Development of an occupational airborne chemical exposure matrix

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ABSTRACT

Background: Population-based studies of the occupational contribution to chronic obstructive pulmonary disease generally rely on self-reported exposures to vapours, gases, dusts and fumes (VGDF), which are susceptible to misclassification.

Aims: To develop an airborne chemical job exposure matrix (ACE-JEM) for use with the UK Standard Occupational Classification (SOC 2000) system.

Methods: We developed the ACE-JEM in stages: (i) agreement of definitions, (ii) a binary assignation of exposed/not exposed to VGDF, fibres or mists (VGDFFiM), for each of the individual 353 SOC codes and (iii) assignation of levels of exposure (L; low, medium and high) and (iv) the proportion of workers (P) likely to be exposed in each code. We then expanded the estimated exposures to include biological dusts, mineral dusts, metals, diesel fumes and asthmagens.

Results: We assigned 186 (53%) of all SOC codes as exposed to at least one category of VGDFFiM, with 23% assigned as having medium or high exposure. We assigned over 68% of all codes as not being exposed to fibres, gases or mists. The most common exposure was to dusts (22% of codes with >50% exposed); 12% of codes were assigned exposure to fibres. We assigned higher percentages of the codes as exposed to diesel fumes (14%) compared with metals (8%).

Conclusions: We developed an expert-derived JEM, using a strict set of *a priori* defined rules. The ACE-JEM could also be applied to studies to assess risks of diseases where the main route of occupational exposure is via inhalation.

Key words: Job Exposure Matrix, airborne workplace pollutants, COPD, population epidemiology, occupational exposure

INTRODUCTION

The contribution made by inhaled occupational exposures to the burden of chronic obstructive pulmonary disease (COPD) is estimated to be a median of 15% [1-4]. Exposures to these potentially causative inhaled agents are complex to categorise; workers may be exposed to a range of individual or combined airborne pollutants including vapours, gases, dusts, fume, fibres and mists (VGDFFiM,) at varying daily intensities, and exposures may interact with each other and with the effects of tobacco smoke [5].

Previous studies of the occupational contribution to COPD have tended to assess exposure to generic ‘vapours, gases, dust or fumes’ (VGDF), rather than specific pollutants. The accuracy of such an approach relies on the worker’s ability to estimate exposures without a relative benchmark. Previous work has shown that individuals are better able to estimate exposure to agents that can be seen and smelt, and that the length of recall period can influence the validity and reliability of self-reports [6]. Assessment of occupational exposures by independent exposure experts may overcome some of these limitations. Allocating exposures to job categories within a job exposure matrix (JEM), based on knowledge of the wide range of factors which affect occupational exposures, can minimise recall bias and exposure misclassification when compared with less accurate self-reported exposures [6-8].

A number of general population JEMs have been developed [9], including the Medical Research Council JEM (MRC JEM) [10], Finnish JEM (FINJEM) [11], Central and Eastern European JEM (CEEJEM) [12], the New Zealand JEM (NZJEM) [13] and the Dutch ‘DOM-JEM’ [14]. However, only a few population JEMs have been specifically developed to assess the risk of occupational COPD, and include the ALOHA JEM [15,16], the European collaborative analyses on occupational risk factors for COPD with job exposure matrices

(ECOJEM) [17] and the University of California, San Francisco JEM (UCSF) [18,19]. More specifically, the ALOHA JEM utilised 350 occupational titles from the Office of Population Censuses and Surveys classifications of exposures, and assigned these to 'biological dust', 'mineral dust', and 'gas/fumes' categories; prevalence (P) and intensities (I) of exposure in each occupational title were both assessed, although how P and I were combined in the final JEM was not detailed. Similarly, the UCSF JEM was developed to assess exposure to organic and inorganic dusts [19], and to assess jobs with greatest respiratory risk (asthma and COPD), rather than estimating exposure levels *per se* across all jobs. Whilst both these JEMs provide valuable information on the role of risk factors for occupational COPD, they do not enable assessment of the harmful effects of the full range of individual or mixed workplace pollutants.

