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ORIGINAL ARTICLE

# Occupational exposure and the risk of airway obstruction and mortality

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## Abstract

**Objectives** To identify occupational groups at high risk of airway obstruction (AO) and mortality and potential interactions with smoking.

**Methods** Lung function data from the LuftiBus project were enriched with occupational and follow-up information from the Swiss National Cohort, resulting in a cohort of 10582 adults between 2000 and 2015. We assigned professions to occupational groups and estimated the risk of AO and mortality using adjusted logistic and Cox regression model. Additionally, we assessed multiplicative and additive interactions between occupational exposure and smoking.

**Results** Chimney sweeps and male workers from the agriculture, construction and food industries had an increased risk of AO (odds ratios ranging from 1.43 to 2.21). The risk of mortality was increased among male workers from the food industry (hazard ratio 1.57, 95% CI 1.10–2.23). Interactions with smoking were present in most associations, but smoking had no effect on the increased risk of mortality in the food industry.

**Conclusions** Some occupational groups have a considerable risk of AO and mortality. The identification of the most affected occupations is of great importance enabling targeted risk reduction strategies.

**Keywords** Occupational exposure · Airway obstruction · Mortality · Industries · Interaction

## Introduction

Occupational exposure to airborne pollutants can affect the respiratory system and lead to lung disease characterized by airway obstruction (AO) such as asthma or chronic obstructive pulmonary disease (COPD) (Balmes et al. 2003; Peters et al. 2012). Patients with a more advanced stage of AO are often physically very limited and suffer from concomitant physical and mental diseases (e.g., cardiovascular disease, skeletal muscle dysfunction, anxiety and depression) (Global Initiative for Chronic Obstructive Lung Disease 2018). Moreover, COPD is the fifth leading cause of death and it is estimated that it will become the third by 2030 (World Health Organization 2020).

Based on different international community and general population studies it has been estimated that occupational exposure contributes 15–31% to the prevalence of COPD and 15% to the prevalence of asthma (Hnizdo et al. 2002; Balmes et al. 2003). In fact, vapors, gases, dusts or fumes (VGDF) have been identified as important airborne pollutant types contributing to the development of lung diseases

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(Sadhra et al. 2016). Furthermore, several studies show an effect of different occupational inhalation exposures on mortality from cardiovascular diseases, COPD or lung cancer (Gallagher et al. 2012; Vehmas et al. 2013; Torén and Järvholm 2014). Considering that up to 25% of the working population is exposed to VGDF, occupational exposures may have the potential to pose a relevant public health threat (Calvert et al. 2013; Si et al. 2016).

In a systematic review of Omland et al. (2014), they found that industry- or occupation-specific studies with exposure to inorganic/mineral (e.g., welder, coal miner, asphalt, foundry and bleach worker) and organic/biological inhaled pollutants (e.g., dairy farmer, textile, wood, rubber and paper worker) were associated with an increased risk of AO.

Nevertheless, population-based studies including multiple industries and job types are rare and the majority did not adjust for important confounders such as outdoor air pollution exposure or educational level (Omland et al. 2014). Furthermore, the number of cases is often not large enough to detect even small associations or most studies just do not have data on mortality. Moreover, older studies often used fixed-ratio criteria for AO, which is no longer recommended (Quanjer et al. 2013). Previous studies indicate a possible interaction between occupational exposures and cigarette smoking, but additive interactions with smoking are documented mainly among asbestos workers developing lung cancer (Balmes et al. 2003; Ngamwong et al. 2015). However, there is only limited evidence of the interaction between occupational exposure and smoking on AO.

The aim of this study was to identify occupational groups in the general population with an increased risk of AO and/or mortality and to estimate to what extent the occupational inhalation exposures alone or their interactions with smoking contribute to these important health effects. We expect that some occupational groups, in particular agriculture, food processing, wood processing and construction industries, are associated with an increased risk of AO and mortality, and that smoking increases the association between occupational exposure and AO/mortality.

## Methods

### Study design and population

For our population-based study, we used data from the "LuftiBus", a health promotion campaign of the not-for-profit health organization "Zurich Lung Association" (Switzerland) (http://www.lunge-zuerich.ch/de/projekte/luftibus). This campaign included a bus, which drove all around Switzerland (all Swiss cantons represented) and offered spirometry to the general population. Eligible were subjects who completed the lung function test in the LuftiBus between 2003 and 2012 ($N = 76421$), aged $\geq 40$ years and had complete demographic information (see Fig. 1 for study flow chart). The LuftiBus dataset included following information: forced expiratory volume in the first second in percent predicted (FEV1% predicted), forced vital capacity (FVC) and smoking status.

We enhanced the LuftiBus dataset by adding information from the Swiss National Cohort (SNC). The SNC is a nationwide census-based cohort combining anonymized individual data from the 1990 and 2000 federal population censuses, the death registry, emigration records and the yearly registry censuses since 2010, covering all residents of Switzerland (http://www.swissnationalcohort.ch). We used follow-up data from the SNC on death, emigration and the yearly registry censuses up to 31st December 2015. The SNC provided information on learned professions (occupations), educational level, date of death and residential distance to major roads (defined as $> 5000$ average daily traffic) based on geo-coordinates of place of residence (see Online Resource 1 for study design).

