Lung Function Initiative 2012 equations fit my population? *Eur Respir J* 2016; 48(6): 1782-1785.
27. Galea S, Tracy M. Participation rates in epidemiologic studies. *Ann Epidemiol* 2007; 17(9): 643-653.
28. Burrows B, Lebowitz MD, Camilli AE, et al. Longitudinal changes in forced expiratory volume in one second in adults. Methodologic considerations and findings in healthy nonsmokers. *Am Rev Respir Dis* 1986; 133(6): 974-980.
29. Ware JH, Dockery DW, Louis TA, et al. Longitudinal and cross-sectional estimates of pulmonary function decline in never-smoking adults. *Am J Epidemiol* 1990; 132(4): 685-700.

30. Sherrill D, Lebowitz M, Knudson R, et al. Continuous longitudinal regression equations for pulmonary function measures. *European Respiratory Journal* 1992; 5(4): 452-462.
31. Lebowitz MD. Age, period, and cohort effects. Influences on differences between cross-sectional and longitudinal pulmonary function results. *Am J Respir Crit Care Med* 1996; 154(6 Pt 2): S273-277.
32. Gulsvik A, Tosteson T, Bakke P, et al. Expiratory and inspiratory forced vital capacity and one-second forced volume in asymptomatic never-smokers in Norway. *Clin Physiol* 2001; 21(6): 648-660.
33. Langhammer A, Johnsen R, Gulsvik A, et al. Forced spirometry reference values for Norwegian adults: the Bronchial Obstruction in Nord-Trøndelag study. *European Respiratory Journal* 2001; 18(5): 770-779.
34. Johannessen A, Lehmann S, Omenaas ER, et al. Post-bronchodilator spirometry reference values in adults and implications for disease management. *Am J Respir Crit Care Med* 2006; 173(12): 1316-1325.

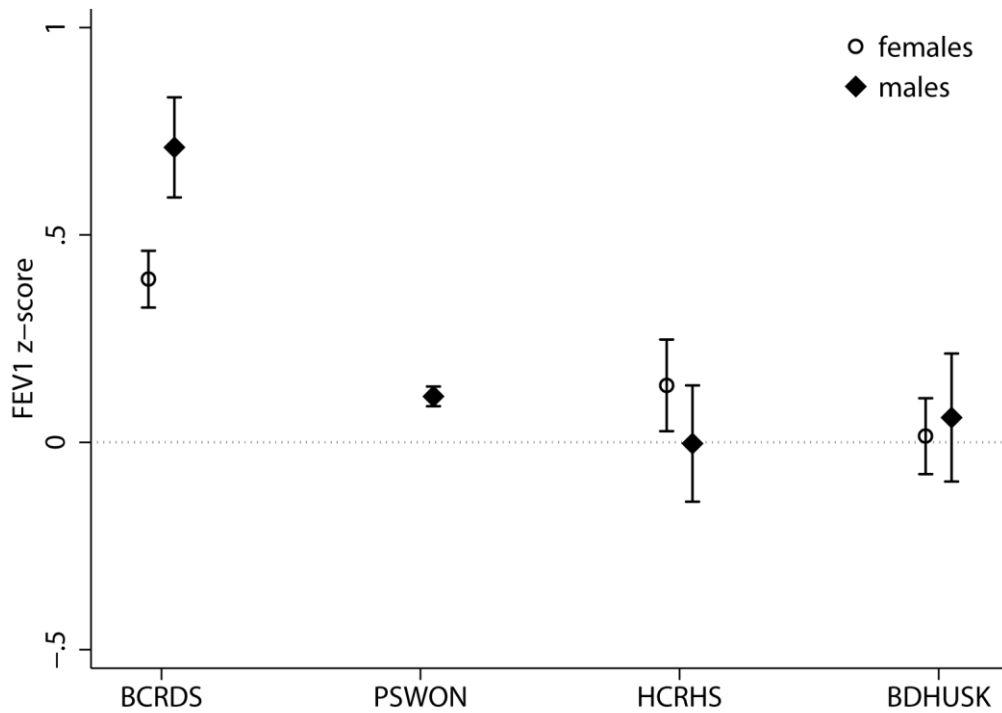


FIGURE 1. Mean FEV1 z-scores of healthy subjects in surveys conducted in different periods of time. Zscores calculated according to GLI-2012 equations. C.I. 95%.