We developed a new JEM to investigate the causes of occupational COPD, and specifically to be applied to the UK Biobank data [20], the latter using the UK Standard Occupational Classification (SOC) 2000 [21] system. We developed this JEM to better understand the relative importance of different inhalant pollutant types associated with occupational exposures, the role of different pollutant types as risk factors for occupational COPD and to improve the identification of jobs and pollutants that are associated with occupational COPD. The SOC 2000 codes were used to categorise employment and consist of nine major groups, 25 sub-major groups, 81 minor groups and 353 (four digit) unit groups. The nine major groups consist of (1) managers and senior officials, (2) professional occupations, (3) associate professional and technical occupations (4) administrative and secretarial occupations (5) skilled trade occupations (6) personal service occupations, (7) sales and customer service occupations, (8) process, plant and machine operatives and (9) elementary occupations.

In this paper we present the methods and exposure attribution results for the airborne chemical exposure JEM (ACE-JEM), and give details of how to access and use this.

METHODS

We developed the ACE-JEM for each of the 353 4-digit SOC 2000 codes, using a phased approach (Figure1): first, we agreed definitions and the process by which consensus would be achieved. We then developed a binary JEM, which assigned for each SOC code whether or not there was exposure to a given pollutant. We then used this binary coding to develop two further JEMs; based respectively on the average daily or weekly exposure Level for those exposed (L-JEM) and the Proportion of workers exposed within a given SOC code (P-JEM). In addition to VGDFFiM, we assigned exposures to sub-fractions of dusts (mineral dust and biological dusts, metals, diesel fumes, VGDF, and asthmagens). Ethical approval was not required for this study as no health or personal information was collected or used.

The authors (SS, DF, HC and OK) discussed and agreed all versions of the JEMs. We checked internal consistency within each JEM by comparing SOC codes assigned the same level of exposure and exposure levels assigned to codes with similar jobs. The final ACE-JEM consisted of a descriptor for each 4-digit SOC 2000 code, together with the sequence of JEMs (binary, L and P). Consensus at each stage was achieved after 4-6 iterations as described below.

The first steps in developing the ACE-JEM were to agree on definitions (supplementary Appendix 1) of pollutant forms and to add the descriptors for all SOC codes. The descriptors summarised job tasks and titles associated with each SOC code.

We based exposures on workplace conditions between 2000 and 2013, representing the period following the introduction of SOC 2000 [21], and the Control of Substances Hazardous to Health (COSHH) Regulations [22]. We initially assigned exposures individually and then agreed them in pairs (SS and OK, DF and HC) before agreeing as a group. (A worked example is illustrated in supplementary Appendix 2).

For the binary JEM, we assigned each pollutant type a binary code for exposure (no/yes) to each of VGDFFiM for each SOC code. A matrix cell assigned as exposed (above the occupational background level) was only accepted if both pairs of authors could provide an example of a specific exposure scenario; for example, welders potentially exposed to metal fumes and inorganic gases including carbon monoxide, nitric oxide, nitrogen dioxide and ozone.

The rules used for assigning each cell as exposed or non-exposed were as follows; (i) exposure by inhalation only was considered; (ii) exposure associated with job/activity as defined by main tasks for each SOC code; (iii) exposure must occur on a regular basis as part of the work i.e. daily or weekly; (iv) exposure must occur as part of planned or routine job activity, i.e. unplanned accidental or one off exposures were not considered; (v) respiratory protective equipment (RPE) was assumed not to be used; (vi) individuals who regularly used road vehicles as part of their job or worked in traffic environments were considered as exposed to diesel fume and its constituent combustion products. We did not consider passive tobacco exposure.