Due to unavailability of a unique person identifier, records were deterministically linked using following identifiers: date of birth, residential postcode and sex. This set of identifiers allows us to identify and link records from the SNC to the LuftiBus dataset that belong to the same subject.

We could link 43424 LuftiBus participants to an SNC record with information from the 2000 census. We had to exclude several subjects ($n = 32842$) for various reasons that are described in Fig. 1. The number of subjects and their professions that were too broad to be assigned to a specific occupational group or professions that were not considered to be exposed ($n = 9165$) are provided in Online Resource 2. All these steps resulted in a cohort of 10582 adults.

### Occupational exposure

In the 2000 census, subjects specified their learned profession with the highest completed level of vocational training (e.g., electrical mechanic, state registered nurse, Doctor of Medicine M.D.). Occupational professions were coded according to the Swiss Standard Classification of Occupations (SSCO) 2000 in the SNC (Federal Statistical Office FSO 2003). The SSCO comprises 380 five digit codes covering complete range of occupations. At a single digit level, all occupations can be classified under nine main occupational groups (divisions).

Based on literature, fifteen occupational groups are associated with an increased risk of lung diseases when

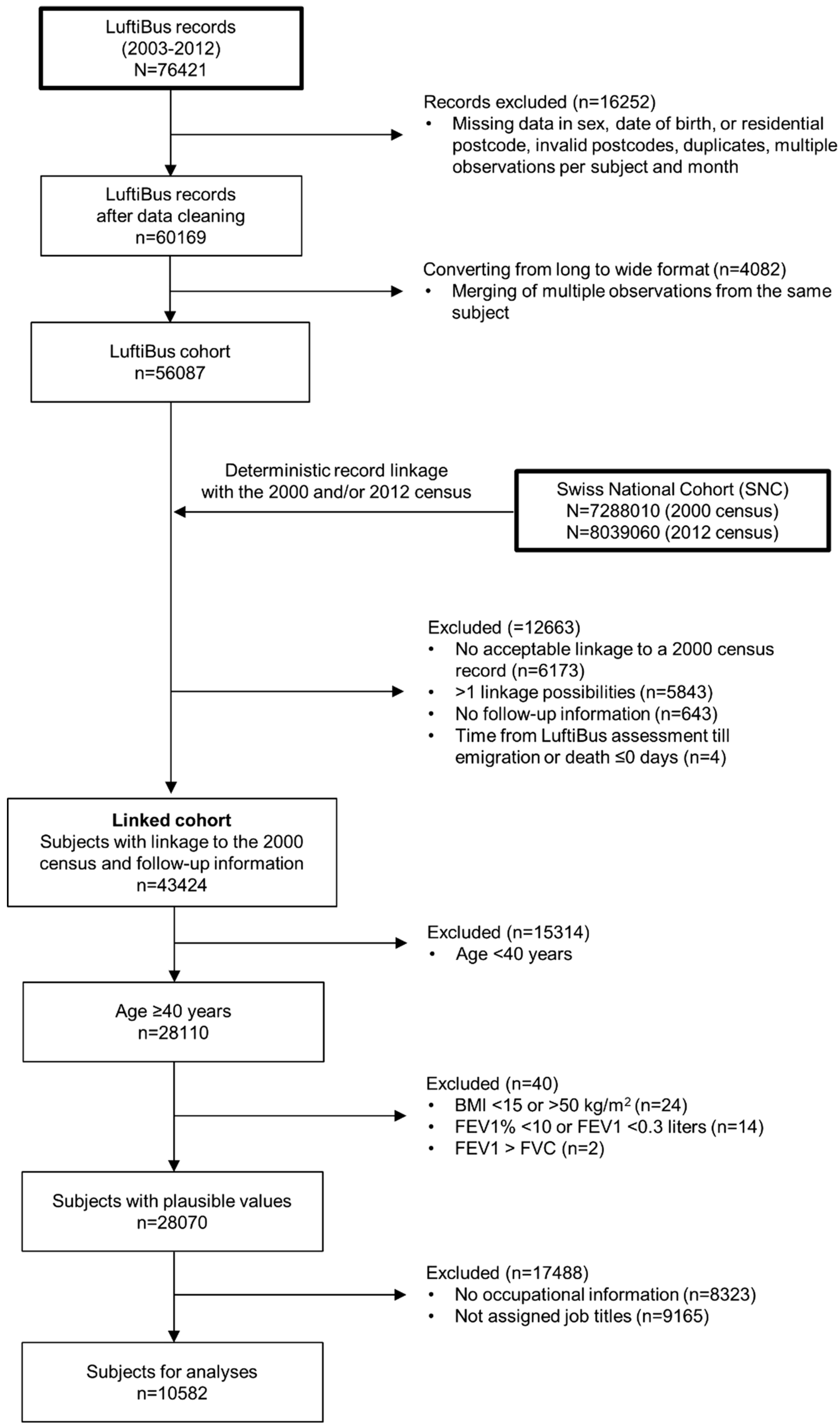


**Fig. 1** Study flow chart, Switzerland (2000–2015). *FEV1* forced expiratory volume in the first second, *FVC* forced vital capacity

exposed to high levels of VGDF, these included individuals working in the following sectors: agriculture, food processing industry, textile processing industry, metal processing industry, wood processing industry, paper processing and printing industry, mechanical engineering and maintenance, vehicles manufacturing, electronics industry, chemical production, construction industry, health care, domestic work and cleaning, hygiene and body care and chimney cleaning (Hendrick et al. 2002; Tarlo et al. 2010; Omland et al. 2014; Alhamdow et al. 2017).