BCRDS= Bergen Chronic Respiratory Disease Survey (1965–1970), PSWON= Pneumoconiosis Survey of Western Norway (1988–1990), HCRHS= Hordaland County Respiratory Health Survey (1996–1997), BDHUSK=Bronchodilatation Survey of the Hordaland Health Study (1998–1999).

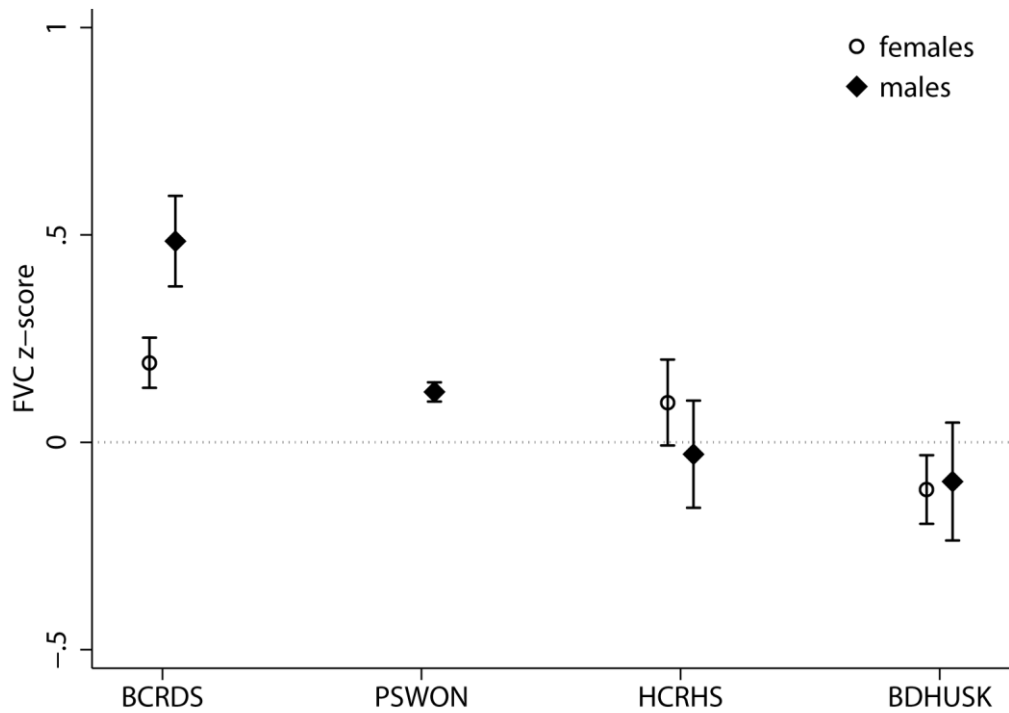


FIGURE 2. Mean FVC z-scores of healthy subjects in surveys conducted in different periods of time. Zscores calculated according to GLI-2012 equations. C.I. 95%.

BCRDS= Bergen Chronic Respiratory Disease Survey (1965–1970), PSWON= Pneumoconiosis Survey of Western Norway (1988–1990), HCRHS= Hordaland County Respiratory Health Survey (1996–1997), BDHUSK=Bronchodilatation Survey of the Hordaland Health Study (1998–1999).

