Chronic obstructive pulmonary disease

ORIGINAL ARTICLE

Occupational exposure to pesticides are associated with fixed airflow obstruction in middle-age

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ABSTRACT

Rationale Population-based studies have found evidence of a relationship between occupational exposures and Chronic Obstructive Pulmonary Disease (COPD), but these studies are limited by the use of prebronchodilator spirometry. Establishing this link using postbronchodilator spirometry is critical, because occupational exposures are a modifiable risk factor for COPD.

Objectives To investigate the associations between occupational exposures and fixed airflow obstruction using postbronchodilator spirometry.

Methods One thousand three hundred and thirty-five participants were included from 2002 to 2008 follow-up of the Tasmanian Longitudinal Health Study (TAHS). Spirometry was performed and lifetime work history calendars were used to collect occupational history. ALOHA plus Job Exposure Matrix was used to assign occupational exposure, and defined as ever exposed and cumulative exposure unit (EU)-years. Fixed airflow obstruction was defined by postbronchodilator FEV1/FVC <0.7 and the lower limit of normal (LLN). Multinomial logistic regressions were used to investigate potential associations while controlling for possible confounders.

Results Ever exposure to biological dust (relative risk (RR)=1.58, 95% CI 1.01 to 2.48), pesticides (RR=1.74, 95% CI 1.00 to 3.07) and herbicides (RR=2.09, 95% CI 1.18 to 3.70) were associated with fixed airflow obstruction. Cumulative EU-years to all pesticides (RR=1.11, 95% CI 1.00 to 1.25) and herbicides (RR=1.15, 95% CI 1.00 to 1.32) were also associated with fixed airflow obstruction. In addition, all pesticides exposure was consistently associated with chronic bronchitis and symptoms that are consistent with airflow obstruction. Ever exposure to mineral dust, gases/fumes and vapours, gases, dust or fumes were only associated with fixed airflow obstruction in non-asthmatics only.

Conclusions Pesticides and herbicides exposures were associated with fixed airflow obstruction and chronic bronchitis. Biological dust exposure was also associated with fixed airflow obstruction in non-asthmatics. Minimising occupational exposure to these agents may help to reduce the burden of COPD.

Key messages

What is the key question?

What are the associations between occupational exposure and fixed airflow obstruction?

What is the bottom line?

This study has shown that pesticides and herbicides exposures were associated with fixed airflow obstruction, chronic bronchitis and respiratory symptoms.

Why read on?

This study is the first to describe an association between all pesticides exposure and fixed airflow obstruction, and certain exposures were only associated with fixed airflow obstruction in non-asthmatics but not in asthmatics.

INTRODUCTION

Chronic Obstructive Pulmonary Disease (COPD) characterised by postbronchodilator (BD) fixed airflow obstruction (AO) is a chronic debilitating respiratory condition and a growing cause of mortality and morbidity worldwide.1 Tobacco smoking remains the predominant risk factor for COPD.2 However, it is now well established that non-smokers also develop COPD and the interest in non-smoking-related risk factors for COPD have exponentially increased in the recent past.3 Occupational exposures are an important potentially modifiable risk factor for COPD, and while the population-based studies conducted to date have provided valuable information about the importance of these exposures in COPD they have had some important limitations.

We recently performed a systematic review assessing the association between occupational exposure to dusts, gases and fumes, and COPD in population-based studies that used job exposure matrices.4 Our review found an overall association between occupational exposures to mineral dust and gases/fumes and COPD. However, the results varied by definitions of COPD and only one study to date had used post-BD spirometry to define COPD.5 This is an important limitation in the current literature as the post-BD measurement of AO is the gold standard to define fixed AO,6 which is the hallmark feature of COPD.1 The one study that did use post-BD to define AO did not find any
association between dust, gases/fumes and fixed AO. However, the age range of this cohort was very broad and more than a quarter of the cohort were younger than 45 years. This highlights a further limitation of the existing studies in this area; they are relatively young cohorts who are not likely to have developed significant fixed AO. Furthermore, only few population-based studies have investigated the effects of lifetime occupational exposures assessed over an individual’s complete working life, which allows for assessment of cumulative exposure. Our systematic review concluded that the combination of young cohorts with pre-BD lung function and the lack of assessment of lifetime occupational exposures highlight the need for further studies in this area addressing these issues.