Office workers were used as a reference group as they were not considered exposed to VGDF (Mastrangelo et al. 2003; Hnizdo et al. 2004). The SSCO 2000 coding system includes seven different administrative professional groups: commercial clerks, administrative officers, accounting clerks, real estate managers, import/export professionals, business professionals and related professions and other administrative workers. Since the latter four occupations are solely largely office based and may include other duties including driving (possible exposure to vehicle exhaust fumes) as a part of their jobs, we limited the reference group to the study participants assigned to any of the following three professions: commercial clerks, administrative workers and accounting clerks. The analyses were conducted on the level of occupational groups and professions. In a few cases similar professions were grouped together (e.g., midwives, paediatric nurses, psychiatric nurses, nurses and assistant nurses were combined into one group "nurse and midwife"). All included professions and their assignment to the occupational groups are depicted in Online Resource 3.

### Lung function testing

Spirometry was performed during LuftiBus assessment using a computerised pneumotachograph (SensorMedics® Vmax Legacy 20c spirometer run by Vision 7-2b software; VIASYS, Yorba Linda, CA, USA) without prior use of bronchodilator. The device was calibrated daily and the LuftiBus technicians were trained at least twice a year. Subjects performed the test in a sitting position with straight back, neck in neutral position, without nose clip and after an oral instruction by the technicians according to the ATS/European Respiratory Society guidelines (ATS 1991; Miller et al. 2005). A minimum of two acceptable tests of a maximum of eight performed tests were required, the FEV1/FVC ratio was taken from the test with the largest sum of FEV1 and FVC.

### Statistical analysis

All analyses were conducted using STATA IC (version 13, College Station [TX], USA). We calculated the risk of AO using logistic regression (odds ratios, OR) and the risk of all-cause mortality using Cox proportional hazards regression (hazard ratios, HR). Occupational groups were entered as a categorical exposure variable into the model. For the analysis, we assumed that participants did not move into a different occupational group during the study period. We defined AO by the lower limit of normal of the FEV1/FVC ratio (Hankinson et al. 1999). The regression analyses were stratified by sex and adjusted for age, smoking status (never, ex-smoker, current smoker), year and season of lung function measurement, residential distance to major roads and educational level. We used residential distance to major roads for each subject as a proxy for (traffic-related) outdoor air pollution (Eisner et al. 2010). Since distance to major roads may be associated with the profession (e.g., farmers living further away from major roads) and the outcomes, we included it as a confounder. Furthermore, we added educational level as a confounder due to its relation to occupation, airway obstruction and mortality through health literacy (Hummer and Hernandez 2013; van der Heide et al. 2013; Mantwill et al. 2015). The risks were only calculated for occupational groups and professions with $\geq 50$ workers.

We calculated the contribution of smoking on the association between occupational exposure and AO/mortality using multiplicative and additive interaction analyses (VanderWeele and Knol 2014). For this purpose, we had to dichotomize the smoking variable into never smoker (0) and ex-/current smoker (1). In the additive interaction analysis, we estimated the relative excess risk due to interaction and the attributable proportion that is due to the interaction. We expected both exposures to increase the risk of AO/mortality, thus, we decided a priori to estimate the interaction effects for those occupational groups with an OR/HR $\geq 1.40$ in the main analyses. The proportional hazards assumptions for the survival analysis were fulfilled. We performed a sensitivity analysis by including all other professions that were excluded ($n = 9165$) into the reference group to minimize confounding through selection bias.

We did not conduct a power analysis since we used two existing datasets. $P$ values less than 0.05 were considered statistically significant.

## Results

### Study population

From a total of 10582 subjects, we identified 6654 subjects to be occupationally exposed to VGDF (Table 1). The mean age, time in study and FEV1/FVC% predicted and the frequency distribution of smoking status were similar between non-exposed and exposed subjects. The residential distance to major roads was higher for exposed subjects than for non-exposed subjects, regardless of sex. Male non-exposed workers were more likely to have a higher

**Table 1** Subject characteristics of the LuftiBus cohort after record linkage with the Swiss National Cohort, stratified by sex and occupational exposure to vapors, gases, dusts or fumes, Switzerland (2000–2015)

