Occupational and Environmental Medicine 1995;52:634–643

Occupational exposures estimated by means of job exposure matrices in relation to lung function in the PAARC survey

N Le Moual, E Orlowski, M B Schenker, M Avignon, P Brochard, F Kauffmann

Abstract

***Objectives*—The aim of this analysis of the French Cooperative PAARC (Pollution Atmosphérique et Affections Respiratoires Chroniques) survey, was to test whether occupational exposures to dusts, gases, or chemical fumes or to specific hazards, estimated by job exposure matrices, were related to a decrease in forced expiratory volume in one second (FEV_1).**

***Methods*—The most recent occupation was recorded in adults, aged 25–59, from non-manual worker households. Analysis was restricted to 10 046 subjects whose occupation was encountered at least 10 times in the study and who performed good FEV_1 tracings. From occupational title, exposures to dusts, gases, and chemical fumes, and to specific hazards were classified in three categories (no, low, and high) with a British, a French, and an Italian job exposure matrix. Specific hazards were analysed for the British and French job exposure matrices for the same 42 specific dusts, gases, and chemical fumes. To limit spurious associations, a selection of seven hazard groups and 12 specific hazards was set before the start of the analysis. Based on the consistency of the relations according to sex and the British and French job exposure matrices, associations of age, height, city, and smoking adjusted FEV_1 score with occupational exposures were classified as very likely, possible, or unlikely.**

***Results*—For the three job exposure matrices and both sexes clear exposure-response relations between the level of exposure to dusts, gases, and chemical fumes, and a decrease in FEV_1 were found. Associations with FEV_1 were classified as very likely for known hazards such as organic dusts and textile dusts, and not previously recognised hazards such as polycyclic aromatic hydrocarbons (PAHs) and detergents, and as possible for solvents, waxes and polishes, and diesel fumes. Associations found for PAHs and solvents were confirmed by the Italian job exposure matrix. Associations remained significant in women, but not in men, after adjustment for educational level.**

***Conclusions*—Hypotheses have been generated for exposure to detergents, PAHs, and solvents, but they need to be interpreted with caution before replication. Significant associations found for known risk factors with a decrease in FEV_1 are arguments for the validity of the matrices. Despite the expected limitations of job exposure matrices, these results encourage further work to improve exposure assessment by job exposure matrices.**

(*Occup Environ Med* 1995;52:634–643)

Keywords: job exposure matrix; occupational exposure; lung function

INSERM U169, Villejuif, France
N Le Moual
F Kauffmann

INSERM U139, Créteil, France
E Orlowski
P Brochard

Occupational and Environmental Medicine and Epidemiology, University of California, Davis, USA
M B Schenker

Institut de l'Homme et de la Technologie, Nantes, France
M Avignon

Correspondence to:
N Le Moual, INSERM U169, 16 avenue Paul Vaillant Couturier, F-94807, Villejuif cedex, France.

Accepted 19 June 1995

Relations between occupational exposures and respiratory diseases, mostly investigated in workforce based populations,[1–3] may have been underestimated by the healthy worker effect, particularly in cross sectional studies. Community based studies have found an association between exposure to dusts, gases, and chemical fumes and lung function, respiratory symptoms, or asthma.[4–14] Although the increased risk related to dusts has been found,[1–14] the role of dusts, gases, and chemical fumes remains a matter of debate. Specific hazards have been rarely studied[4 7 9 11] because the number of subjects exposed was too small. In most of the community based studies,[4–14] occupational exposures were estimated by self reported information[4–14] and more recently by using job exposure matrices.[7 9 11 13] The validity of job exposure matrices is a matter of debate.[15–18] Furthermore, the grading of exposure affects the performances of job exposure matrices.[15 16] The British matrix developed by Pannett *et al*[17] was applied in the Zutphen survey,[7 9] to study the relations between specific hazards and chronic non-specific lung disease, but associations with lung function values were not studied.