Another limitation of the existing literature around occupational exposures and COPD is the lack of studies examining pesticide exposures. There is increasing evidence that pesticide exposure is associated with respiratory symptoms and diseases, with the strongest evidence for asthma. Recent studies from the Netherlands have found an association between pesticide and COPD, and lung function decline. However, these studies are again limited by the use of pre-BD spirometry, which does not allow for the identification of fixed AO.

Given the limitations in the studies conducted to date, we investigated the association between occupational exposure and COPD using post-BD spirometry in a general population. We explored both ever exposure and cumulative exposure unit (EU)-years of occupational exposure. Some of the results of this study have been previously published in the form of an abstract.

### METHODS

#### Study design and participants

We included participants from the 2002 to 2008 follow-up of the population-based Tasmanian Longitudinal Health Study (TAHS), details of which have been reported elsewhere, and are summarised in figure 1. Briefly, TAHS started in 1968 when all children aged 7 years (n=8583) attending school in Tasmania were enrolled in a study of asthma. Their parents completed a respiratory health questionnaire, and the children underwent a clinical examination and lung function measurements. Follow-up surveys were conducted in 1974, 1979 and 1991 at the ages of 12, 18 and 30 years, respectively. The 2002–2008 follow-up started in 2002 when participants were in their fifth decade of life. We traced 7562 (88.1%) of the original 1968 cohort to a residential address and achieved a response of 5729 (78.4%) to a postal survey. A subgroup of these respondents, selected from their participation in previous follow-ups and enriched for participants with a history of asthma and bronchitis, were invited to participate in a more detailed laboratory study and information was collected using questionnaire, pre-BD and post-BD lung function test, skin prick testing, lung volumes and diffusing capacity. Of 2387 invited, 1397 (58.6%) took part in full laboratory testing, 354 (14.8%) completed a telephone questionnaire only and 636 (26.7%) withdrew from the study. The 2002 to 2008 follow-up was approved on December 11, 2023.
by the Human Research Ethics Committee of the University of Melbourne (HREC no. 040375). All participants provided written informed consent.

Data collection
Pre-BD and post-BD lung function was measured with the Easyone Ultrasonic spirometer (ndd, Medizintechnik, AG, Switzerland). Participants were asked not to smoke for 4–6 hours before testing. FEV₁ and FVC were measured according to international guidelines and the highest value for FEV₁ and FVC obtained from three acceptable and repeatable tests was recorded. Spriometry was repeated 10–15 min after short-acting bronchodilator (200 µg salbutamol) administration via a spacer.

Outcome definitions
Fixed AO was defined according to Global Initiative for Chronic Obstructive Lung Disease (GOLD) criteria: ratio of post-BD FEV₁/FVC < 0.70. We also used the lower limit of normal (LLN) to define fixed AO, on the basis of Global Lung Function Initiative 2012 regression equations. Fixed AO was defined according to Global Initiative for Chronic Obstructive Lung Disease (GOLD) criteria: ratio of post-BD FEV₁/FVC < 0.70. We also used the lower limit of normal (LLN) to define fixed AO, on the basis of Global Lung Function Initiative 2012 regression equations.18

Chronic bronchitis was defined as a cough with phlegm on most days for at least 3 months of each year for 2 successive years. Chronic cough was defined as usually cough without a cold on most days for at least 3 months for at least 2 years. Chronic phlegm was defined as usually phlegm without a cold on most days for at least 3 months for at least 2 years. Dyspnoea was defined as shortness of breath when hurrying on level ground or walking up a slight hill.