| | Men | | Women | | |
|---|---|---|---|---|---|
| | Non-exposed | Exposed | Non-exposed | Exposed | Total |
| Subjects | 972 (18.9) | 4181 (81.1) | 2956 (54.5) | 2473 (45.6) | 10582 (100.00) |
| Age years | 60.8 ± 12.1 | 58.9 ± 11.6 | 58.7 ± 11.0 | 58.4 ± 11.1 | 58.9 ± 11.4 |
| Smoking[a] | | | | | |
| Never smoker | 443 (45.7) | 2004 (48.1) | 1788 (60.7) | 1 617 (65.6) | 5852 (55.5) |
| Ex-smoker | 337 (34.8) | 1395 (33.5) | 719 (24.4) | 512 (20.8) | 2963 (28.1) |
| Current smoker | 189 (19.5) | 771 (18.5) | 438 (14.9) | 337 (13.7) | 1735 (16.5) |
| Residential distance to major roads (m) | 507.7 ± 765.7 | 687.1 ± 1230.0 | 504.4 ± 768.8 | 591.0 ± 928.3 | 597.1 ± 1012.1 |
| Educational level | | | | | |
| Higher education[b] | 260 (26.8) | 828 (19.8) | 364 (12.3) | 344 (13.9) | 1796 (17.0) |
| Season | | | | | |
| Fall | 385 (39.6) | 1616 (42.9) | 1257 (42.5) | 1010 (40.8) | 4452 (42.1) |
| Winter | 60 (6.2) | 279 (7.4) | 170 (5.8) | 125 (5.1) | 652 (6.2) |
| Spring | 256 (26.3) | 1020 (27.1) | 838 (28.4) | 755 (30.5) | 2996 (28.3) |
| Sommer | 271 (27.9) | 849 (22.6) | 691 (23.4) | 583 (23.6) | 2482 (23.5) |
| Years in study from LuftiBus assessment[c] | 7.5 ± 2.8 | 7.5 ± 2.7 | 7.8 ± 2.7 | 7.8 ± 2.8 | 7.7 ± 2.7 |
| Years in study from the 2000 census[c] | 14.0 ± 1.5 | 14.1 ± 1.4 | 14.2 ± 0.9 | 14.2 ± 1.0 | 14.2 ± 1.2 |
| FEV1/FVC% predicted[d] | 96.7 ± 10.9 | 96.5 ± 10.8 | 97.3 ± 9.3 | 97.8 ± 9.4 | 97.1 ± 10.1 |
| Airway obstruction[d] | 119 (12.3) | 554 (13.3) | 367 (12.4) | 279 (11.3) | 1319 (12.5) |
| Event | | | | | |
| Censored | 880 (90.6) | 3811 (91.2) | 2820 (95.4) | 2364 (95.6) | 9875 (93.3) |
| Died | 92 (9.5) | 370 (8.9) | 136 (4.6) | 109 (4.4) | 707 (6.7) |

Data are presented as *n* (%) or mean ± SD. Airway obstruction was defined by the lower limit of normal of the FEV1/FVC ratio. *FEV1* forced expiratory volume in the first second, *FVC* forced vital capacity

[a]32 missing values

[b]Higher education: maturity schools and teaching school, higher vocational education and higher college, university of applied sciences and university, college

[c]Time till death or censoring

[d]24 missing values

education than exposed workers, this did not apply to the female workers.

## Risk of airway obstruction

The adjusted logistic regression showed an increased risk of AO among men from the agriculture (OR 1.70, 95% CI 1.22–2.37, $p = 0.002$), construction (OR 1.55, CI 1.10–2.17, $p = 0.011$) and food processing industries (OR 1.43, CI 1.03–1.98, $p = 0.032$) (Fig. 2). The highest risk of AO among men had chimney sweeps with more than double the risk compared to the reference group (OR 2.21, CI 1.03–4.77, $p = 0.043$) followed by farmers and kitchen staff. Butchers, bricklayers, painters/decorators and physicians showed also increased risks of AO, but this was not statistically significant. In the sensitivity analysis, the effect estimates were similar but only statistically significant for the agriculture (OR 1.43, CI 1.09–1.89) and kitchen staff (OR 1.56, CI 1.02–2.39) (Online Resource 4). We could not find any increased risk of AO among female workers (Online Resource 5 and 6).

In our interaction analysis with smoking on AO, we found that additive and multiplicative interaction with smoking was present in workers from the agriculture, food processing and construction industries, although not very high in the latter two industries (Table 2).

## Risk of mortality

We found an increased risk of mortality among men from the food processing industry (HR 1.57, CI 1.10–2.23, $p = 0.012$) (Fig. 3). The risk among dairy workers of the food processing industry was more than two and a half times greater than among the reference group (HR 2.90, CI

