



**HAL**  
open science

## **Occupational exposures and 20-year incidence of COPD: the European Community Respiratory Health Survey**

Theodore Lytras, Manolis Kogevinas, Hans Kromhout, Anne-Elie Carsin,  
Josep M. Antó, Hayat Bentouhami, Joost Weyler, Joachim Heinrich, Dennis  
Nowak, Isabel Urrutia, et al.

### ► To cite this version:

Theodore Lytras, Manolis Kogevinas, Hans Kromhout, Anne-Elie Carsin, Josep M. Antó, et al.. Occupational exposures and 20-year incidence of COPD: the European Community Respiratory Health Survey. *Thorax*, 2018, 73 (11), pp.1008–1015. 10.1136/thoraxjnl-2017-211158 . hal-02348853

**HAL Id: hal-02348853**

**<https://hal.science/hal-02348853>**

Submitted on 23 Jan 2024

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

## **Occupational exposures and 20-year incidence of COPD: The European Community Respiratory Health Survey**

Theodore Lytras<sup>1,2</sup>, Manolis Kogevinas<sup>1,2,3,4</sup>, Hans Kromhout<sup>5</sup>, Anne-Elie Carsin<sup>1,2,3</sup>, Josep Maria Antó<sup>1,2,3,4</sup>, Hayat Bentouhami<sup>6</sup>, Joost Weyler<sup>6</sup>, Joachim Heinrich<sup>7</sup>, Dennis Nowak<sup>7</sup>, Isabel Urrutia<sup>8</sup>, Jesús Martínez-Moratalla<sup>9,10</sup>, José Antonio Gullón<sup>11</sup>, Antonio Pereira Vega<sup>12</sup>, Chantal Raheison Semjen<sup>13</sup>, Isabelle Pin<sup>14,15,16</sup>, Pascal Demoly<sup>17,18</sup>, Bénédicte Leynaert<sup>19</sup>, Simona Villani<sup>20</sup>, Thorarinn Gislason<sup>21,22</sup>, Cecilie Svanes<sup>23,24</sup>, Mathias Holm<sup>25</sup>, Bertil Forsberg<sup>26</sup>, Dan Norbäck<sup>27</sup>, Amar J Mehta<sup>28</sup>, Nicole Probst-Hensch<sup>29</sup>, Geza Benke<sup>30</sup>, Rain Jogi<sup>31</sup>, Kjell Torén<sup>32</sup>, Torben Sigsgaard<sup>33</sup>, Vivi Schlünssen<sup>33,34</sup>, Mario Olivieri<sup>35</sup>, Paul D Blanc<sup>36</sup>, Roel Vermeulen<sup>5</sup>, Judith Garcia-Aymerich<sup>1,2,3,4</sup>, Deborah Jarvis<sup>37,38</sup>, Jan-Paul Zock<sup>1,2,3</sup>

1. ISGlobal, Centre for Research in Environmental Epidemiology (CREAL), Barcelona, Spain
2. Universitat Pompeu Fabra (UPF), Barcelona, Spain
3. CIBER Epidemiología y Salud Pública (CIBERESP), Madrid, Spain
4. Hospital del Mar Medical Research Institute, Barcelona, Spain
5. IRAS, University of Utrecht, The Netherlands
6. Department of Epidemiology and Social Medicine (ESOC), Faculty of Medicine and Health Sciences, StatUA Statistics Centre, University of Antwerp, Antwerp, Belgium
7. Institute and Outpatient Clinic for Occupational, Social and Environmental Medicine, University Hospital of Ludwig Maximilians University, Munich, Comprehensive Pneumology Centre Munich, German Centre for Lung Research
8. Pulmonology Department, Galdakao Hospital, Spain
9. Servicio de Neumología, Complejo Hospitalario Universitario, Albacete, Spain
10. Facultad de Medicina Albacete, University of Castilla-La Mancha, Ciudad Real, Spain
11. Respiratory Department, Hospital Universitario San Agustín, Avilés, Asturias, Spain
12. Respiratory and Allergy Clinical Unit, University Hospitalary Complex, Huelva, Spain
13. Université de Bordeaux, Inserm, Bordeaux Population Health Research Center, team EPICENE, UMR 1219, Bordeaux, France
14. Department of Pédiatrie, CHU de Grenoble Alpes, Grenoble, France
15. Inserm, U1209, IAB, Team of Environmental Epidemiology applied to Reproduction and Respiratory Health, Grenoble, France
16. Université Grenoble Alpes, Grenoble, France
17. University Hospital of Montpellier, Montpellier, France
18. Sorbonne Universités, Paris, France
19. Inserm UMR 1152-Equipe Epidémiologie, Université Paris Diderot, Paris, France
20. Department of Health Sciences, Section of Epidemiology and Medical Statistics, University of Pavia, Pavia, Italy
21. Dept. of Respiratory Medicine and Sleep, Landspítali University Hospital 108 Reykjavik, Iceland

22. Faculty of Medicine, University of Iceland, Reykjavik, Iceland
23. Department of Occupational Medicine, Haukeland University Hospital, Bergen, Norway
24. Centre for International Health, University of Bergen, Norway
25. Department of Occupational and Environmental Medicine, Sahlgrenska University Hospital, Gothenburg, Sweden
26. Department of Public Health and Clinical Medicine, Occupational and Environmental Medicine, Umeå University, Umeå, Sweden
27. Uppsala University, Department of Medical Sciences, Uppsala, Sweden
28. Boston Public Health Commission, Office of Research and Evaluation, Boston, MA, USA
29. Department Epidemiology and Public Health, Swiss Tropical and Public Health Institute, Basel, Switzerland
30. Monash Centre for Occupation and Environmental Health, School of Public Health and Preventive Medicine, Monash University, Melbourne, Australia
31. Tartu University Hospital, Lung Clinic, Estonia, Europe
32. Section of Occupational and Environmental Medicine, Institute of Medicine, Sahlgrenska Academy, University of Gothenburg, Gothenburg, Sweden
33. Department of Public Health, section for Environment, Occupation and Health, Danish Ramazzini center, Aarhus University, Denmark
34. National Research Center for the Working Environment, Copenhagen, Denmark
35. Unit of Occupational Medicine, University Hospital of Verona, Verona
36. University of California San Francisco, San Francisco Veterans Affairs Medical Center, San Francisco, United States
37. Population Health and Occupational Disease, National Heart and Lung Institute, Imperial College, London, United Kingdom
38. MRC-PHE Centre for Environment and Health, Imperial College London, London, United Kingdom

Word count: 3,545 (main text), 227 (abstract)

## **Abstract**

*Background:* Occupational exposures have been associated with an increased risk of Chronic Obstructive Pulmonary Disease (COPD). However, few studies have related objectively-assessed occupational exposures to prospectively-assessed incidence of COPD, using post-bronchodilator lung function tests. Our objective was to examine the effect of occupational exposures on COPD incidence in the European Community Respiratory Health Survey (ECRHS).