Occupational exposures
Occupational exposures were classified using the lifetime work history calendar that was collected from participants during the laboratory visit or telephone interview. A total of 1599 participants provided complete work histories, but this analysis was restricted to 1335 participants who completed both spirometry testing and one for low exposure. This cumulative EU-years was calculated for each of the exposure types and scaled continuous variable of cumulative exposure per 10 years. Participants missing any years in the lifetime work history calendar were excluded from the cumulative EU-years analysis and so 1255 participants were included in the unadjusted analysis.

Statistical analysis
All the statistical analyses were conducted using Stata V.13.1 (StataCorp, College Station, Texas, USA). The population prevalence of the outcomes were estimated as observed proportions with 95% CI based on the binomial distribution. The estimate prevalences was calculated using inverse-probability-of-inclusion weights to adjust for the enriched sample of the 2002 to 2008 follow-up. The associations between outcomes and occupational exposures were estimated using multinomial logistic regression models. We adjusted for sex, smoking, pack-years, asthma in childhood and adulthood, and socioeconomic status in childhood and adulthood. Due to the correlation between any VGDF exposure and all pesticides exposure (see online supplementary table 6) all models that examined biological dust, mineral dust, gases/fumes or VGDF exposures were additionally adjusted for ever exposure to all pesticides. Similarly, models examining all pesticides, herbicides or insecticides exposure were additionally adjusted for VGDF exposure.

Effect modification by sex, smoking and current asthma was assessed by including interaction terms (occupational exposure×sex, occupational exposure×smoking, occupational exposure×current asthma) in the models. We performed a multiple imputation analysis to impute the values of missing confounders and compared this analysis with the complete-case analysis. The results of the imputed analysis did not differ from the complete-case analysis and the results of the imputation analysis are presented in online supplementary tables 3, 4 and 5. A p value ≤0.05 was considered to be statistically significant.

RESULTS
Characteristics of study population
A comparison of respondents and non-responders to the laboratory study and postal survey for selected characteristics can be found in the online supplementary table 1. Briefly selected characteristics of the participants those who did and did not attend the laboratory study were similar. Table 1 shows the characteristics of included study participants. The mean age of the participants was 44.8 years (±0.8 SD), over half (51.6%) were men, 87.4% were currently employed and 25.1% were current smokers, with a median smoking history of 21 pack-years (Table 1). There was very little difference in the prevalence of fixed AO when using the GOLD (6%; 95% CI 4.8 to 7.5) or LLN (6%; 95% CI 4.8 to 7.5) criteria. The prevalence of chronic bronchitis was 8.6% (95% CI 7.6 to 9.9) and dyspnoea 12.1% (95% CI 10.4 to 14.1). Over 28% of all participants had ever reported asthma.

Ever exposure
Table 2 shows the association between ever exposure and fixed AO, chronic bronchitis and respiratory symptoms. Ever exposed to biological dust was associated with fixed AO (relative risk (RR)=1.58, 95% CI 1.01 to 2.48), while mineral dust was associated with symptoms. Ever exposed to gases/fumes was not associated with fixed AO or symptoms.

Ever exposure to all pesticides was associated with GOLD-defined fixed AO, chronic bronchitis and also with all respiratory symptoms (table 2). Ever exposed to herbicides was also associated with fixed AO, chronic bronchitis and chronic cough. Ever...
exposed to insecticides was associated with chronic bronchitis and chronic cough. Using LLN definition of fixed AO (table 1), we found a significant association between ever exposure to herbicides and fixed AO and a trend of association between all pesticides and fixed AO. In general, using both definitions, we found both all pesticides and herbicides were associated with fixed AO.

**Cumulative EU-years**

For every 10-year increase in cumulative EU-years of exposure to biological dust, there was a 7% increase of chronic cough (RR=1.07, 95% CI 1.00 to 1.15). Cumulative EU-years of exposure to mineral dust and gases and fumes were associated with a 5% increase of dyspnoea (table 3). Cumulative EU-years of exposure to all pesticides was consistently associated with both definitions of fixed AO, chronic bronchitis, chronic cough and chronic phlegm. Cumulative EU-years of exposure to herbicides was associated with fixed AO and chronic bronchitis. Cumulative EU-years of exposure to insecticides was associated with 15% increase of chronic bronchitis (RR=1.15, 95% CI 1.02 to 1.29).