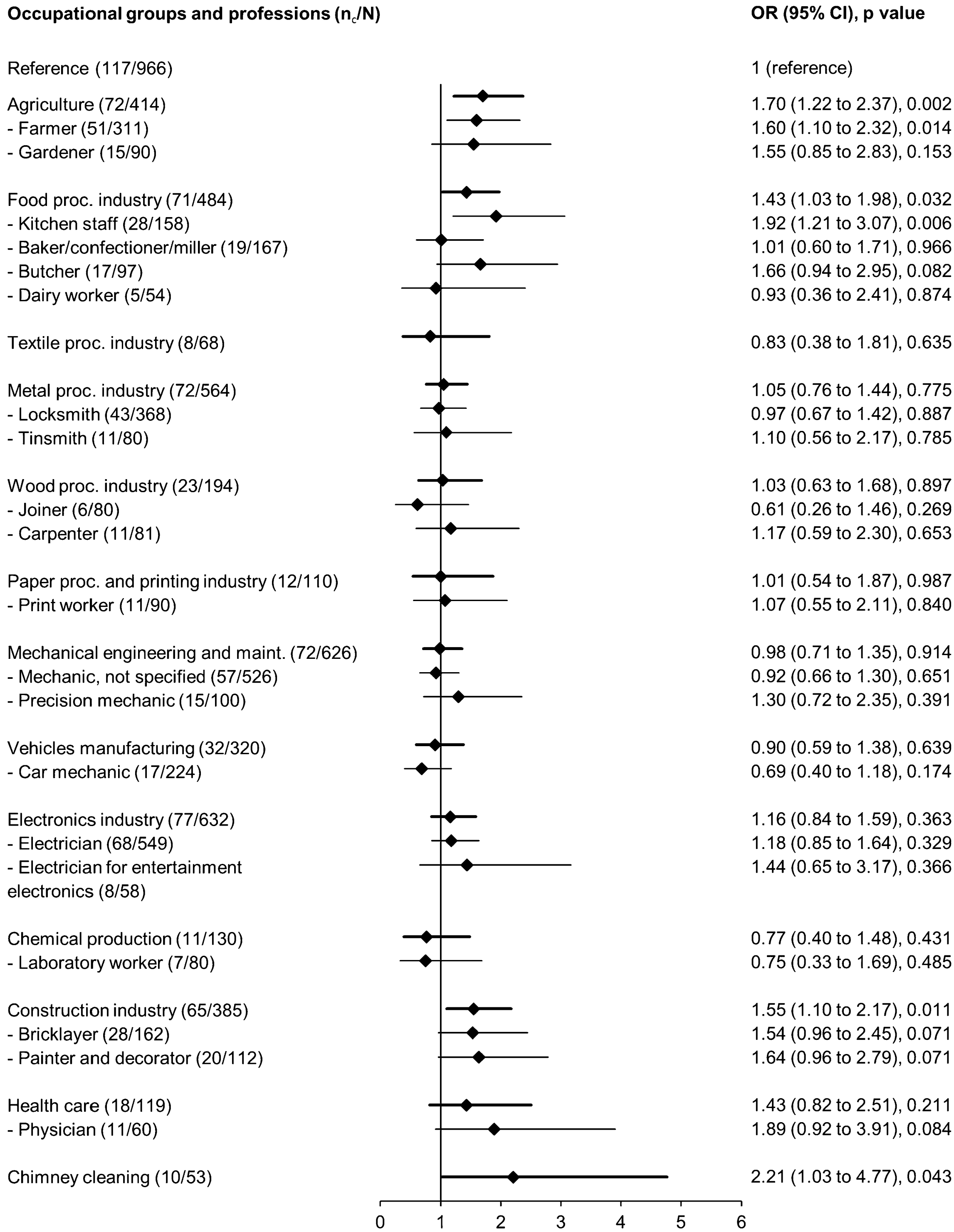


**Fig. 2** Risk of airway obstruction in occupational groups and professions among men, Switzerland (2000–2015). The regressions were adjusted for age, smoking status, year and season of assessment, residential distance to major roads and educational level. Observations with missing values in lung function ($n = 41$) and smoking status ($n = 40$) were excluded. *OR* odds ratio, *CI* confidence interval, $n_c$ number of cases, *N* total number of subjects in each group, *proc.* processing, *maint.* maintenance

1.39–6.06, $p = 0.005$), the risk was also increased among butchers but this was not statistically significant. Workers from the wood processing, electronics and construction industries also showed an increased risk of mortality, but this was not statistically significant. Within these occupational groups joiners, electricians and bricklayers were

**Table 2** Multiplicative and additive interactions between occupational groups and smoking on airway obstruction among men, Switzerland (2000–2015)

| Occupational group | $n_c/N$ | Never smoker OR (95% CI) | $n_c/N$ | Ex-/current smoker OR (95% CI) |
|---|---|---|---|---|
| Not occupationally exposed | 43/442 | 1 (reference) | 74/524 | 1.62 (1.08 to 2.44) |
| Agriculture | 28/230 | 1.48 (0.87 to 2.50) | 44/184 | 3.44 (2.12 to 5.59) |
| Multiplicative interaction: | 1.48 × 1.62 = 2.40 (exp. effect) < 3.44 (obs. effect) | | | |
| Additive interaction: | $RERI_{OR}$ (95% CI) | 1.34 (− 0.07 to 2.76) | | |
| | AP% (95% CI) | 39.0 (7.9 to 70.2) | | |
| Not occupationally exposed | 43/442 | 1 (reference) | 74/524 | 1.68 (1.12 to 2.53) |
| Food processing industry | 26/225 | 1.38 (0.82 to 2.34) | 45/259 | 2.44 (1.53 to 3.91) |
| Multiplicative interaction: | 1.38 × 1.68 = 2.32 (exp. effect) < 2.44 (obs. effect) | | | |
| Additive interaction: | $RERI_{OR}$ (95% CI) | 0.38 (− 0.72 to 1.48) | | |
| | AP% (95% CI) | 15.5 (− 27.1 to 58.0) | | |
| Not occupationally exposed | 43/442 | 1 (reference) | 74/524 | 1.65 (1.10 to 2.48) |
| Construction industry | 18/138 | 1.50 (0.82 to 2.74) | 47/247 | 2.51 (1.57 to 4.00) |
| Multiplicative interaction: | 1.50 × 1.65 = 2.48 (exp. effect) < 2.51 (obs. effect) | | | |
| Additive interaction: | $RERI_{OR}$ (95% CI) | 0.36 (− 0.85 to 1.57) | | |
| | AP% (95% CI) | 14.4 (− 31.6 to 60.5) | | |
| Not occupationally exposed | 43/442 | 1 (reference) | 74,524 | 1.11 (0.72 to 1.71) |
| Health care | 9/65 | 1.47 (0.43 to 5.10) | 9/54 | 0.36 (0.08 to 1.60) |
| Multiplicative interaction: | 1.47 × 1.11 = 1.63 (exp. effect) > 0.36 (obs. effect) | | | |
| Additive interaction: | $RERI_{OR}$ (95% CI) | − 1.22 (− 3.20 to 0.76) | | |
| | AP% (95% CI) | − 340.3 (− 1135.6 to 455.0) | | |