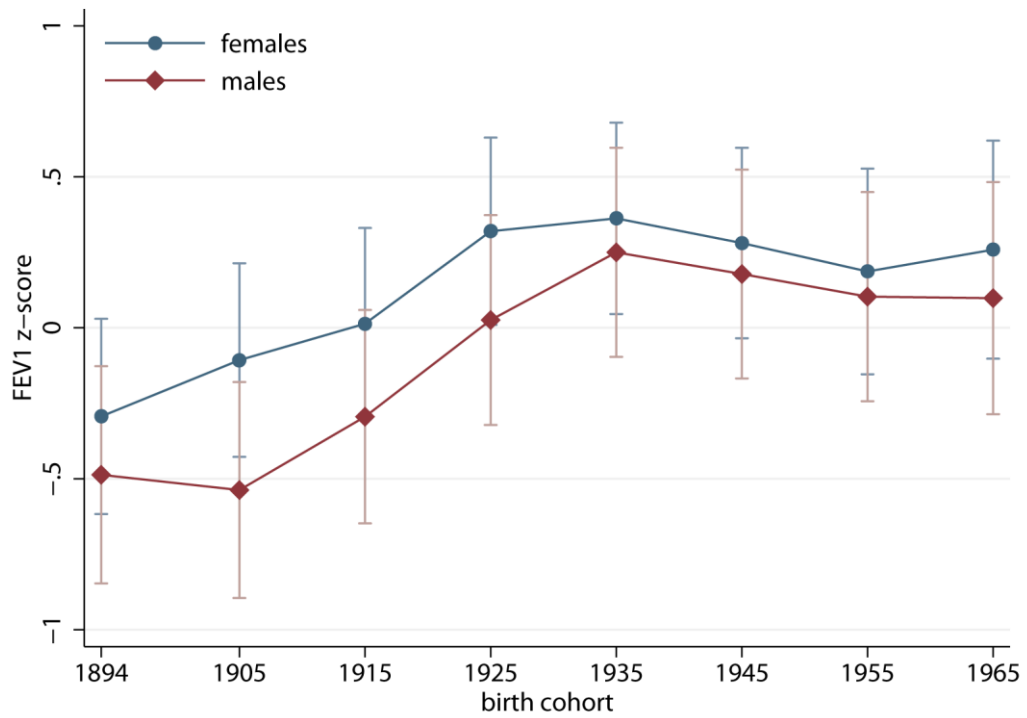


FIGURE 3. Adjusted predictions of FEV1 z-scores according to birth cohort, for subjects without a history of smoking, lung diseases and respiratory symptoms. Z-scores calculated according to GLI-2012 equations. C.I. 95%.

Birth cohorts: 1894–1904, 1905–1914, 1915–1924, 1925–1934, 1935–1944, 1945–1954, 1955–1964, 1965–1969.

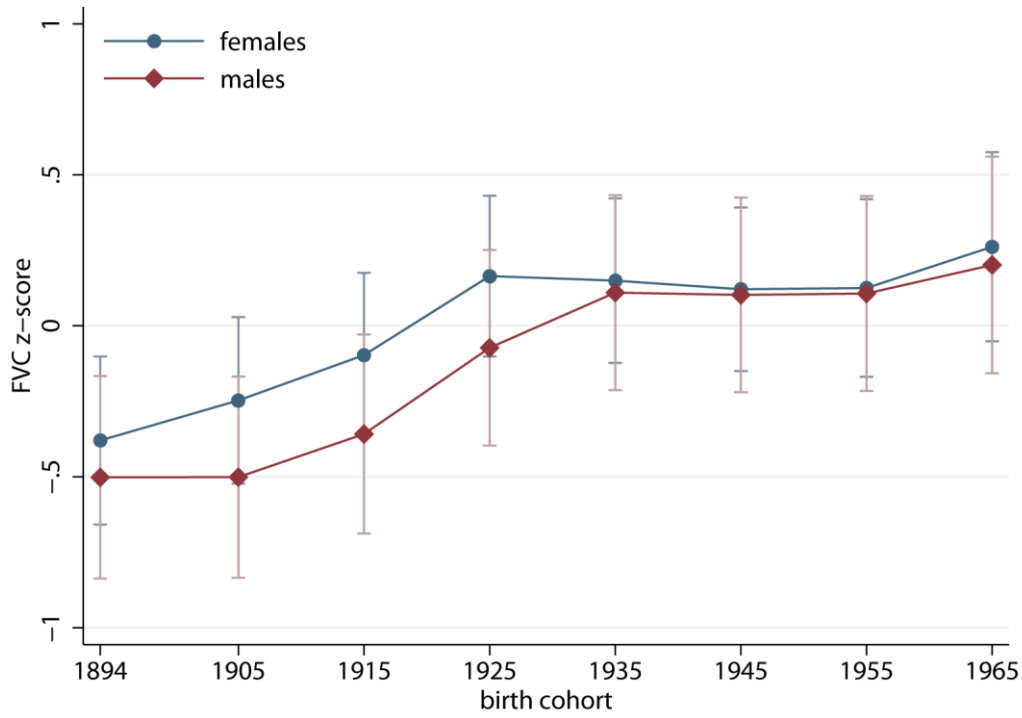


FIGURE 4. Adjusted predictions of FVC z-scores according to birth cohort, for subjects without a history of smoking, lung diseases and respiratory symptoms. Z-scores calculated according to GLI-2012 equations. C.I. 95%.