*Methods:* General population samples aged 20-44 were randomly selected in 1991-1993, and followed up 20 years later (2010-2012). Spirometry was performed at baseline and at follow-up, with incident COPD defined using a Lower Limit of Normal (LLN) criterion for post-bronchodilator FEV1/FVC. Only participants without COPD and without current asthma at baseline were included. Coded job histories during follow-up were linked to a Job-Exposure Matrix, generating occupational exposure estimates to twelve categories of agents. Their association with COPD incidence was examined in log-binomial models fitted in a Bayesian framework.

*Findings:* 3,343 participants fulfilled the inclusion criteria; 89 of them had COPD at follow-up (1.4 cases/1000 person-years). Participants exposed to biological dust had a higher incidence of COPD compared to those unexposed (RR=1.6, 95% Credible Interval: 1.1 – 2.3), as did those exposed to gases & fumes (RR=1.5, 95%CrI: 1.0 – 2.2) and pesticides (RR=2.2, 95%CrI: 1.1 – 3.8). The combined Population Attributable Fraction for these exposures was 21.0%.

*Interpretation:* These results substantially strengthen the evidence base for occupational exposures as an important risk factor for COPD.

## **Key messages**

*What is the key question?*

- What is the effect of occupational exposures on postbronchodilator spirometry-defined COPD incidence?

*What is the bottom line?*

- Exposure to biological dusts, gases & fumes, and pesticides were associated with increased COPD incidence, and together accounted for 21% of cases in the study population.

*Why read on?*

- This is the first multicentre prospective study to show an effect of biological dusts and of pesticides on COPD incidence, substantially strengthening the evidence base for occupation as a risk factor for COPD.

## Introduction

Chronic Obstructive Pulmonary Disease (COPD) is a progressive respiratory disease characterized by a largely non-reversible obstruction of the airways leading to airflow limitation.<sup>1</sup> It is a leading cause of morbidity and mortality worldwide, whose impact is expected to further increase as the population ages.<sup>2-4</sup> Tobacco smoking is the primary risk factor for COPD;<sup>5</sup> however, many other environmental factors have been implicated in COPD, including occupational exposures.<sup>6,7</sup> Numerous studies, both population-based and industry-based, have examined the relationship between occupation and COPD-related outcomes.<sup>6,8,9</sup> An interaction between smoking and occupational exposures has also been observed.<sup>10</sup> It has been estimated that about 15% of COPD cases are attributable to exposures at the workplace,<sup>8</sup> with a higher population attributable fraction among non-smokers.<sup>11,12</sup>

Despite a wealth of evidence on COPD risk factors from population-based studies, few such studies have assessed the incidence of COPD in a prospective manner,<sup>13,14</sup> and even fewer have specifically examined the association between occupational exposures and the incidence of spirometry-defined COPD.<sup>15</sup> The European Community Respiratory Health Survey (ECRHS) is a large multicentre population-based longitudinal study with a long follow-up duration; earlier cross-sectional and longitudinal analyses in this relatively young cohort showed an association between occupation and asthma as well as chronic bronchitis symptoms, but not with accelerated lung function decline or increased COPD incidence.<sup>16,17</sup> The objective of the current analysis was to examine the effect of occupational exposures on post-bronchodilator spirometry-defined COPD incidence in the ECRHS, after 20 years of follow-up.

## Methods

### *ECRHS study overview*

The ECRHS is a multicentre longitudinal study initiated in 1991–1993 which enrolled random general population samples aged 20 to 44 years in 55 centres from 23 countries.<sup>18</sup> Participants at baseline (ECRHS I) completed a detailed questionnaire via face-to-face interview and underwent a clinical examination, spirometry and other tests. They were followed-up again between 1998 and 2002 (ECRHS II), and a second time between 2010 and 2012 (ECRHS III). Ethical approval for each centre was obtained from their respective competent bodies, and written informed consent was obtained from all participants.

### *Study population, spirometry and COPD definition*

The population eligible for this study included all participants who completed spirometry at baseline (ECRHS I) and at the second follow-up (ECRHS III). Spirometry was performed according to the ATS/ERS standards for reproducibility, using the maximum value observed per participant for the Forced Volume Capacity (FVC) and Forced Expiratory Volume in 1 second (FEV<sub>1</sub>). Baseline spirometry at ECRHS I was performed without bronchodilation; spirometry at ECRHS III was performed post-bronchodilation, 15 minutes after administering two 100 mcg puffs of salbutamol using a spacer. We excluded participants with a baseline FEV<sub>1</sub>/FVC ratio under the Lower Limit of Normal (LLN) for their age, sex and gender according to

the GLI-2012 equations.<sup>19</sup> We also excluded participants who reported having current asthma at baseline; current asthma was defined as a positive response to either of the following three questions: “have you had an attack of asthma in the last 12 months?”, “are you currently taking any medicines for asthma?” and “have you been woken by an attack of shortness of breath at any time in the last 12 months?”. Incident COPD was defined using spirometry only, as a post-bronchodilator FEV1/FVC ratio under the LLN at the end of follow-up.