We used the binary JEM from phase 2 as the platform upon which semi-quantitative assessments of all the exposures were added. We assigned the estimated proportion of workers within a given SOC code that were exposed to each of pollutant type arbitrarily as <5% (not exposed), 5-19%, 20-49%, and ≥50% exposed. We assigned the proportion by considering job titles and tasks, together with examples of pollutant types and the pattern of exposure to the pollutant. We assigned the levels of exposure using four levels: not exposed, low, medium, and high, and defined as a typical average daily or weekly exposure. Low level of exposure was considered to be higher than the general background occupational level. We considered medium and high exposures to be 10-50% and >50% respectively of the UK workplace exposure limit (WEL). We considered the following factors: (i) exposure sources and their emission potential; (ii) duration of exposure over a typical working shift (a guide used was a medium rating for exposure over 10-50% of shift, a high rating for over 50% of the shift); (iii) how well airborne exposure was likely to be controlled by process and engineering means (categorised by the team as good, adequate or poor); as in phase 2 RPE was assumed not to be used when assigning exposure; (iv) the likelihood of peak exposures during typical work shifts; and (v) the work environment, in particular whether exposure occurred mainly indoors or outdoors or in a confined space.

In developing both the P- and L-JEMs, we automatically assigned all matrix cells assigned as exposed in the binary JEM the lowest exposed category for both P- and L-JEMs, i.e. 5-19% exposed and low level of exposure. We then assessed each matrix cell individually for a higher score for both JEMs.

We then assigned exposure estimates to different sub-pollutants (mineral dust, biological dust and metals) and combination of pollutant forms e.g. ‘VGDF’. Finally, we added exposure to asthmagens by compiling a working list of common causative agents of occupational asthma, using a combination of sources [23-25]. We assigned examples and the pollutant form of the common asthmagens to each SOC code. We then assigned asthmagens the same level and proportion exposed as for the corresponding pollutant form. Notably, asthmagen classification in the ACE-JEM was based on the likelihood of exposure to occupational airborne pollutants, i.e. level or proportion exposed was determined by consideration of the SOC descriptor, job titles, sources of exposure and the work environments, and not influenced by the likelihood of respiratory disorders as is the case for one existing occupational asthma JEM [26].

We classified each of the SOC codes assigned as exposed to dust as exposed to mineral and / or biological dust. Similarly, we then considered SOC codes assigned as exposed to mineral dust and / or fumes when assigning exposure to metals. Finally, we assigned exposure to diesel fumes by considering individual cells that had been assigned to fume exposure. We categorised these cells as either exposed to diesel fume or other fumes (welding, solder and rubber fume) or both.

Having agreed the above classification, we assigned exposures using the following guidelines: (i) if the sub-pollutant constituted the majority of the exposure, then its exposure level was the same as the main pollutant form e.g. ‘biological dust’ was assigned the same level of exposure as ‘dust’ for wood workers; (ii) if exposure occurred to a different sub-pollutant within the same code then each exposure was assigned separately e.g. labourers in building and wood working trades would be assigned as exposed to dust as well as mineral and biological dusts; and (iii) the exposure level for the sub-pollutant could not be greater than that assigned to the main pollutant form, i.e. the exposure level assigned to mineral dusts or metals or diesel fume could not exceed the level assigned to dusts and fumes.

Finally, we created a combination VGDF' exposure, where we assigned exposure estimates for these pollutants the same level as the highest exposure of its component pollutants. The logic used for assigning exposure levels to sub-pollutants and their combinations was repeated when assigning proportions exposed; by assigning proportion exposed to VGDFFiM first, and then the sub-pollutants and combination of pollutants.

We evaluated the level of agreement between ALOHA JEM and the ACE-JEM using Cohen's kappa for the pollutants common to both matrices; mineral dusts, biological dusts, and VGDF. We conducted the comparison for exposed and non-exposed cells, after aligning the SOC 2000 codes with the ISCO-88 codes on which ALOHA is based. We considered Kappa values in the ranges 0.41-0.60 and 0.61-0.80 as' moderate' and 'good' agreements respectively.

RESULTS

We included 353 SOC 2000 codes in ACE-JEM, and exposures to 12 different airborne pollutant types were assigned, including six main pollutant forms (VGDFFiM), four sub-pollutants (mineral dust, biological dusts, diesel fume and metals), asthmagens and combined exposures (VGDF).