**Interactions with sex, smoking and current asthma**

We explored the potential interactions between occupational exposures and sex, smoking and current asthma. We did not find any interactions with sex or smoking (data not shown). However, we found significant interactions between ever exposure and current asthma. We found a significant interaction between current asthma and biological dust (interaction p=0.003), mineral dust (interaction p=0.03), gases/fumes (interaction p=0.005) and VGDF (interaction p=0.01) for GOLD-defined fixed AO (table 4). For all of these occupational exposures, there was association with fixed AO in the non-asthmatic group but not in the asthmatic group.

**DISCUSSION**

This is the first study to examine fixed AO using the gold standard measurement of post-BD spirometry and two measures of occupational exposure, ever exposure and lifetime cumulative EU-years. Using these robust measures, we have demonstrated significant and consistent associations between all pesticides exposure, fixed AO, chronic bronchitis and chronic cough. We are the first to show that ever exposure to pesticides is associated with fixed AO and increasing cumulative EU-years to pesticides are associated with fixed AO.

A number of previous workplace-based studies have reported increased prevalence of respiratory symptoms and reduced lung function among farmers or agriculture workers exposed to pesticides. However, there has only been one population-based study published in relation to pesticides exposure and AO. This study examined two Dutch cohorts and found an association between pre-BD AO in people exposed to pesticides in one cohort, and a trend towards an association in the other for moderate/severe AO (defined as pre-BD FEV1/FVC <70% and FEV1/FVC <80%). Both cohorts in this study used pre-BD spirometry to define AO, which may have overestimated the prevalence of AO. They also used current or last held job and the results may have been confounded by past exposure. We have demonstrated, in a similarly aged population, an association between ever exposure and cumulative EU-years to all pesticides and fixed AO confirming that minimising exposure to all pesticides may help to reduce the burden of COPD.

We also observed significant association between chronic bronchitis, chronic cough and chronic phlegm with both ever exposure and cumulative EU-years to pesticides. We are first to show cumulative EU-years to pesticides is associated with chronic respiratory symptoms in a population-based study. Recent systematic reviews found chronic bronchitis was associated with pesticides exposure and a study of the US farmers found association between exposure to pesticides and chronic bronchitis. Similar to our findings, a study from Latin America also found an association between pesticides exposure and respiratory symptoms. However, all these studies were conducted in specific occupational groups making the results not applicable to the broader general population, unlike the results from our study.

Pesticides can be classified according to their targets into three main areas: insecticides, herbicides and fungicides. Insecticides include organochlorines, organophosphates and carbamates. Herbicides include phenoxy herbicides and fungicides include dithiocarbamates, and all have been used extensively in agriculture to control pests and weeds. Pesticides can enter the body through inhalation into the respiratory tract and absorption through the skin during use for fumigation, preparation and spraying or during manufacture, storage or transport. Long-term exposure to organophosphate and carbamate pesticides has been shown to lead to inhibition of acetylcholinesterase synthesis from M2 muscarinic receptors that results in mucus hypersecretion and airway smooth muscle contraction causing breathlessness, cough and wheeze. The inactive acetylcholinesterase is also responsible for thickening of alveolar-capillary membrane leading to reduced level of lung function.

The ALOHA plus Job Exposure Matrix assigned exposure to pesticides as ever exposure to all pesticides and then also had...
## Table 2: Association between ever exposure and fixed airflow obstruction, chronic bronchitis and respiratory symptoms