#### *Occupational exposure assessment*

At both follow-up interviews, participants were asked to provide a detailed list of their occupations and industries from jobs held since the previous study visit that were performed for at least 8 hours a week for at least three months. Each such employment was recorded in free text and subsequently coded in the International Classification of Occupations-88 (ISCO-88) by trained local coders. Occupations were also further grouped into 14 wider job categories, as previously defined.<sup>17</sup> Occupational exposures were assessed by linking the ISCO-88 occupational codes to the semi-quantitative ALOHA(+) Job-Exposure Matrix (JEM).<sup>20</sup> This JEM assigns, for every job code, three grades of exposure (none, low, high) to ten categories of agents (biological dusts, mineral dusts, gases/fumes, herbicides, insecticides, fungicides, aromatic solvents, chlorinated solvents, other solvents, and metals) plus two composites of the above (All pesticides and Vapors/Gases/Dusts/Fumes – VGDF). Exposures for every participant were defined and analyzed for the entire follow-up period, i.e. from ECRHS I to ECRHS III.

#### *Data analysis*

Log-binomial regression models were used to estimate the probability of COPD at the end of follow-up period as a function of exposure, covariates and length of follow-up; these models directly provide Relative Risk estimates for each covariate. Given that the incidence of COPD is heavily associated with lung function at baseline,<sup>21</sup> we further adjusted all models for participants' FEV1/FVC ratio at baseline, expressed as percent predicted according to the GLI-2012 equations. Other covariates used for adjustment were age at baseline, sex, lifetime smoking pack-years, Socioeconomic Status (SES) and early life disadvantage score. Early life disadvantage score is a composite variable that includes maternal smoking, maternal asthma, paternal asthma, childhood asthma (before age 10), and having a serious respiratory infection before age 5.<sup>22</sup> SES was defined according to the participants' age of completion of formal education, and classified in three categories: high (>19 years), middle (16-19 years), low (<16 years). We also included quadratic terms for age at baseline and lifetime smoking pack-years, in order to account for any non-linear relationships between these important covariates and COPD incidence.<sup>23</sup>

Each of the 12 ALOHA(+) exposures was assessed in a univariate fashion, i.e. exposed vs unexposed (to the respective agent). Given the substantial overlap between exposures in certain jobs, we also examined each one in comparison to a common group consisting of those unexposed to all 12 occupational agents under study. In addition for certain exposures we fit bivariate models, i.e. models with two exposures, where the effect of each one is adjusted for the presence of the other. Stratified effects by sex were obtained by including appropriate interaction terms in the models, and dose-response was examined by including

separate terms for only low and for ever high exposure. As a sensitivity analysis, we refitted the models after excluding incident asthma cases, i.e. those reporting asthma (as defined above) in either of the two ECRHS follow-up visits. As a further sensitivity analysis, we also fitted “reduced” models without adjustment for SES, early life disadvantage score and baseline FEV1/FVC. A secondary analysis involved using job categories as the exposure, i.e. ever working in a particular category during follow-up, in comparison to a common unexposed group consistently working in white-collar occupations.

All models were fitted in a Bayesian framework with the JAGS software,<sup>24</sup> setting non-informative gaussian priors for all fixed-effects parameters, and using 4 chains and 32,000 iterations per chain, discarding the first 2,000 as burn-in. Convergence was checked by visual inspection of the MCMC traceplots and by the Gelman-Rubin statistic. The Bayesian framework avoids convergence issues that have sometimes been reported when fitting log-binomial models in a frequentist setting. To address covariate missingness with respect to lifetime smoking pack-years (for current and ex-smokers), a fully Bayesian imputation sub-model was included, whereby the distribution of pack-years was modelled with a Gamma distribution based on the observed cases, under an ignorable missingness assumption (see Online Supplement).

Based on the Relative Risk estimates, Population Attributable Fractions (PAFs) were calculated both for individual exposures and combinations of exposures (see Online Supplement).<sup>25</sup> All analyses were performed with the R statistical environment, version 3.4.1.<sup>26</sup>

#### *Role of the funding source*

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

## **Results**

The flow of ECRHS participants into our study sample is illustrated in Figure 1; in total 3343 participants were analyzed, originating from 24 study centres in 12 countries (Australia, Belgium, Estonia, France, Germany, Iceland, Italy, Norway, Spain, Sweden, Switzerland and United Kingdom). Of these participants, 1409 were never smokers and 1934 were ever smokers (current or ex-smokers at the end of follow-up). The characteristics of our study population are shown on Table 1. Median age at baseline was 34.5 years, and the mean duration of follow-up was 20.0 years (range 18.0-22.4). COPD occurred in 96 participants, for an incidence of 1.4 cases/1000 person-years. As expected, COPD incidence in ever smokers was much higher than in never smokers (2.0 vs 0.6 cases/1000 person-years,  $p < 0.001$ ). Lifetime smoking pack-years at follow-up were missing in 448/1934 ever smokers (23.2%, or 13.4% of the entire study population), for whom Bayesian imputation was performed.

Baseline characteristics were generally similar between the 3343 participants included in the analysis and the 4644 who were eligible (FEV1/FVC > LLN and no current asthma at baseline) but could not be included; those not included in the analysis were slightly more likely to be ever smokers and of lower socioeconomic



status than those finally analyzed (Supplementary Table 1).

The percentage of participants exposed ranged across the occupational agents, from a minimum of 4.9% to pesticides to a maximum of 48.4% to VGDF; 1696 participants (50.7%) did not have any low or high occupational exposure during the follow-up period. There was substantial overlap and thus correlation between exposures (Figure 2), particularly between the various types of pesticides and solvents, and also between gases & fumes and other exposures.

The effect (Relative Risk and 95% Credible Interval) of occupational exposures on COPD incidence compared to participants unexposed (to the respective agent) is presented on Table 2. For all exposures except solvents and metals, the crude incidence of COPD among exposed (percentage of participants with COPD at the end of follow-up) was higher than among those unexposed. After adjusting for covariates in log-binomial models, there was a significant effect for biological dust (RR = 1.6, 95% CrI: 1.1 – 2.3 vs unexposed) as well as for all pesticides (RR = 2.2, 95% CrI: 1.1 – 3.8), and in particular insecticides (RR = 2.3, 95% CrI: 1.1 – 4.2); however, the effect for all pesticides and insecticides was based on a small number of cases (10 and 8 respectively). Gases & fumes showed a significant effect compared to participants with no such exposure (RR = 1.5, 95% CrI: 1.0 – 2.2), while for mineral dust and VGDF the effect was not significant.