Birth cohorts: 1894–1904, 1905–1914, 1915–1924, 1925–1934, 1935–1944, 1945–1954, 1955–1964, 1965–1969.

SUPPLEMENTARY MATERIAL

Period and cohort effects: consequences on spirometric lung function in Norway during the 20th century

Lucia Cestelli, Ane Johannessen, Knut Stavem, Amund Gulsvik, Rune Nielsen

TABLE S1.	Main characteristics of the four surveys included in the study.	p.2
TABLE S2.	Prevalence of respiratory symptoms and lung diseases in the total population.	p.3
FIGURE S1.	Adjusted predictions of FEV ₁ z-scores according to birth cohort in the total population.	p.4
FIGURE S2.	Adjusted predictions of FVC z-scores according to birth cohort in the total population.	p.5
FIGURE S3.	Adjusted predictions of height according to birth cohort in the total population.	p.6

TABLE S1. Main characteristics of the four surveys included in the study.

	Years	Geography	Objectives	Design
BCRDS	1965–1970	Bergen, old city borders	To examine the manifestations of cardiovascular and pulmonary diseases.	Random sample of subjects born on the 3rd, 13th, and 23rd of each month between 1894–1943.
PSWON	1988–1990	Hordaland county and Sauda municipality	To examine the association between occupational exposures and spirometric airflow limitation.	All eligible males born 1944–1958.
HCRHS	1996–1997	Hordaland county	To examine the urban-rural gradient of obstructive lung diseases and the contribution of occupational exposure. To develop lung function reference values. To estimate the prevalence of risk factors like allergies and respiratory viruses.	Two-phased, stratified, random sample. First follow-up: all those who lived in Bergen and 11 surrounding municipalities.
BD-HUSK	1998–1999	Bergen municipality	To evaluate the applicability of the adrenergic bronchodilator test and to estimate prevalence and predictors of a positive bronchodilatation response.	Follow-up of the Hordaland Homocystein Study population. Random sample of ten sex-birth year strata, of all subjects born 1925–1927 and 1950–1951.

BCRDS= Bergen Chronic Respiratory Disease Survey, PSWON= Pneumoconiosis Survey of Western Norway, HCRHS= Hordaland County Respiratory Health Survey, BD-HUSK= Bronchodilatation Survey of the Hordaland Health Study

TABLE S2. Prevalence of respiratory symptoms and lung diseases in the total population.

	BCRDS	PSWON	HCRHS	BD-HUSK	Total
Males					
Breathlessness walking uphill and/or climbing two flights of stairs	598 (24)	3431 (13)	180 (22)	245 (22)	4454 (15)
Attacks of breathlessness	38 (2)	2574 (10)	84 (10)	69 (6)	2765 (9)
Cough morning	246 (10)	2560 (10)	209 (26)	300 (27)	3315 (11)
Cough chronic	189 (8)	1386 (6)	100 (12)	118 (11)	1793 (6)
At least one respiratory symptom	737 (29)	6654 (26)	344 (42)	475 (43)	8210 (27)
Lung diseases	160 (6)	4212 (16)	147 (18)	274 (25)	4793 (16)
Females					
Breathlessness walking uphill and/or climbing two flights of stairs	1164 (38)	-	357 (30)	397 (24)	1918 (33)
Attacks of breathlessness	72 (2)	-	130 (11)	110 (7)	312 (5)
Cough morning	110 (4)	-	307 (26)	382 (23)	799 (13)
Cough chronic	93 (3)	-	150 (13)	189 (11)	432 (7)
At least one respiratory symptom	1210 (39)	-	556 (47)	688 (41)	2454 (41)
Lung diseases	147 (5)	-	313 (27)	426 (26)	886 (15)

Variables are presented as number (%).