In the French community based study PAARC (Pollution Atmosphérique et Affections Respiratoires Chroniques), no relation was found between self reported occupational exposure to dusts, gases, and chemical fumes and forced expiratory volume in one second (FEV_1).[6] An association was found for dusts, gases, and chemical fumes and respiratory symptoms in both sexes and for FEV_1/FVC (forced vital capacity) in men.[6] The purpose of the present study was to investigate the relations of occupational exposures assessed by job exposure matrices to lung function in a large population based study. The specific aims were (a) to test whether occupational exposures to dusts, gases, and chemical fumes estimated by three independent job exposure matrices were related to a decrease in FEV_1 and whether exposure-response relations may be shown; (b) to investigate known associations and generate hypotheses for specific hazards.

Materials and methods

The detailed protocol of the French Cooperative PAARC survey, performed in 1975, has been published elsewhere.[19] About 20 000 adults (9082 men and 11 228 women) aged 25–59 years, residing in seven French cities (Bordeaux, Lille, Lyons, Mantes-la-Jolie, Marseilles, Rouen, Toulouse), were surveyed at home. The primary aim of the study was to look at a possible effect of air pollution on respiratory diseases.[19] Households headed by manual workers were excluded to reduce the effect of occupational exposure. Therefore, subjects of the PAARC survey were less exposed to occupational hazards than the general population.

OCCUPATIONAL EXPOSURE

Subjects were interviewed about occupational exposure (Were you exposed to dusts, gases and/or chemical fumes? yes/no), in their most recent occupation (458 different ones) coded with the 1968 INSEE four digit classification,[20] and about exposure in previous jobs. Information about economic activity was not collected.

A job exposure matrix is a table in which rows represent job title and columns represent different occupational hazards. Each cell contains an estimation of exposure for a given job (occupation × economic activity) and a given hazard. Two external job exposure matrices, a British one[17] with occupation coded by the British classification,[21] and an Italian one[18 22] based on the International Labour Office (ILO) classification,[23] were used for the analysis.

The British job exposure matrix,[17] developed for a case-control study on lung cancer, estimates by job intensity (no, low, and high) and probability (no, low, and high) of exposure to 50 hazards, including 42 specific dusts, gases, and chemical fumes (table 1), for two calendar periods (<1950, ⩾1950). No exposure corresponds to exposure expected for unemployed subjects. The estimations of exposure after 1950, for occupations with unknown economic activity, were used. Three levels of exposure were created: no, low (low probability and low intensity), and high (high probability or high intensity). A French job exposure matrix, built for the present analysis by an industrial hygienist (MA) and two occupational physicians (EO, PB), assigned to each occupation a level of exposure (no, low, and high) to the same hazards as in the British job exposure matrix. For both the British and the French job exposure matrices, subjects were considered exposed to dusts, gases, and chemical fumes in general if they were exposed to at least one of the 42 specific dusts, gases, and chemical fumes. The Italian job exposure matrix[18 22] developed for an international case-control study on laryngeal cancer, estimates by job the exposure to 16 known or suspected respiratory carcinogens. Estimation of exposures for both sexes, irrespective of calendar period, were used. For each occupation the highest exposure estimated for a given hazard according to economic activity was retained. Similar to Macaluso *et al*,[18] three levels of exposure were created: no, low (probability < 1), and high (probability = 1; high exposure). Subjects were considered as exposed to dusts, gases, and chemical fumes in general if they were exposed to at least one of the 16 hazards. Five hazards common to the British and the French job exposure matrix were analysed. As the conclusions were the same for the two asbestos assessments described in the Italian job exposure matrix, results are presented for the first one.

There were 6699 subjects excluded for the following reasons: lack of an answer to the question about exposure (87 subjects), coding mistakes for the French codes (521), occupation with less than 10 subjects (755), French codes not precise enough to be translated into British codes (1626), no occupation at the time of the survey (3710). For 164 occupations, corresponding to 13 611 subjects, French codes have been translated into the British and international (ILO) codes. For the analysis of exposure based on the Italian job exposure matrix, 183 men and 48 women were further excluded either because the French codes could not be translated into ILO codes or the corresponding ILO codes do not appear in the Italian job exposure matrix.