Running the models after excluding incident asthma cases did not materially change the results (Supplementary Table 2); biological dust and gases & fumes showed a marginally stronger effect (RR = 2.0, 95% CrI: 1.2 – 3.1, and RR = 1.9, 95% CrI: 1.2 – 3.0, respectively), while the effect for pesticides was the same (RR = 1.9, 95% CrI: 0.8 – 3.9). We also ran the models using a common, fully unexposed comparator group (Supplementary Table 3); this also did not substantially alter the results, although for gases & fumes the effect fell below the conventional level of statistical significance (RR = 1.4, 95% CrI: 1.0 – 2.1).

Including both any biological dust and any pesticide exposure in the same log-binomial model, mutually adjusting each effect for the presence of the other, resulted in a RR of 1.5, 95% CrI: 1.0 – 2.2 and 1.8, 95% CrI: 0.9 – 3.2 for biological dust and pesticides respectively. Adding also exposure to gases & fumes to this model resulted in increased uncertainty and an RR of 1.3, 95% CrI: 0.8 – 2.2 for biological dust, 1.7, 95% CrI: 0.9 – 3.2 for pesticides, and 1.2, 95% CrI: 0.7 – 2.0 for gases & fumes. Assuming these point Relative Risks and the proportions of exposed participants in our study population, the corresponding Population Attributable Fractions (PAFs) were 10.5% for biological dust, 4.4% for pesticides and 9.2% for gases & fumes; the combined PAF<sup>25</sup> for all three exposures was 21.0%.

No differences between men and women were observed in the effect of occupational exposures on the incidence of COPD (Supplementary Table 4). We also ran models for each exposure stratified by intensity, i.e. no exposure vs any low vs any high exposure. In these models there was weak evidence of a dose response relationship for biological dust, but none for pesticides, gases & fumes or other exposures (Table 3). The additional Relative Risk for high biological dust exposure compared to low exposure was 1.5, 95% CrI: 0.8 – 2.8, as there were few incident COPD cases particularly in the high exposure group (10/111, 9.0%).

Among covariates in the models, age and smoking pack-years were strongly associated with COPD, as expected. Men were only slightly more likely than women to suffer from COPD (adjusted RR = 1.2, 95% CrI: 0.8 – 1.7). Importantly, there was a strong inverse relationship between %predicted FEV1/FVC at baseline and COPD incidence at the end of the follow-up period (Figure 3); each percentage point of increase lowered the incidence of COPD by a factor (RR) of 0.8, 95% CrI: 0.8 – 0.9. Early life disadvantage score did not affect COPD incidence (RR per unit change = 1.0, 95% CrI: 0.8 – 1.3), and neither did medium (RR = 0.9, 95% CrI: 0.6 – 1.3) or low socioeconomic status (RR = 0.8, 95% CrI: 0.4 – 1.5).

Associations between occupational exposures and COPD incidence were not substantially modified by omitting adjustments for SES, early life disadvantage score and/or %predicted FEV1/FVC at baseline (Supplementary Table 5).

The secondary analysis by job category indicated a higher incidence of COPD in participants who had worked in the transport industry (1.7, 95% CrI: 0.9 – 3.2), in the wood, paper and textile industry (2.1, 95% CrI: 0.9 – 4.5) and in agriculture, fishery and forestry (2.3, 95% CrI: 0.9 – 5.0); however the precision of these estimates was limited by the low number of study participants working in each job category (Supplementary Table 6). Occupations belonging to these three categories were very frequently exposed to biological dust, pesticides and gases/fumes. Overall the most frequent occupations with exposure to these agents are shown on Supplementary Table 7.

## Discussion

Our study found that exposure to biological dust in a general population cohort did result in an increased incidence of spirometrically-defined COPD over the course of 20 years. Biological dust has been shown to affect lung function decline and chronic respiratory symptoms in several worker-based studies such as in farmers, cotton textile and woodworkers.<sup>27–30</sup> An association with COPD prevalence has also been demonstrated in a community-based cross-sectional study,<sup>20</sup> and recently in another one from Australia.<sup>31</sup> To our knowledge this is the first study to demonstrate an effect of biological dust exposure on the incidence of COPD in a prospective fashion in a general population cohort. This effect remained strong even after adjustment for other exposures or exclusion of incident asthma cases, and also exhibited some evidence of a dose-response relationship, i.e. a higher incidence of COPD with high exposure to biological dust. As such the study is a significant addition to the evidence base about the role of biological dust on respiratory health.

Exposure to pesticides has also been linked with asthma and possibly COPD in a variety of studies.<sup>31–33</sup> More recently an association of pesticide exposure with accelerated lung function decline was observed in a longitudinal community-based study from the Netherlands; this association was stronger for smokers.<sup>34</sup> Our study adds further prospective confirmation that pesticides increase the incidence of COPD. Interestingly in our study exposure to pesticides occurred in the 1990s and 2000s, while in the Dutch study exposure happened mostly before 1990; this may indicate that contemporary changes in active ingredients, pesticide application methods and personal protective measures may have been insufficient to mitigate the risk to workers.

On the other hand, the lack of association between mineral dust exposure and COPD incidence may be explained by the composition of jobs included in this category (Supplementary Table 7). Older studies found a link between mining (especially coal mining), as well as various industrial occupations, and COPD. Such mining and industrial jobs were a minority in our study population, which was recruited in the early '90s. Instead, the most frequent jobs with exposure to mineral dust in our study were truck and lorry drivers for men, and cleaners for women.

Disentangling the effects of multiple overlapping occupational exposures is a particular challenge. Our approach was twofold, i.e. we compared each exposure with those unexposed, and separately with a common fully occupationally unexposed comparison group. The first choice of comparator is simpler, but includes other occupational exposures which may attenuate any association with the exposure under study. The second comparator (fully unexposed group) avoids this problem, but may increase the potential for residual confounding particularly with respect to SES, as the people in this group (mostly white-collar workers) are likely to be different in more ways than a model can handle. Nevertheless, in our case we found similar results with both approaches. We then followed up with bivariate and multivariate models, i.e. models that include more than one occupational exposure, as well as an analysis by job category; however this requires a large sample size to maintain precision in the effect estimates.