BCRDS= Bergen Chronic Respiratory Disease Survey (1965–1970), PSWON= Pneumoconiosis Survey of Western Norway (1988–1990), HCRHS= Hordaland County Respiratory Health Survey (1996–1997), BD-HUSK= Bronchodilatation Survey of the Hordaland Health Study (1998–1999).

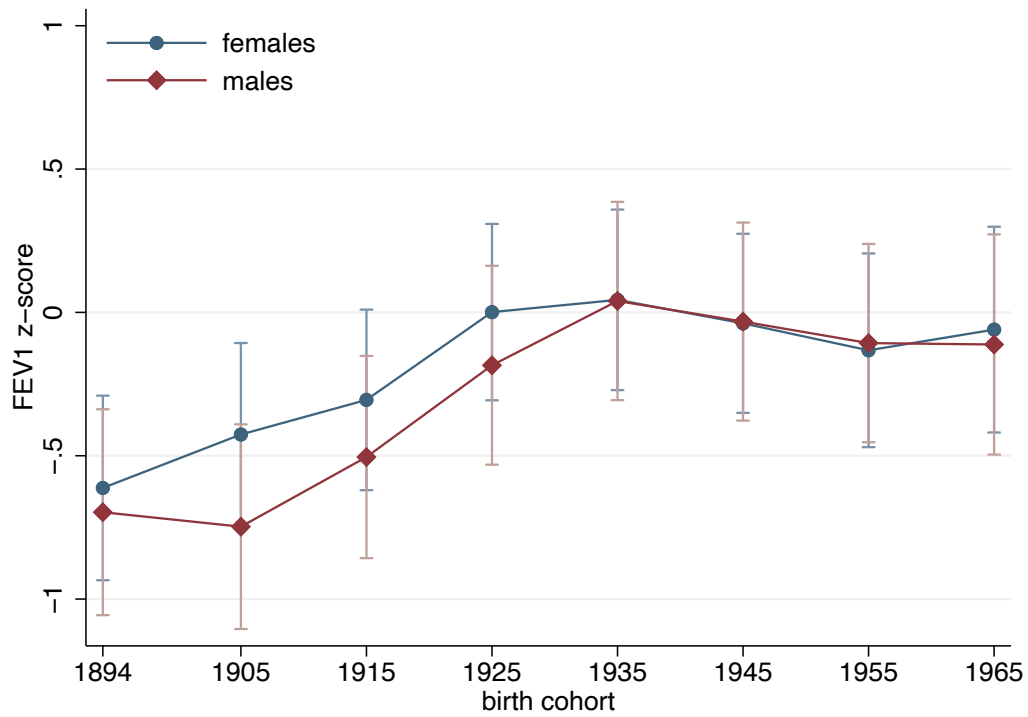


FIGURE S1. Adjusted predictions of FEV₁ z-scores according to birth cohort in the total population. Z-scores calculated according to GLI-2012 equations. C.I. 95%.

Birth cohorts: 1894–1904, 1905–1914, 1915–1924, 1925–1934, 1935–1944, 1945–1954, 1955–1964, 1965–1969.