Tables 1 and 2 show the numbers of SOC 2000 codes attributed to each pollutant, and the L- and P-JEM breakdown. Of the six main pollutants assessed, the most commonly assigned was dust (40% of all codes), then fumes (26%); only 12% of the codes were fibre exposed.

Over 68% of all SOC codes were not assigned as exposed to fibres, gases or mists. We assigned 52% of the SOC codes as exposed to vapours, gases, dust or fume (VGDF). We assigned more codes as exposed to mineral (29%) compared with biological dusts (18%). We assigned exposure to metal dust (8% exposed) by considering both exposures to mineral dust and fumes. We assigned 14% of codes as exposed to diesel fumes after considering each of the SOC codes assigned as exposed to any fume (26%), which included solder fume, rubber fume, welding fume as well as diesel fume. We assigned 31% of codes as exposed to asthmagens with the majority assigned to the low exposure group (18%).

We assigned the same proportion (53%) of SOC codes as exposed to VGDFFiM as for VGDF. Table 3 shows the numbers of pollutant forms attributed overall between SOC codes. For example, we assigned 13% of the SOC codes as being exposed to only one of the six pollutants, we assessed 40% of the SOC codes as exposed to two or more, and approximately 13% were exposed to four or more.

Table 4 illustrates the breakdown of major pollutant types by the nine major (1-digit) SOC 2000 groups. It was evident that major SOC groups 5, 6, 8 and 9 had the greatest number of SOC codes associated with exposure to VGDF. Skilled trade occupations (group 5) had the highest percentage of the codes assigned as exposed to dusts, fibres, metals and asthmagens. Major group 8 (process, plant and machine operatives) had the highest proportion of codes assigned as exposed to gases, fumes, mineral dust, diesel fume and VGDF.

Analysis to assess the level of agreement between the ALOHA JEM and the ACE-JEM derived a kappa value of 0.67 for VGDF, and moderate agreement for mineral dust (0.56) and biological dust (0.49).

DISCUSSION

The principle output of this stepwise process was a new job exposure matrix, the 'ACE-JEM', based on SOC 2000 codes. Given that the ACE-JEM was developed to analyse data from the UK Biobank [20], it considered a wide range of individual and sub fraction airborne pollutant types, and more novel exposures including asthmagens, diesel fumes and metals. This level of consideration not only allowed the assessment of the adverse effects of single inhaled agents, but also of differing combinations of pollutants. This ability may be important, as most occupations involve a range of exposures over a working shift.

Given the method of its development, we believe this JEM has certain potential strengths. Its development, unlike other population JEMs to our knowledge, used a strict set of *a priori* defined job descriptors, definitions of pollutant types, and guidelines for assigning exposures. This JEM offers an alternative to the widely used ALOHA and other JEMs that have estimated risks for COPD associated with exposures to mineral dust, biological dust, gas/fumes and VGDF [16, 27-29]. The ACE JEM enables analysis at three levels; exposed versus non-exposed, level of exposure (L) and proportion (P) of individuals exposed for each of the 353 SOC codes.

There are various downsides and weaknesses to the current JEM. Although evidence-based where possible, decision making was based largely on expert judgment. Also, SOC codes covered a range of jobs, thus code-based exposures may not have represented the exposures of all workers within that code. In addition, the exposure estimates were based on typical work routines, and did not take account of accidental exposures, seasonal variation (such as seen in farming) or the use of RPE. It is also recognised that the ACE-JEM was developed specifically for a particular time period (2000-2013), and its applications to jobs held prior to

2000 may result in underestimation of occupational exposures. Future work will allow time periods of exposure to be taken into account, which is important given the gradual onset of certain respiratory illnesses including COPD. Finally, the new JEM requires *post hoc* validation, using personal inhalation exposure data supported by suitable contextual information on work activities during the sampling period.

The process of developing the ACE-JEM was strengthened by defining pollutant types and agreeing descriptors of each of the SOC codes, including typical job titles and tasks, which led to consideration of pre-defined occupational factors when assigning exposure levels. The job descriptors were found to be useful when assigning the proportion of individuals exposed in each code, a process that could have introduced uncertainties; particularly where codes covered a wide range of activities and work environments.