<table>
<thead>
<tr>
<th>Exposures</th>
<th>Fixed AO-GOLD</th>
<th>Fixed AO-LNN</th>
<th>Chronic bronchitis</th>
<th>Chronic cough</th>
<th>Chronic phlegm</th>
<th>Dyspnoea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biological dust</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not exposed</td>
<td>541 37 Ref.</td>
<td>522 98 Ref.</td>
<td>554 148 Ref.</td>
<td>576 121 Ref.</td>
<td>563 57 Ref.</td>
<td>544 84 Ref.</td>
</tr>
<tr>
<td>Exposed</td>
<td>681 76 1.58 (1.01 to 2.48)</td>
<td>681 75 1.56 (1.00 to 2.45)</td>
<td>592 159 0.99 (0.67 to 1.48)</td>
<td>620 126 1.24 (0.83 to 1.84)</td>
<td>639 109 0.98 (0.66 to 1.46)</td>
<td>603 152 1.32 (0.95 to 1.85)</td>
</tr>
<tr>
<td>Mineral dust</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not exposed</td>
<td>585 42 Ref.</td>
<td>586 42 Ref.</td>
<td>522 98 Ref.</td>
<td>555 64 Ref.</td>
<td>563 57 Ref.</td>
<td>544 84 Ref.</td>
</tr>
<tr>
<td>Exposed</td>
<td>636 71 1.29 (0.81 to 2.04)</td>
<td>637 70 1.29 (0.81 to 2.04)</td>
<td>554 148 1.10 (0.72 to 1.67)</td>
<td>576 121 1.62 (1.06 to 2.48)</td>
<td>583 114 1.51 (1.00 to 2.30)</td>
<td>563 143 1.57 (1.10 to 2.23)</td>
</tr>
<tr>
<td>Gases/fumes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not exposed</td>
<td>352 22 Ref.</td>
<td>314 57 Ref.</td>
<td>335 33 Ref.</td>
<td>336 33 Ref.</td>
<td>337 33 Ref.</td>
<td>327 48 Ref.</td>
</tr>
<tr>
<td>Exposed</td>
<td>869 91 1.50 (0.88 to 2.54)</td>
<td>870 90 1.47 (0.87 to 2.51)</td>
<td>762 189 0.91 (0.58 to 1.45)</td>
<td>796 152 1.25 (0.80 to 1.98)</td>
<td>810 138 1.20 (0.76 to 1.90)</td>
<td>780 179 1.31 (0.89 to 1.91)</td>
</tr>
<tr>
<td>VGDF</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not exposed</td>
<td>300 21 Ref.</td>
<td>273 45 Ref.</td>
<td>293 23 Ref.</td>
<td>290 26 Ref.</td>
<td>281 41 Ref.</td>
<td></td>
</tr>
<tr>
<td>Exposed</td>
<td>921 92 1.29 (0.73 to 2.17)</td>
<td>922 91 1.25 (0.72 to 2.15)</td>
<td>803 201 0.95 (0.58 to 1.53)</td>
<td>838 162 1.69 (1.01 to 2.84)</td>
<td>856 145 1.31 (0.80 to 2.17)</td>
<td>826 186 1.29 (0.86 to 1.93)</td>
</tr>
<tr>
<td>All pesticides</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not exposed</td>
<td>1024 85 Ref.</td>
<td>916 183 Ref.</td>
<td>961 134 Ref.</td>
<td>971 124 Ref.</td>
<td>940 169 Ref.</td>
<td></td>
</tr>
<tr>
<td>Exposed</td>
<td>198 28 1.74 (1.00 to 3.07)</td>
<td>199 27 1.63 (0.91 to 3.07)</td>
<td>160 63 1.81 (1.12 to 2.93)</td>
<td>170 51 1.77 (1.04 to 3.01)</td>
<td>175 47 2.06 (1.23 to 3.47)</td>
<td>167 58 1.95 (1.23 to 3.09)</td>
</tr>
<tr>
<td>Herbicides</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not exposed</td>
<td>1061 87 Ref.</td>
<td>947 191 Ref.</td>
<td>993 141 Ref.</td>
<td>1002 132 Ref.</td>
<td>966 182 Ref.</td>
<td></td>
</tr>
<tr>
<td>Exposed</td>
<td>161 26 2.09 (1.18 to 3.70)</td>
<td>162 25 1.95 (1.08 to 3.49)</td>
<td>129 55 1.81 (1.08 to 3.02)</td>
<td>138 44 1.79 (1.04 to 3.09)</td>
<td>144 39 1.62 (0.93 to 2.83)</td>
<td>141 45 1.44 (0.89 to 2.34)</td>
</tr>
<tr>
<td>Insecticides</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not exposed</td>
<td>1060 91 Ref.</td>
<td>947 194 Ref.</td>
<td>996 141 Ref.</td>
<td>1002 135 Ref.</td>
<td>970 181 Ref.</td>
<td></td>
</tr>
<tr>
<td>Exposed</td>
<td>162 22 1.70 (0.93 to 3.10)</td>
<td>163 21 1.56 (0.84 to 2.90)</td>
<td>129 52 1.64 (1.00 to 2.72)</td>
<td>135 44 1.74 (1.00 to 3.05)</td>
<td>144 36 1.62 (0.93 to 2.84)</td>
<td>137 46 1.58 (0.97 to 2.57)</td>
</tr>
</tbody>
</table>