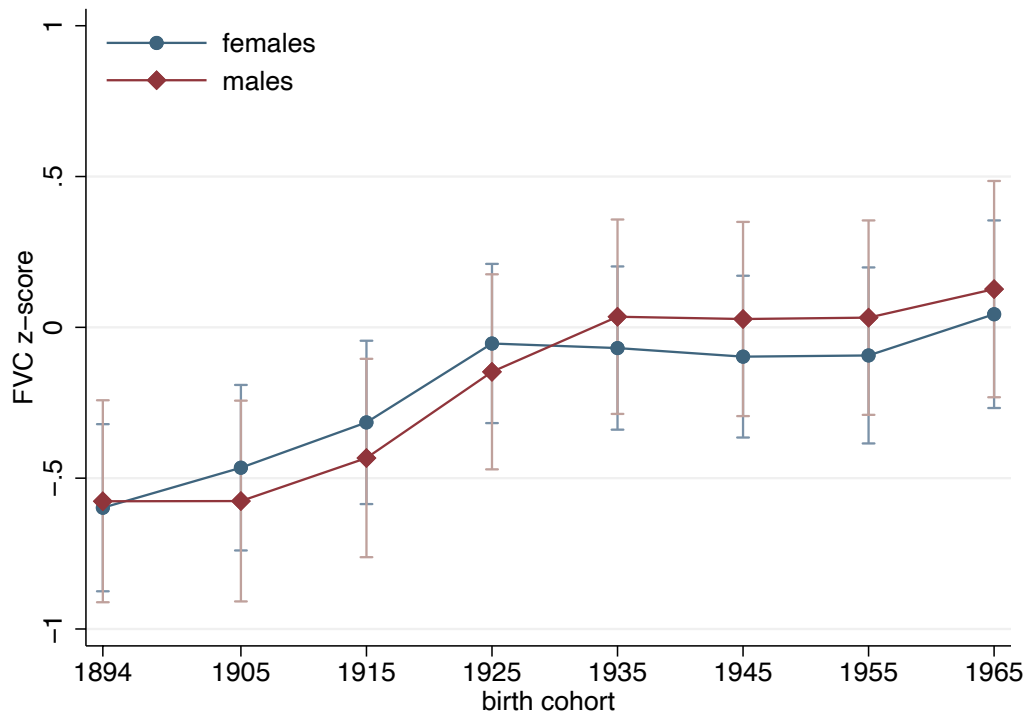


FIGURE S2. Adjusted predictions of FVC z-scores according to birth cohort in the total population. Z-scores calculated according to GLI-2012 equations. C.I. 95%.

Birth cohorts: 1894–1904, 1905–1914, 1915–1924, 1925–1934, 1935–1944, 1945–1954, 1955–1964, 1965–1969.

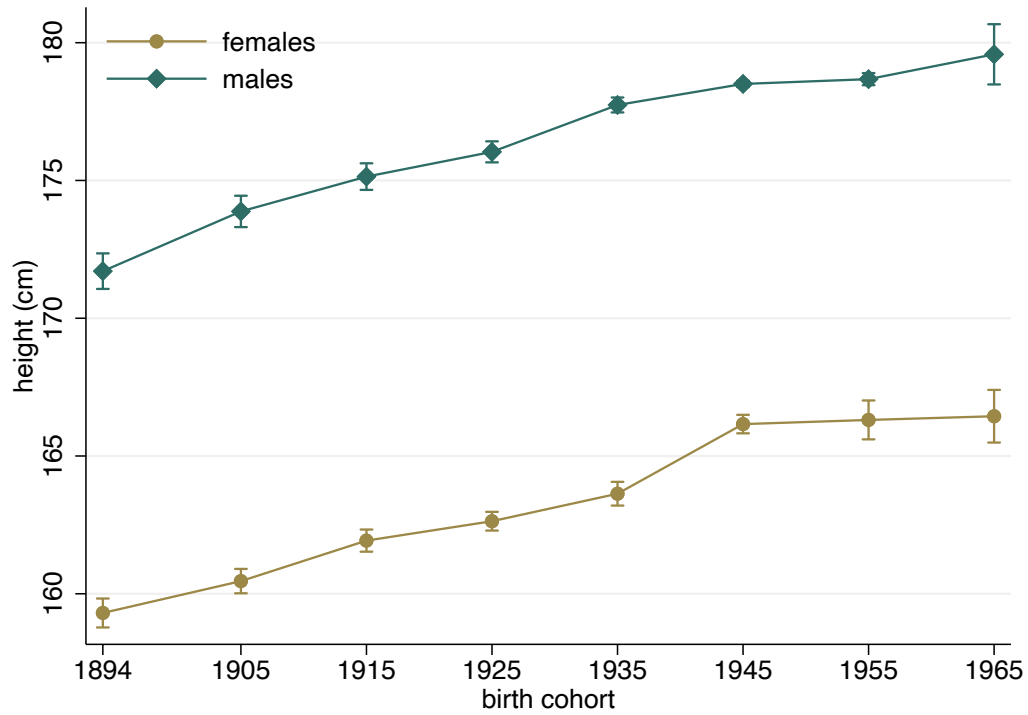


FIGURE S3. Adjusted predictions of height according to birth cohort in the total population, for 45-year-old males and females. C.I. 95%.

Birth cohorts: 1894–1904, 1905–1914, 1915–1924, 1925–1934, 1935–1944, 1945–1954, 1955–1964, 1965–1969.