This ACE-JEM also provides a platform to develop both new JEMs, and future research and validation based on this JEM, and comparison with other JEMs. There is also potential for expansion by considering further sub-pollutants of fumes (solder fume, welding and rubber fume) and fibres (asbestos and man-made fibres) which will help to further understand the relative importance of different airborne pollutants in occupational COPD and other environmental diseases. Additionally, as pollutant types were considered *per se*, not simply including only pollutants known to be associated with COPD, its use could be extended to explore risk factors for the development of other occupational respiratory diseases including asthma, extrinsic allergic alveolitis and interstitial lung diseases. Once these risk factors are identified, effective interventions to prevent the occupational contribution of conditions such as asthma and COPD will be easier to target.

It is anticipated that the ACE-JEM will be a useful addition to pre-existing general population JEMs and, in addition will allow conversion of its contents (including SOC 2010 and ISCO-88) to be used with international standard occupational classification systems such as The International Standard Classification of Occupations (ISCO).

Key points

- Existing population job exposure matrices (JEMs) for use with chronic obstructive pulmonary disease have focused on few airborne pollutant forms.
- We developed an expert derived general population JEM (ACE-JEM) for a range of workplace airborne pollutants (vapours, gases, dusts, fume, fibres and mists), based on the UK SOC 2000 codes.
- The new expert ACE-JEM can be applied to assess risk of diseases other than COPD where the main route of occupational exposure is via inhalation**.**

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ACEJEM availability

The present version of ACEJEM (ACEJEM 2015 version) is available for collaborative purposes as an MS Excel file. Further information can be obtained from s.sadhra@bham.ac.uk

Conflicts of Interest: None

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Table 1; Overall numbers of SOC 2000 codes attributed to each category of pollutant exposure in the L-JEM

Category of pollutant exposure	Exposure level	Number of SOC codes (% of all 353 SOC codes)	
Vapours (V)	Exposed	80	(23)
	Low	53	(15)
	Medium	17	(5)
	High	10	(3)
Gases (G)	Exposed	72	(20)
	Low	54	(15)
	Medium	16	(5)
	High	2	(1.0)
Dusts (D)	Exposed	142	(40)
	Low	87	(25)
	Medium	35	(10)
	High	20	(6)
Fumes (F)	Exposed	93	(26)
	Low	59	(17)
	Medium	28	(8)
	High	6	(2)
Fibres (Fi)	Exposed	41	(12)
	Low	27	(8)
	Medium	12	(3)
	High	2	(1)
Mists (M)	Exposed	50	(14)
	Low	31	(9)
	Medium	13	(4)
	High	6	(2)
Any pollutant form (VGDFFiM)	Exposed	186	(53)
	Low	106	(30)
	Medium	47	(13)
	High	33	(9)
Asthmagens	Exposed	108	(31)
	Low	63	(18)
	Medium	31	(9)
	High	14	(4)
Mineral dusts	Exposed	102	(29)
	Low	56	(16)
	Medium	34	(10)
	High	12	(3)
Biological dusts	Exposed	64	(18)
	Low	50	(14)
	Medium	8	(2)
	High	6	(2)
Metals	Exposed	29	(8)
	Low	12	(3)
	Medium	11	(3)
	High	6	(2)
Diesel	Exposed	50	(14)
	Low	40	(11)
	Medium	10	(3)
	High	-	-

Note: In total there are 353 SOC 2000 codes. 'Exposed' denotes the number of codes assigned as exposed to the pollutant form. Low, Medium and High are the assigned exposure levels for all codes assigned as exposed which are expressed as percentage of all SOC codes.