Multiplicative and additive interactions are present when the observed joint effect exceeds the expected joint effect (product or sum of the observed effects). Multiplicative interaction: the expected joint effect can be obtained by $OR_{10}$*$OR_{01}$ (e.g. agriculture * smoking: 1.48 * 1.62 = 2.40, the observed joint effect of 3.44 is higher than the expected effect of 2.40, therefore positive multiplicative interaction is present). Additive Interaction: the RERI shows the relative risk excess that is due to the additive interaction and can be obtained by $OR_{11}$-$OR_{10}$-$OR_{00}$ + 1. If RERI = 0 no additive interaction, RERI > 0 positive additive interaction and RERI < 0 negative additive interaction is present. The AP (RERI/$OR_{11}$) shows the proportion of the risk in the doubly exposed group that is due to the interaction. All regressions were adjusted for age, smoking status, year and season of assessment, residential distance to major roads and educational level. *OR* odds ratio, *CI* confidence interval, $n_c$ number of cases, *N* total number of subjects in each group, *exp. effect* expected effect, *obs. effect* observed effect, *RERI* relative excess risk due to interaction, *AP* attributable proportion

affected the most. In the sensitivity analysis, the risk of mortality was statistically significantly increased among construction workers (HR 1.44, CI 1.02–2.03, $p = 0.039$), in particular bricklayers (HR 1.77, CI 1.05–2.98, $p = 0.033$) (Online Resource 4). Again, we could not find any increased risk of AO among female workers (Online Resource 6 and 7).

We did not find additive or multiplicative interaction with smoking in male workers from the food processing and construction industries. In the wood processing and electronics industries, smoking increased the risk of mortality on the additive and multiplicative scales (Table 3).

## Discussion

In this study population-based study, we found that male workers from the agriculture, food processing and construction industries had an increased risk of AO. The highest risk was found among chimney sweeps where the risk was nearly two and a half times higher compared to non-exposed workers. The risk of mortality was increased among workers from the food processing industry. We could not find any substantial increase of risk of AO and/or mortality among the female population. The lack of effect among the female population may be due to the fact that men may tend to exercise tasks with higher exposure to VGDF more often than women (Preston 1999).

The increased risk of AO among the male population ranged from OR 1.43 to 2.21, which is in line with the findings of organic and inorganic exposure in the systematic review of Omland et al. (2014) (OR 1.20–8.86) and other systematic reviews (Borup et al. 2017; Guillien et al. 2019). Farmers and construction workers in particular are exposed to a wide range of organic and inorganic pollutants. For farmers these include grain dust, pesticides and diesel exhaust, construction workers are commonly exposed to welding fumes, solvents (paint and adhesives),