The bolded text identifies results reaching statistical significance (p≤0.05).

*Adjusted for sex, smoking, pack-years, childhood and adulthood socioeconomic status, and childhood and adulthood asthma. The analyses with biological dust, mineral dust, gases/fumes and VGDF were additionally adjusted for all pesticides, whereas the analyses with all pesticides, herbicides and insecticides were additionally adjusted for VGDF exposure.

AO, airflow obstruction; GOLD, Global Obstructive Lung Disease; LLN, lower limit of normal; RR, relative risk; VGDF, vapour, gases, dust and fumes.
The table below displays the association between cumulative EU-years and fixed airflow obstruction, chronic bronchitis, and respiratory symptoms (n=1255) for fixed AO-GO, all linear, and respiratory symptoms. The results reaching statistical significance (p≤0.05) are bolded.

<table>
<thead>
<tr>
<th>Cumulative exposures</th>
<th>Fixed AO-GO</th>
<th>Fixed AO-LLN</th>
<th>Fixed AO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biological dust</td>
<td>RR (95% CI)</td>
<td>RR (95% CI)</td>
<td>RR (95% CI)</td>
</tr>
<tr>
<td>1.03 (0.96 to 1.11)</td>
<td>0.07</td>
<td>0.07</td>
<td>0.05</td>
</tr>
<tr>
<td>Mineral dust</td>
<td>1.10 (0.93 to 1.27)</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Vapours/fumes</td>
<td>1.03 (0.97 to 1.09)</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>VGDF</td>
<td>1.03 (0.97 to 1.09)</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>All pesticides</td>
<td>1.12 (1.00 to 1.25)</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Herbicides</td>
<td>1.10 (0.94 to 1.08)</td>
<td>0.05</td>
<td>0.05</td>
</tr>
</tbody>
</table>

The table above indicates that there is a significant association between cumulative EU-years and fixed airflow obstruction, chronic bronchitis, and respiratory symptoms. The associations observed in this study were largely consistent across all three categories, with some not quite reaching statistical significance for some symptoms. The possible explanation for this slight variation across the subcategories of all pesticides exposure is differences in exposures between different occupational groups with some groups, for example, cattle farmers not being exposed to herbicides but to insecticides. Another example of this is forestry workers who formed a large proportion of our exposed workers (23.8%), but who had ‘all pesticides exposure’ and ‘herbicides exposure’ but not ‘insecticides exposure’. Another explanation is the presence of very strong correlation between these exposures (see online supplementary table 6). In our study, participants with high all pesticides exposures included people who described themselves as farm hands/ labourers, forestry workers, gardeners, horticultural/nursery workers, and crop/vegetable growers.

For the other common exposures to biological dust, mineral dust and gases/fumes, we only observed association with fixed AO for those ever exposed to biological dust. This finding is consistent with previous studies that have also found association between biological dust and COPD. The finding with biological dust in the present study is also consistent with the meta-analysis conducted by our group, although the effect estimates did not reach statistical significance in our meta-analysis. The reason for this slight variation in the effect estimate may be due to the inclusion of pre-BD in most of the included studies in our meta-analysis. We did not observe any association between mineral dust and gases/fumes exposure and fixed AO, but we did observe associations with respiratory symptoms. Several previous studies also found an association between dust exposure in general and respiratory symptoms.