Occupational exposures have been associated with both asthma and COPD incidence in population studies;<sup>15,35</sup> COPD and asthma are two different disease entities, modulated by distinct pathophysiological mechanisms, but with considerable clinical and symptom overlap.<sup>36</sup> As a result, in our basic analyses we did not exclude incident asthma cases. A sensitivity analysis with incident asthma cases excluded did not substantially modify the results.

In all models we adjusted for the FEV1/FVC ratio at baseline, expressed as %predicted, which we found to be a strong predictor of subsequent COPD incidence. This is hardly surprising, since COPD is not a stochastic event, but one that results from a progressive lung function decline below a given threshold. As such the “distance to be covered” between baseline FEV1/FVC and the LLN threshold is critical, and we believe it should be adjusted for in future prospective studies of COPD incidence.

The study has several strengths. Being a population-based study increases generalizability of the findings, especially given the prospective design and follow up of 20 years, one of the longest to date. Complete occupational histories were collected, and a full spectrum of exposures for the follow-up period was determined using a JEM instead of self-report, which could be more vulnerable to bias. We were thus able to explore the effect of particular exposures on COPD incidence and their contribution to the disease burden. Confounders were tightly controlled: we included adjustments for SES and baseline lung function, and we accounted for non-linear relationships with age and smoking pack-years using quadratic terms; therefore residual confounding by intensity of smoking is most unlikely. Lifetime pack-years of smoking were missing in many current or ex-smokers of our study population; we used fully Bayesian imputation to handle the problem and draw reliable inference while reflecting the appropriate uncertainty, assuming ignorable missingness (see Online supplement).

On the other hand, COPD incidence in our study population was much lower than in other published studies;<sup>13,37,38</sup> the most likely reason for this was the still fairly young age of our cohort at follow-up (median age 55, range 39 – 68 years). Also the use of pre-bronchodilation spirometry at baseline to filter out prevalent COPD cases, may have led to the exclusion of some participants with reversible or borderline obstruction at baseline. Because of the low number of incident COPD cases, especially in lifetime non-smokers, we could not stratify our analysis by smoking status to check for effect modification. For the same reason several of our effect estimates were characterized by low precision, especially those stratified by sex and by intensity of exposure. In addition, we defined COPD with post-bronchodilation spirometry only and not based on symptoms of chronic bronchitis, which would have raised specificity but severely limited the number of incident cases in this analysis. Another limitation stems from the fact that the outcome of COPD was only assessed at the end of follow-up, thus could in theory have predated the exposure. However, out of 56 occupationally exposed participants with incident COPD, most were already working at an exposed job at the start of follow-up, or had a pre-bronchodilation FEV1/FVC > LLN at ECRHS II after having started working at exposed jobs. Only for 7/56 participants (12.5%) it could not be disproven that COPD might have occurred before the occupational exposure. Still this is very unlikely, as COPD incidence is strongly related to age, and because participants developing COPD might be less likely to start working in exposed jobs unless previously exposed.

Nevertheless, the fact that some occupational exposure effects (namely biological dust, gases & fumes and pesticides) were observed even in this relatively young study population, is highly important from a public health point of view. A large proportion of workers have these exposures (49% among ever smokers in our study population), and their association with COPD incidence translates into a substantial number of attributable cases in the population (an estimated 21.0% in this analysis); this suggests that up to one in five new COPD cases among middle-aged people in Western countries could be prevented by avoiding or controlling occupational exposures in contemporary jobs. Our study confirms previous findings regarding the role of occupation on the burden of COPD,<sup>6,8</sup> and provides strong prospective evidence and direct quantitative estimates for the impact of occupational exposures on COPD incidence. Future studies should clarify whether these effects are modified by smoking, their interplay with asthma, and further detail the risks involved with respect to particular occupations, activities and noxious agents.

## **Author Contributions**

Study idea & design: TL, MK, JPZ, HK, JMA, KT, DJ

Data collection: MK, HK, AEC, JMA, HB, JW, JH, DN, IU, JMM, JAG, APV, CRS, IP, PD, BL, SV, TG, CS, MH, BF, DN, AJM, NPH, GB, RJ, KT, TS, VS, JGA, DJ, JPZ

Data analysis: TL, MK, JPZ

Data interpretation: all authors

Initial manuscript draft: TL, MK, JPZ

Critical revision of the manuscript for important intellectual content: all authors

Final approval of the manuscript for publication: all authors

## **Funding**

### *Financial support for ECRHS I, for the local centres included in this study:*

Australia: Asthma Foundation of Victoria, Allen and Hanbury's, Belgium: Belgian Science Policy Office, National Fund for Scientific Research, Estonia: Estonian Science Foundation, grant no 1088, France: Ministère de la Santé, Glaxo France, Insitut Pneumologique d'Aquitaine, Contrat de Plan Etat-Région Languedoc-Rousillon, CNMATS, CNMRT (90MR/10, 91AF/6), Ministre delegué de la santé, RNSP, France; GSF, Germany: Bundesminister für Forschung und Technologie, Italy: Ministero dell'Università e della Ricerca Scientifica e Tecnologica, CNR, Regione Veneto grant RSF n. 381/05.93, Norway: Norwegian Research Council project no. 101422/310; Spain: Fondo de Investigación Sanitaria (#91/0016-060-05/E, 92/0319 and #93/0393), Hospital General de Albacete, Hospital General Juan Ramón Jiménez, Dirección Regional de Salud Pública (Consejería de Sanidad del Principado de Asturias), CIRIT (1997 SGR 00079) and Servicio Andaluz de Salud; Sweden: The Swedish Medical Research Council, the Swedish Heart Lung Foundation, the Swedish Association against Asthma and Allergy; Switzerland: Swiss national Science Foundation grant 4026-28099; UK: National Asthma Campaign, British Lung Foundation, Department of Health, South Thames Regional Health Authority.