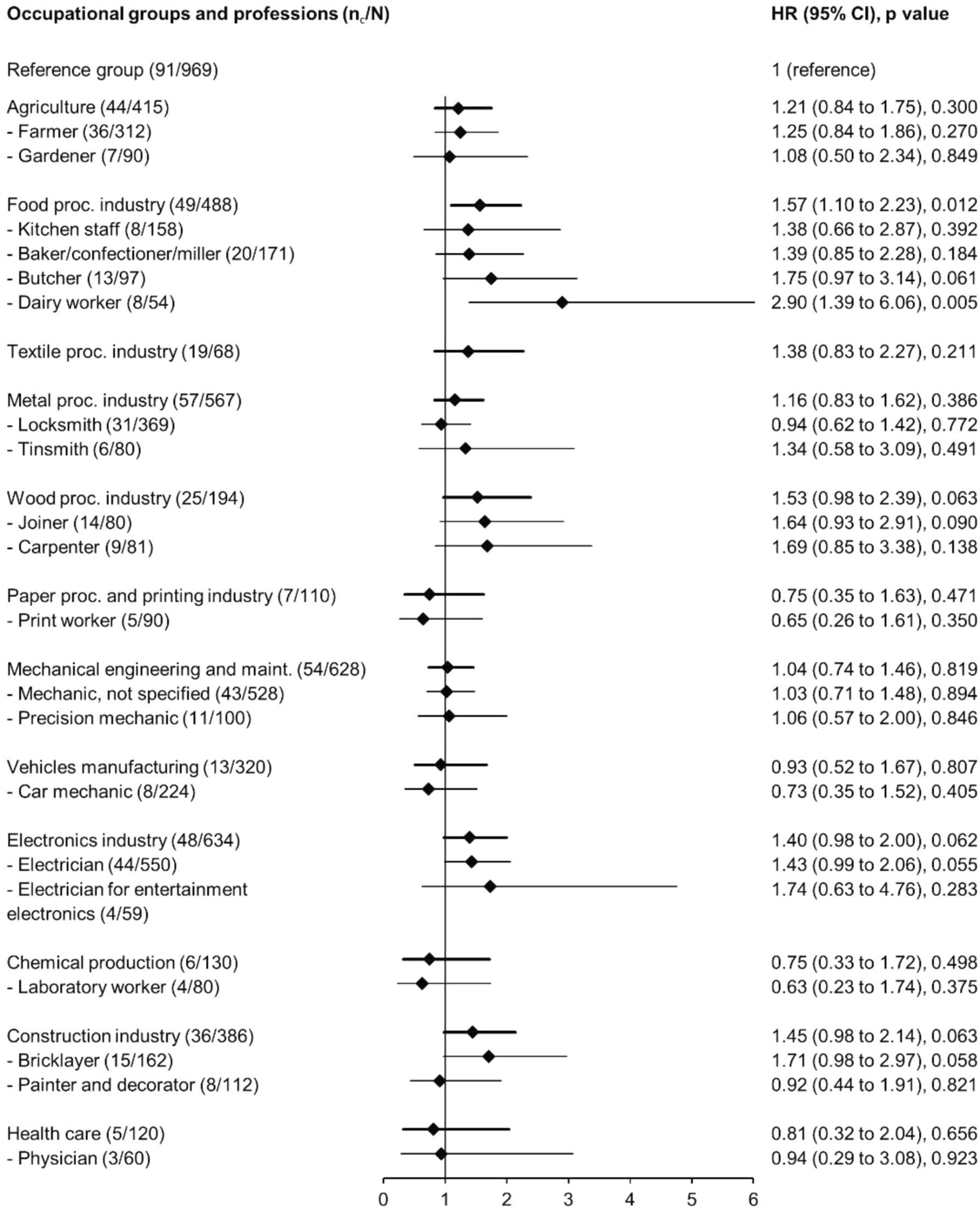


**Fig. 3** Risk of mortality in occupational groups and professions among men, Switzerland (2000–2015). The regressions were adjusted for age, smoking status, year and season of assessment, residential distance to major roads and educational level. Chimney sweeps could not be considered in this analysis since there were too few cases. Observations with missing values in smoking status ($n = 40$) were excluded. *HR* hazard ratio, *CI* confidence interval, $n_c$ number of cases, *N* total number of subjects in each group, *proc.* processing, *maint.* maintenance

diesel exhaust, wood and cement dust. An overview of occupational groups and potential exposure hazards is provided in Online Resource 8.

The interaction analysis showed that smoking increased the association between occupational exposure and AO in nearly all of the occupational groups. In the food processing and construction industries we did not find an

**Table 3** Multiplicative and additive interactions between occupational groups and smoking on mortality among men, Switzerland (2000–2015)

| Occupational group | $n_c/N$ | Never smoker HR (95% CI) | $n_c/N$ | Ex-/current smoker HR (95% CI) |
|---|---|---|---|---|
| Not occupationally exposed | 34/443 | 1 (reference) | 57/526 | 1.17 (0.76 to 1.80) |
| Food processing industry | 22/226 | 1.54 (0.90 to 2.66) | 27/262 | 1.54 (0.92 to 2.58) |
| Multiplicative Interaction: | 1.54 × 1.17 = 1.80 (exp. effect) > 1.54 (obs. effect) | | | |
| Additive Interaction: | $RERI_{HR}$ (95% CI) | − 0.17 (− 1.19 to 0.84) | | |
| | AP% (95% CI) | − 11.3 (− 78.2 to 55.6) | | |
| Not occupationally exposed | 34/443 | 1 (reference) | 57/526 | 1.14 (0.74 to 1.76) |
| Wood processing industry | 10/98 | 1.18 (0.57 to 2.46) | 15/96 | 1.80 (0.98 to 3.34) |
| Multiplicative interaction: | 1.18 × 1.14 = 1.35 (exp. effect) < 1.80 (obs. effect) | | | |
| Additive interaction: | $RERI_{HR}$ (95% CI) | 0.48 (− 0.77 to 1.73) | | |
| | AP% (95% CI) | 26.5 (− 35.8 to 88.8) | | |
| Not occupationally exposed | 34/443 | 1 (reference) | 57/526 | 1.15 (0.75 to 1.77) |
| Electronics industry | 21/328 | 1.24 (0.71 to 2.15) | 27/306 | 1.57 (0.93 to 2.63) |
| Multiplicative Interaction | 1.24 × 1.15 = 1.43 (exp. effect) < 1.57 (obs. effect) | | | |
| Additive Interaction: | $RERI_{HR}$ (95% CI) | 0.18 (− 0.73 to 1.08) | | |
| | AP% (95% CI) | 11.4 (− 44.9 to 67.6) | | |
| Not occupationally exposed | 34/443 | 1 (reference) | 57/526 | 1.17 (0.76 to 1.80) |
| Construction industry | 11/138 | 1.53 (0.76 to 3.08) | 25/248 | 1.69 (0.99 to 2.87) |
| Multiplicative interaction: | 1.53 × 1.17 = 1.79 (exp. effect) > 1.69 (obs. effect) | | | |
| Additive interaction: | $RERI_{HR}$ (95% CI) | − 0.01 (− 1.23 to 1.21) | | |
| | AP% (95% CI) | − 0.8 (− 73.2 to 71.6) | | |