Our study observed a significant interaction between current asthma and four of the occupational exposures for fixed AO. In the non-asthmatics, there was an association between ever exposure to biological dust, mineral dust and gases/fumes and fixed AO, even with a low crude prevalence of 7.12% in non-asthmatics, compared with asthma (16.98%). We did not observe the same interaction for cumulative EU-years to these agents. This finding is suggestive of a healthy worker effect, that is, asthmatics who remain in the study are relatively unaffected by these occupational exposures. It also may suggest that asthma alone is a significant risk factor for fixed AO in middle-age and additional occupational exposure does not substantially increase the risk observed at this age. We did explore childhood asthma status, recorded prospectively in this cohort, but we did not find any interaction with occupational exposures and fixed AO. We also did not observe any interaction between current asthma and all pesticides for fixed AO suggesting the ever exposure and cumulative EU-years of all pesticides significantly associated with fixed AO independent of asthma.

Previous studies of occupational exposure and COPD using the ALOHA Job Exposure Matrix have taken asthma into account in their analysis by different methods. They have either excluded asthmatics completely or performed sensitivity analysis to see if excluding participants with asthma influenced the results. Including participants with asthma would inflate the prevalence of fixed AO, especially if pre-BD was used in a relatively young cohort, as was the case for several of these studies, leading to spurious results. We included both childhood and adult asthma as a confounder in the statistical analyses and investigated the possible interaction with current asthma. Our study has demonstrated for the first time in a general population that asthma significantly modifies the effect of biological dust, mineral dust and gases, and fumes on fixed AO in middle-age.

### Table 3: Association between cumulative EU-years and fixed airflow obstruction, chronic bronchitis, and respiratory symptoms (n=1255)

<table>
<thead>
<tr>
<th>Cumulative exposures</th>
<th>Fixed AO-GO</th>
<th>Fixed AO-LLN</th>
<th>Fixed AO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biological dust</td>
<td>RR (95% CI)</td>
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<td>RR (95% CI)</td>
</tr>
<tr>
<td>1.03 (0.96 to 1.11)</td>
<td>0.07</td>
<td>0.07</td>
<td>0.05</td>
</tr>
<tr>
<td>Mineral dust</td>
<td>1.10 (0.93 to 1.27)</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Vapours/fumes</td>
<td>1.03 (0.97 to 1.09)</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>VGDF</td>
<td>1.03 (0.97 to 1.09)</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>All pesticides</td>
<td>1.12 (1.00 to 1.25)</td>
<td>0.05</td>
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</tr>
<tr>
<td>Herbicides</td>
<td>1.10 (0.94 to 1.08)</td>
<td>0.05</td>
<td>0.05</td>
</tr>
</tbody>
</table>

### Notes:
- RR = Relative Risk
- CI = Confidence Interval
- *Adjusted for sex, smoking, pack-years, education, and country
- Bolded text identifies results reaching statistical significance (p≤0.05).

Chronic obstructive pulmonary disease
Both GOLD and LLN definitions of fixed AO in our study produced similar effect estimates with most of the exposures except all pesticides exposure, where we found a significant association using GOLD definition, but when we used the LLN definition the association with all pesticides did not quite reach statistical significance. The previous study on occupational exposure and COPD in Switzerland also found similar to our results, although they used pre-BD to define COPD.29 Post-BD is essential to define fixed AO, but there is still debate over the best cut-off values to define fixed AO.30 The GOLD definition of fixed ratio (FEV1/FVC <0.7) has been widely used for clinical application as well as large-scale population-based studies.31 More recently, statistical reference equation-based LLN definition also provide an opportunity to overcome age-related overestimation of the total effect by GOLD.32 We observed very little variation between the two definitions of fixed AO, with only one person being classified as having fixed AO by the GOLD and not the LLN definition. This person was on the borderline of being categorised as having fixed AO by the LLN definition. Other data from this individual (ie, heavy personal smoking history and occupational history with high likelihood of occupational exposure to herbicides and all pesticides) and the relatively small change in the estimates between the two definitions we would not regard this person as an extreme outlier or having undue influence and so he has not been removed from the analysis.