### *Financial Support for ECRHS III:*

Australia: National Health & Medical Research Council, Belgium: Antwerp South, Antwerp City: Research Foundation Flanders (FWO), grant code G.0.410.08.N.10 (both sites), Estonia: Tartu- SF0180060s09 from the Estonian Ministry of Education. France: (All) Ministère de la Santé. Programme Hospitalier de Recherche Clinique (PHRC) national 2010. Bordeaux: INSERM U897 Université Bordeaux segalen, Grenoble: Comite Scientifique AGIRadom 2011. Paris: Agence Nationale de la Santé, Région Ile de France, domaine d'intérêt majeur (DIM) Germany : Erfurt: German Research Foundation HE 3294/10-1 Hamburg: German Research Foundation MA 711/6-1, NO 262/7-1 Iceland: Reykjavik, The Landspítali University Hospital Research Fund, University of Iceland Research Fund, ResMed Foundation, California, USA, Orkuveita Reykjavíkur (Geothermal plant), Vegagerðin (The Icelandic Road Administration (ICERA). Italy: All Italian centres were funded by the Italian Ministry of Health, Chiesi Farmaceutici SpA, in addition Verona was funded by Cariverona foundation, Education Ministry (MIUR). Norway: Norwegian Research council grant no 214123, Western Norway Regional Health Authorities grant no 911631, Bergen Medical Research Foundation. Spain: Fondo de Investigación Sanitaria (PS09/02457, PS09/00716 09/01511) PS09/02185 PS09/03190), Servicio Andaluz de Salud, Sociedad Española de Neumología y Cirugía Torácica (SEPAR 1001/2010); Sweden: All centres were funded by The Swedish Heart and Lung Foundation, The Swedish Asthma and Allergy Association, The Swedish Association against Lung and Heart Disease. Fondo de Investigación Sanitaria (PS09/02457 Barcelona: Fondo de Investigación Sanitaria (FIS PS09/00716) Galdakao: Fondo de Investigación Sanitaria (FIS 09/01511) Huelva: Fondo de Investigación Sanitaria (FIS PS09/02185) and Servicio Andaluz de Salud Oviedo: Fondo de Investigación Sanitaria (FIS PS09/03190) Sweden: All centres were funded by The Swedish Heart and Lung Foundation, The Swedish

Asthma and Allergy Association, The Swedish Association against Lung and Heart Disease. Swedish Research Council for health, working life and welfare (FORTE) Göteborg : Also received further funding from the Swedish Council for Working life and Social Research. Umea also received funding from Vasterbotten Country Council ALF grant. Switzerland: The Swiss National Science Foundation (grants no 33CSCO-134276/1, 33CSCO-108796, 3247BO-104283, 3247BO-104288, 3247BO-104284, 3247-065896, 3100-059302, 3200-052720, 3200-042532, 4026-028099) The Federal office for forest, environment and landscape, The Federal Office of Public Health, The Federal Office of Roads and Transport, the canton's government of Aargau, Basel-Stadt, Basel-Land, Geneva, Luzern, Ticino, Valais and Zürich, the Swiss Lung League, the canton's Lung League of Basel Stadt/ Basel, Landschaft, Geneva, Ticino, Valais and Zurich, SUVA, Freiwillige Akademische Gesellschaft, UBS Wealth Foundation, Talecris Biotherapeutics GmbH, Abbott Diagnostics, European Commission 018996 (GABRIEL), Wellcome Trust WT 084703MA, UK: Medical Research Council (Grant Number 92091). Support also provided by the National Institute for Health Research through the Primary Care Research Network

The coordination of the ECRHS III was funded through the Medical Research Council (Grant Number 92091).

ISGlobal is a member of the CERCA Programme / Generalitat de Catalunya.

The present analyses are part of the Ageing Lungs in European Cohorts (ALEC) Study ([www.alecstudy.org](http://www.alecstudy.org)), which has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 633212.

## Bibliography

- 1 Global Initiative for Chronic Obstructive Lung Disease (GOLD). Global strategy for the diagnosis, management, and prevention of chronic obstructive pulmonary disease, 2017 report. 2017.
- 2 Lozano R, Naghavi M, Foreman K, *et al.* Global and regional mortality from 235 causes of death for 20 age groups in 1990 and 2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet* 2012; **380**: 2095–128.
- 3 Prince MJ, Wu F, Guo Y, *et al.* The burden of disease in older people and implications for health policy and practice. *Lancet* 2015; **385**: 549–62.
- 4 Herse F, Kiljander T, Lehtimäki L. Annual costs of chronic obstructive pulmonary disease in Finland during 1996-2006 and a prediction model for 2007-2030. *NPJ Prim Care Respir Med* 2015; **25**: 15015.
- 5 Kohansal R, Martinez-Cambor P, Agustí A, Buist AS, Mannino DM, Soriano JB. The natural history of chronic airflow obstruction revisited: an analysis of the Framingham offspring cohort. *Am J Respir Crit Care Med* 2009; **180**: 3–10.
- 6 Eisner MD, Anthonisen N, Coultas D, *et al.* An official American Thoracic Society public policy statement: Novel risk factors and the global burden of chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 2010; **182**: 693–718.
- 7 Paulin LM, Diette GB, Blanc PD, *et al.* Occupational exposures are associated with worse morbidity in patients with chronic obstructive pulmonary disease. *Am J Respir Crit Care Med* 2015; **191**: 557–65.
- 8 Balmes J, Becklake M, Blanc P, *et al.* American Thoracic Society Statement: Occupational contribution to the burden of airway disease. *Am J Respir Crit Care Med* 2003; **167**: 787–97.
- 9 Omland O, Würtz ET, Aasen TB, *et al.* Occupational chronic obstructive pulmonary disease: a systematic literature review. *Scand J Work Environ Health* 2014; **40**: 19–35.
- 10 Blanc PD, Iribarren C, Trupin L, *et al.* Occupational exposures and the risk of COPD: dusty trades revisited. *Thorax* 2009; **64**: 6–12.
- 11 Hnizdo E, Sullivan PA, Bang KM, Wagner G. Association between chronic obstructive pulmonary disease and employment by industry and occupation in the US population: a study of data from the Third National Health and Nutrition Examination Survey. *Am J Epidemiol* 2002; **156**: 738–46.
- 12 Salvi SS, Barnes PJ. Chronic obstructive pulmonary disease in non-smokers. *Lancet* 2009; **374**: 733–43.
- 13 Terzikhan N, Verhamme KMC, Hofman A, Stricker BH, Brusselle GG, Lahousse L. Prevalence and incidence of COPD in smokers and non-smokers: the Rotterdam Study. *Eur J Epidemiol* 2016; **31**: 785–92.
- 14 Afonso ASM, Verhamme KMC, Sturkenboom MCJM, Brusselle GGO. COPD in the general population: prevalence, incidence and survival. *Respir Med* 2011; **105**: 1872–84.
- 15 Mehta AJ, Miedinger D, Keidel D, *et al.* Occupational exposure to dusts, gases, and fumes and incidence of chronic obstructive pulmonary disease in the Swiss Cohort Study on Air Pollution and Lung and Heart Diseases in Adults. *Am J Respir Crit Care Med* 2012; **185**: 1292–300.
- 16 Zock JP, Sunyer J, Kogevinas M, Kromhout H, Burney P, Antó JM. Occupation, chronic bronchitis, and lung function in young adults. An international study. *Am J Respir Crit Care Med* 2001; **163**: 1572–7.
- 17 Sunyer J, Zock JP, Kromhout H, *et al.* Lung function decline, chronic bronchitis, and occupational