All regressions were adjusted for age, smoking status, year and season of assessment, residential distance to major roads and educational level. *HR* hazard ratio, *CI* confidence interval, $n_c$ number of cases, *N* total number of subjects in each group, *exp. effect* expected effect, *obs. effect* observed effect, *RERI* relative excess risk due to interaction, *AP* attributable proportion

interaction with smoking on mortality, which means that occupational exposure rather than smoking plays an important role in our cohort to explain the higher risk of mortality. Newman et al. have previously reported high risk of fatal injuries and mortality in the food production and processing industries (Newman et al. 2015). They reported that injuries and mortality are mainly a result of exposure to toxic substances or environments and transportation incidents. We did not find strong associations in the interaction analyses which may be due to lack of power in the subgroups.

Occupational exposure to VGDF is often assessed using specific job-exposure matrices (JEM). In a preliminary analysis, we applied general population JEMs from two different European countries because no JEM with the Swiss classification of occupations existed so far. Due to lack of agreement between the JEMs we decided not use JEMs to identify exposures (unpublished data), but rather focus on specific occupational groups. Although the use of JEMs to identify occupational exposure has become very common in the last decades, the naive application of a JEM can lead to misclassifications, for example due to differences in job descriptions and classifications between countries or new job types that are not considered in the JEM (Kauppinen et al. 1992).

Our study has some limitations that need to be considered. For our analyses, we had to assume that study participants did not move into a different occupational group during the study period. However, study participants are more likely to switch jobs within the occupational group and less likely to move into a different occupational group requiring a different set of skills. Although we had information on the current occupation in 2000, we chose not to use this information for two reasons. First, we would have had to exclude all retired subjects and would have lost information on the long-term effects of the exposure if we had included them in the analysis. Second, using the current occupation in 2000 could have generated a "healthy worker effect" bias causing a reversed causation phenomenon (e.g. lower mortality rates or better lung function in exposed occupational groups) (Eisner et al. 2010).

Another important aspect is the use of smoking status, pack years or years of smoking as a confounder. Whereas some consider pack years as the most appropriate metric for cigarette related airway disease, others found that duration of smoking provides stronger risk estimates of airflow obstruction (Balmes et al. 2003; Bhatt et al. 2018). Having both pack years and smoking status available in our dataset, we decided to include smoking status as a confounder, since pack years is prone to recall bias and it does not provide information on smoking cessation. Another limitation is that we cannot rule out a potential healthy participant bias, i.e., subjects participating in the LuftiBus campaign may be healthier than the general Swiss population (Bopp et al. 2014).

In a sensitivity analysis, we repeated the analysis and included all other professions in the reference group. As expected, by gaining a larger sample size and including professions that were very broadly defined or not clearly un-/exposed, the effect sizes decreased and the CIs became narrower. However, the directions of the associations for the occupational groups and professions remained the same and were thus robust towards this change.

We would like to point out that AO in this study is not limited to (largely irreversible) COPD, but also refers to reversible obstructions such as asthma. Lung function measurements below the lower limit of normal indicate obstructed airways that may or may not result in serious lung disease in the long run.

The population-based design and the large sample size that gave us enough power to detect differences on the level of several occupational groups and professions are strengths of this study. By using a standardized classification system of professions instead of self-reported exposures, we could minimize recall bias. Error measurements in spirometry can be considered to be very low, since the tests were performed by trained technicians and according to strict guidelines.

In this large population-based cohort study, we found that certain occupational groups and professions are at increased risk of AO and/or mortality. The identification of these groups and professions is of great importance to public health since it enables government to better target national risk reduction strategies with the aim to reduce burden of work-related respiratory diseases.

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**Author contributions** MAP, AS, MK and HD contributed to the conception and design of the study. AT provided the LuftiBus dataset and MB the anonymized data from the SNC. AS cleaned and prepared the "LuftiBus" dataset. MB and AS performed the record linkage. MR and KH estimated the residential distance to major roads. AS and HD did the assignment of the professions to the occupational groups and MK assisted AS with the statistical analysis. SS provided important input to the analysis plan for the application of a job exposure matrix to the dataset and the interpretation of the resulting findings. AS, HD, MK and MAP contributed to the interpretation of data. AS and MAP drafted the manuscript and all commented on it.

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## Compliance with ethical standards

**Conflict of interest** The authors declare that they have no conflict of interest.

**Ethical approval** The Ethics Committee of the Canton of Zurich (Switzerland) approved this study (BASEC-Nr. 2017-01804).

**Informed consent** The Ethics Committee of the Canton of Zurich (Switzerland) gave consent on behalf of the subjects.

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