The availability of post-BD data was a major strength of our study. The availability of work history calendars for the participants’ entire working life was also a major strength and enabled the calculation of ever exposure and cumulative EU-years. We have attempted to minimise any bias related to recalling of work exposures by using standardised lifetime work history calendars and then assigning exposure via the use of a Job Exposure Matrix to estimate cumulative EU-years across all jobs. Job Exposure Matrices are affected by non-differential misclassification of exposure, which occurs when there is heterogeneity of exposure in a given job or occupation. However, this generally results in misclassification towards the null, leading to an underestimation of the effect of the exposure on the risk of the disease. Multiple comparisons were performed but the associations, particularly with all pesticides and herbicides exposure, were consistent across several outcomes, suggesting genuine associations rather than chance findings. However, our laboratory attendees, enriched for asthma and chronic bronchitis and had similar clinical profiles despite the lung function testing.

In conclusion, our study has shown that both ever and cumulative EU-years to pesticides are associated with fixed AO and respiratory symptoms. We have also shown this effect of pesticides is independent of asthma. For other occupational exposures to VDGF, we found an association with fixed AO only in those without current asthma. However, we did not find any significant association between fixed AO and chronic bronchitis with exposure to mineral dust, gases/fumes and VDGF. Future population-based studies need to use post-BD to define fixed AO, which allows asthma to be adequately taken into account. Our study has shown even in a middle-aged group of people, a significant proportion of fixed AO is associated with occupational exposures. Our findings highlight the need to reduce workplace exposure to pesticides by improving adherence to use of recommended protective equipment, and workplace monitoring of exposure levels could be implemented. By enhanced monitoring and use of protective equipment, the burden of COPD caused by occupational exposures has the potential to be substantially reduced.

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Table 4 Association between ever exposure to biological dust, mineral dust, gases/fumes and VDGF stratified by current asthma

<table>
<thead>
<tr>
<th>Exposures</th>
<th>Current asthmatics</th>
<th>Non-asthmatics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fixed AO-GOLD</td>
<td>Non-fixed AO</td>
</tr>
<tr>
<td></td>
<td>No % (n/N)</td>
<td>Yes % (n/N)</td>
</tr>
<tr>
<td>Biological dust</td>
<td>63% (167/265)</td>
<td>55.6% (25/45)</td>
</tr>
<tr>
<td>Mineral dust</td>
<td>56% (149/266)</td>
<td>53.3% (24/45)</td>
</tr>
<tr>
<td>Gases/fumes</td>
<td>76.3% (203/266)</td>
<td>71.1% (32/45)</td>
</tr>
<tr>
<td>VDGF</td>
<td>79.7% (212/266)</td>
<td>73.3% (33/45)</td>
</tr>
</tbody>
</table>

The bolded text identifies results reaching statistical significance (p≤0.05).
*Adjusted for sex, smoking, pack-years, childhood and adulthood socioeconomic status, and all pesticides as coexposure.
No interaction was observed with exposure to all pesticides, herbicides and insecticides (results not shown).
AO, airflow obstruction; GOLD, Global Obstructive Lung Disease; RR, relative risk; VDGF, vapour, gases, dust and fumes.
Contributors  Study concept and design: SMA, SCD, GB, RV, HK, EHW, MJA, MCM. Acquisition of data: SMA, SCD, JLP, PST, RWF, BRT, IFF, RV, HK, EHW, MJA, MCM. Analysis and interpretation of data: SMA, SCD, GB, MD, LCG, RV, HK, MJA, MCM. Drafting of the manuscript: SMA, SCD, GB, MD, MCM. Critical revision of the manuscript for important intellectual content: All Authors. Statistical analysis: SMA, LCG, MCM. Obtained funding: SCD, GB, DJP, LCG, PST, JLH, RWB, BRT, IFF, EHW, MJA, MCM. Study supervision: SMA, SCD, GB, MD, MCM. SMA and MCM had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

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