- exposures in young adults. *Am J Respir Crit Care Med* 2005; **172**: 1139–45.
- 18 Burney PG, Luczynska C, Chinn S, Jarvis D. The European Community Respiratory Health Survey. *Eur Respir J* 1994; **7**: 954–60.
- 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**: 1324–43.
- 20 Matheson MC, Benke G, Raven J, *et al.* Biological dust exposure in the workplace is a risk factor for chronic obstructive pulmonary disease. *Thorax* 2005; **60**: 645–51.
- 21 de Marco R, Accordini S, Cerveri I, *et al.* Incidence of chronic obstructive pulmonary disease in a cohort of young adults according to the presence of chronic cough and phlegm. *Am J Respir Crit Care Med* 2007; **175**: 32–9.
- 22 Svanes C, Sunyer J, Plana E, *et al.* Early life origins of chronic obstructive pulmonary disease. *Thorax* 2010; **65**: 14–20.
- 23 Castaldi PJ, Demeo DL, Hersh CP, *et al.* Impact of non-linear smoking effects on the identification of gene-by-smoking interactions in COPD genetics studies. *Thorax* 2011; **66**: 903–9.
- 24 Plummer M. JAGS: A program for analysis of Bayesian graphical models using Gibbs sampling. Vienna, 2003: 125.
- 25 Rockhill B, Newman B, Weinberg C. Use and misuse of population attributable fractions. *Am J Public Health* 1998; **88**: 15–9.
- 26 R Core Team. R: A Language and Environment for Statistical Computing. Vienna, Austria: R Foundation for Statistical Computing, 2015 <http://www.R-project.org/>.
- 27 Christiani DC, Wang XR, Pan LD, *et al.* Longitudinal changes in pulmonary function and respiratory symptoms in cotton textile workers. A 15-yr follow-up study. *Am J Respir Crit Care Med* 2001; **163**: 847–53.
- 28 Jacobsen GH, Schlünssen V, Schaumburg I, Sigsgaard T. Cross-shift and longitudinal changes in FEV1 among wood dust exposed workers. *Occup Environ Med* 2013; **70**: 22–8.
- 29 Kahraman H, Sucakli MH, Kilic T, Celik M, Koksall N, Ekerbicer HC. Longitudinal pulmonary functional loss in cotton textile workers: a 5-year follow-up study. *Med Sci Monit* 2013; **19**: 1176–82.
- 30 Mandryk J, Alwis KU, Hocking AD. Work-related symptoms and dose-response relationships for personal exposures and pulmonary function among woodworkers. *Am J Ind Med* 1999; **35**: 481–90.
- 31 Alif SM, Dharmage SC, Benke G, *et al.* Occupational exposure to pesticides are associated with fixed airflow obstruction in middle-age. *Thorax* 2017; published online July 7. DOI:10.1136/thoraxjnl-2016-209665.
- 32 Doust E, Ayres JG, Devereux G, *et al.* Is pesticide exposure a cause of obstructive airways disease? *Eur Respir Rev* 2014; **23**: 180–92.
- 33 Negatu B, Kromhout H, Mekonnen Y, Vermeulen R. Occupational pesticide exposure and respiratory health: a large-scale cross-sectional study in three commercial farming systems in Ethiopia. *Thorax* 2017; **72**: 498–9.
- 34 de Jong K, Boezen HM, Kromhout H, Vermeulen R, Postma DS, Vonk JM. Association of occupational pesticide exposure with accelerated longitudinal decline in lung function. *Am J Epidemiol* 2014; **179**: 1323–30.

- 35 Kogevinas M, Zock J-P, Jarvis D, *et al.* Exposure to substances in the workplace and new-onset asthma: an international prospective population-based study (ECRHS-II). *Lancet* 2007; **370**: 336–41.
- 36 Postma DS, Rabe KF. The Asthma-COPD Overlap Syndrome. *N Engl J Med* 2015; **373**: 1241–9.
- 37 Pallasaho P, Kainu A, Sovijärvi A, Lindqvist A, Piirilä PL. Combined effect of smoking and occupational exposure to dusts, gases or fumes on the incidence of COPD. *COPD* 2014; **11**: 88–95.
- 38 Lindberg A, Jonsson A-C, Rönmark E, Lundgren R, Larsson L-G, Lundbäck B. Ten-year cumulative incidence of COPD and risk factors for incident disease in a symptomatic cohort. *Chest* 2005; **127**: 1544–52.