Table 2; Overall numbers of SOC 2000 codes attributed to each category of pollutant exposure in the P-JEM

Category of pollutant exposure	Proportion exposed	Number of SOC codes (% of all 353 SOC codes)	
Vapours (V)	<5%	274	(78)
	5-19%	12	(3)
	20-49%	34	(10)
	≥50%	34	(10)
Gases (G)	<5%	281	(80)
	5-19%	15	(4)
	20-49%	28	(8)
	≥50%	29	(8)
Dusts (D)	<5%	211	(60)
	5-19%	27	(8)
	20-49%	39	(11)
	≥50%	76	(22)
Fumes (F)	<5%	260	(74)
	5-19%	21	(6)
	20-49%	28	(8)
	≥50%	44	(13)
Fibres (Fi)	<5%	312	(88)
	5-19%	9	(3)
	20-49%	15	(4)
	≥50%	17	(5)
Mists (M)	<5%	303	(86)
	5-19%	18	(5)
	20-49%	18	(5)
	≥50%	14	(4)
Any pollutant form (VGDFFiM)	<5%	167	(47)
	5-19%	22	(6)
	20-49%	54	(15)
	≥50%	110	(31)
Asthmagens	<5%	245	(69)
	5-19%	4	(1)
	20-49%	38	(11)
	≥50%	66	(19)
Mineral dusts	<5%	251	(71)
	5-19%	19	(5)
	20-49%	29	(8)
	≥50%	54	(15)
Biological dusts	<5%	289	(82)
	5-19%	19	(5)
	20-49%	16	(5)
	≥50%	29	(8)
Metals	<5%	324	(92)
	5-19%	-	-
	20-49%	11	(3)
	≥50%	18	(5)
Diesel	<5%	303	(86)
	5-19%	12	(3)
	20-49%	11	(3)
	≥50%	27	(8)

Table 3; Numbers of pollutant forms assigned as exposed to the SOC 2000 codes

Number of pollutant forms (Vapours, Gases, Dusts, Fumes, Fibres and Mists)	Number of SOC codes (% of all 353 SOC codes)	
0	167	(47)
1	45	(13)
2	61	(17)
3	33	(9)
4	26	(7)
5	18	(5)
6	3	(1)

Table 4; Breakdown of assigned weighted exposure by SOC 2000 major groups.

SOC major group	n (codes)	Vapours n (%)	Gases n (%)	Dusts n (%)	Fumes n (%)	Fibres n (%)	Mists n (%)	VGDFFiM n (%)	Mineral Dusts n (%)	Biological Dusts n (%)	Metals n (%)	Diesel fume n (%)	Asthmagens n (%)
1	45	4 (9)	3 (7)	10 (22)	7 (16)	4 (9)	3 (7)	13 (29)	8 (18)	5 (11)	1 (2)	4 (9)	8 (18)
2	46	10 (22)	8 (17)	13 (28)	4 (9)	-	3 (7)	14 (30)	10 (22)	7 (15)	3 (7)	1 (2)	10 (22)
3	73	16 (22)	12 (16)	21 (29)	14 (19)	4 (6)	11 (15)	27 (37)	16 (22)	10 (14)	3 (4)	8 (11)	16 (22)
4	24	-	-	-	2 (8)	-	-	2 (8.3)	-	-	-	2 (8.3)	-
5	54	20 (37)	14 (26)	45 (**83**)	20 (37)	17 (**32**)	15 (**28**)	51 (94)	29 (54)	18 (**33**)	12 (**22**)	4 (7)	36 (**67**)
6	23	9 (**39**)	5 (22)	7 (30)	2 (9)	-	6 (26)	14 (61)	2 (9)	6 (26)	-	2 (9)	10 (44)
7	11	-	1 (9)	-	2 (18)	-	-	2 (18)	-	-	-	2 (18)	-
8	42	9 (21)	22 (**52**)	28 (67)	30 (**71**)	11 (26)	7 (17)	**41 (100)**	24 (**57**)	10 (24)	8 (19)	17 (**41**)	15 (36)
9	35	12 (34)	7 (20)	18 (51)	12 (34)	5 (14)	5 (14)	21 (60)	13 (37)	7 (20)	2 (6)	10 (29)	13 (37)

Note:
The table shows the number (percentage) of codes within each of the 9 major SOC codes which were assigned as exposed to the different pollutant forms. Highest percentage for each pollutant (in bold)