**Table 1: Characteristics of the study population**

	Total	Ever smokers	Never smokers	Men	Women
Number of participants	3343	1934	1409	1638	1705
Person-years of follow-up	66854	38648	28207	32709	34145
Mean follow up & range (y)	20.0 (18.0 – 22.4)	20.0 (18.0 – 22.4)	20.0 (18.2 – 22.1)	20.0 (18.0 – 22.3)	20.0 (18.2 – 22.4)
Number of incident COPD cases	96	79	17	51	45
COPD incidence per 1000 person-years	1.4	2.0	0.6	1.6	1.3
% men	49.0	51.7	45.4	–	–
Mean age at baseline (y)	34.2	34.7	33.5	34.3	34.0
Mean lifetime pack-years of smoking at follow-up	10.6	20.6	–	13.3	7.9
% current asthma at follow-up	8.1	8.4	7.7	6.2	10.0
% of participants exposed (low or high)					
Biological dust	32.3	32.5	32.0	30.0	34.4
Mineral Dust	25.2	28.1	21.2	36.7	14.1
Gases & fumes	43.5	45.8	40.4	51.7	35.7
Vapors, Gases, Dusts & Fumes	48.4	50.1	46.1	56.4	40.7
Herbicides	2.2	2.1	2.4	3.2	1.3
Insecticides	3.4	3.5	3.3	4.9	1.9
Fungicides	3.9	4.2	3.5	6.3	1.7
All pesticides	4.9	5.4	4.3	7.7	2.2
Aromatic solvents	16.4	17.1	15.4	26.7	6.4
Chlorinated solvents	13.1	14.2	11.7	21.1	5.5
Other solvents	28.5	27.8	29.4	32.1	25.0
Metals	12.6	13.6	11.2	22.9	2.7

**Table 2: Associations between occupational exposures and COPD incidence. Seperate models for ever low or ever high exposure to an agent compared to no exposure to that specific agent. N=3,343 ECRHS participants from 24 study centres without COPD and without asthma at baseline.**

	Cases in unexposed	Cases in exposed	Relative Risk (95% Credible Interval)	Population Attributable Fraction (%)
Biological dust	55/2264 (2.4%)	41/1079 (3.8%)	1.6 (1.1 – 2.3)	16.0%
Mineral Dust	65/2501 (2.6%)	31/842 (3.7%)	1.1 (0.7 – 1.7)	3.9%
Gases & fumes	41/1888 (2.2%)	55/1455 (3.8%)	1.5 (1.0 – 2.2)	19.4%
Vapors, Gases, Dusts & Fumes	40/1725 (2.3%)	56/1618 (3.5%)	1.3 (0.9 – 2.0)	14.1%
Herbicides	91/3269 (2.8%)	5/74 (6.8%)	2.0 (0.7 – 4.1)	2.6%
Insecticides	88/3229 (2.7%)	8/114 (7.0%)	2.3 (1.1 – 4.2)	4.7%
Fungicides	88/3211 (2.7%)	8/132 (6.1%)	1.9 (0.9 – 3.6)	3.9%
All pesticides	86/3179 (2.7%)	10/164 (6.1%)	2.2 (1.1 – 3.8)	5.6%
Aromatic solvents	80/2796 (2.9%)	16/547 (2.9%)	0.9 (0.5 – 1.5)	–
Chlorinated solvents	83/2904 (2.9%)	13/439 (3.0%)	0.8 (0.5 – 1.4)	–
Other solvents	71/2391 (3.0%)	25/952 (2.6%)	0.8 (0.5 – 1.3)	–
Metals	82/2922 (2.8%)	14/421 (3.3%)	1.0 (0.5 – 1.6)	–

Relative Risks adjusted for sex, age, pack-years of smoking, FEV1/FVC ratio at baseline (%predicted), socioeconomic status and early life disadvantage score.

**Table 3: Associations between occupational exposures and COPD incidence, stratified by intensity of exposure**

	Cases in unexposed	Cases in ever low-exposed	Cases in ever high-exposed	Relative Risk (95% Credible Interval), ever low vs no exposure	Relative Risk (95% Credible Interval), ever high vs no exposure
Biological dust	55/2264 (2.4%)	31/905 (3.4%)	10/174 (5.7%)	1.5 (1.0 – 2.2)	2.2 (1.2 – 4.0)
Mineral Dust	65/2501 (2.6%)	18/554 (3.2%)	13/288 (4.5%)	1.0 (0.6 – 1.7)	1.3 (0.7 – 2.2)
Gases & fumes	41/1888 (2.2%)	45/1102 (4.1%)	10/353 (2.8%)	1.6 (1.1 – 2.5)	1.0 (0.5 – 1.9)
Vapors, Gases, Dusts & Fumes	40/1725 (2.3%)	35/1067 (3.3%)	21/551 (3.8%)	1.3 (0.8 – 2.0)	1.3 (0.8 – 2.3)
Herbicides	91/3269 (2.8%)	1/49 (2.0%)	4/25 (16.0%)	0.5 (0.0 – 3.0)	2.8 (1.0 – 5.9)
Insecticides	88/3229 (2.7%)	3/54 (5.6%)	5/60 (8.3%)	2.0 (0.5 – 5.2)	2.2 (0.8 – 4.5)
Fungicides	88/3211 (2.7%)	4/72 (5.6%)	4/60 (6.7%)	1.5 (0.5 – 3.7)	2.0 (0.7 – 4.6)
All pesticides	86/3179 (2.7%)	5/94 (5.3%)	5/70 (7.1%)	2.0 (0.7 – 4.4)	2.1 (0.8 – 4.3)
Aromatic solvents	80/2796 (2.9%)	14/495 (2.8%)	2/52 (3.8%)	0.8 (0.5 – 1.4)	1.3 (0.2 – 4.6)
Chlorinated solvents	83/2904 (2.9%)	9/320 (2.8%)	4/119 (3.4%)	0.8 (0.4 – 1.6)	0.7 (0.2 – 1.7)
Other solvents	71/2391 (3.0%)	22/883 (2.5%)	3/69 (4.3%)	0.8 (0.5 – 1.2)	1.4 (0.4 – 4.0)
Metals	82/2922 (2.8%)	10/287 (3.5%)	4/134 (3.0%)	1.0 (0.5 – 1.9)	0.7 (0.2 – 1.7)

Relative Risks adjusted for sex, age, pack-years of smoking, FEV1/FVC ratio at baseline (%predicted), socioeconomic status and early life disadvantage score.

## Figure Legends

**Figure 1: Flow chart of ECRHS participants into the study population, and reasons for exclusion**

**Figure 2: Correlation map (Spearman's rho) between occupational exposures in the study population (N=3343).**

**Figure 3: Percentage of incident COPD cases according to %predicted FEV1/FVC at baseline, observed and model-fitted.** For the observed cases, the percentage is calculated considering the participants with %predicted FEV1/FVC  $\pm 1$  percentage point.