SMOKING HABITS, EDUCATIONAL LEVEL, AIR POLLUTION, LUNG FUNCTION

The PAARC questionnaire was derived from the British MRC and European Coal and Steel Community questionnaire. Four categories of smokers, based on tobacco (g) smoked as cigarettes, cigars, or pipes a day, were set: non-smokers, exsmokers (stopped for at least one month), light smokers (<10 g/day), moderate smokers (10 to 19 g/day), and heavy smokers (⩾ 20 g/day). Subjects were classified into three groups based on educational level: primary, secondary, and university. The only airborne pollutant measured found to be related to ventilatory function was annual mean exposure to SO_2.[24] Subjects were classified as living in areas of low pollution ($SO_2 < 50$ mg/m^3), moderate pollution (50 mg/m$^3 \leqslant SO_2 < 100$ mg/m^3), or heavy pollution ($SO_2 \geqslant 100$ mg/m^3).

Lung function measurements were performed with a dry spirograph (Vitalograph). For the 10 046 subjects who performed good tracings, analysis was carried out on FEV_1, FEV_1/FVC, and FEF_{25-75} (forced midexpiratory flow between 25% and 75% of the vital capacity). The distribution of poor tracings (27% of the subjects) was similar for each level of exposure to dusts, gases, or fumes estimated by the British and the French job exposure matrices. Standardised age, height, city, and

FEV_1 score adjusted for smoking (mean (SD) = 0 (1)) was obtained after adjustment of FEV_1 for age, height, and smoking habits (expressed by four dummy variables: exsmokers, light smokers, moderate smokers, heavy smokers) for each sex and city (model a). Two other models have been used. In model b, two variables for smoking habits were entered, a dummy variable (exsmokers *v* others) and a quantitative variable (tobacco (g) smoked a day). Analysis carried out with model c used FEV_1 score adjusted for age and height for each sex and city. The four dummy variables for smoking habits were put in the model in retrospect with occupational hazards. All analyses gave the same results, which are reported for scores adjusted before the start of the analysis for smoking (model a). Analyses were also performed for two definitions of airflow limitation: less than 60% and less than 80% of the European Coal and Steel Community predicted values.[25]

STRATEGY OF ANALYSIS

Exposure to dusts, gases, and chemical fumes in general was estimated according to the three job exposure matrices and the relation between dusts, gases, and chemical fumes and lung function were analysed. A high approach (comparison of high exposure with others) has been recommended,[15] when the prevalence of exposure is low, to optimise the validity of the estimate. To assess potential exposure-response relations, three class variables were also used. For specific hazards, an initial selection of hazards was set, to limit spurious associations. Analysis was done in two steps: firstly, the 42 specific dusts, gases, and chemical fumes assessed by the French and British job exposure matrices were classified in seven hazard groups (table 1): organic dusts, mineral dusts, combustion products, heavy metals, welding and soldering, solvents, and other chemical products. Secondly, specific hazards were listed based on chemical principles or initial hypotheses, and were analysed if at least 100 men or women were exposed to that hazard according to both the French and British job exposure matrices. Twelve specific hazards were therefore initially defined and analysed: contact with animals, textile dusts, asbestos, diesel fumes, polycyclic aromatic hydrocarbons (PAHs), chromate, welding fumes, soldering fumes, epoxy resins, formaldehyde, waxes and polishes, and detergents. As Heederick *et al* reported a relation between paint exposure and lung disease, exposure to paint was analysed although less than 100 subjects were exposed.[7]

The association was classified as very likely if the association was significant for one job exposure matrix and both sexes with a coherent trend for the other job exposure matrix or significant for men (women) in both job exposure matrices with a coherent trend for women (men). The association was classified as unlikely if the association was not significant for both job exposure matrices and both sexes, or if an isolated significant association was found without other coherent results. In the other cases, the association was classified as possible.

STATISTICAL ANALYSIS

Linear regression and analysis of variance were used.[26] The analysis has been performed, for the three job exposure matrices, with the high approach, the total approach[15] (low or high *v* non-exposed) and three class variables. Considering qualitative (or quantitative) three class or dichotomous variables, the results were similar. The tables show analyses for the three class variables and P values for trend.

Table 1 Assessment of exposure to various dusts, gases, and chemical fumes according to the British and the French job exposure matrices (JEM)

	Men (n = 5046)				*Women (n = 5000)*			
	British JEM		*French JEM*		*British JEM*		*French JEM*	
Occupational exposure	*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*
Any exposure to dusts, gases, or fumes (%)	23·25	12·56	23·44	12·66	40·98	20·42	22·12	16·02
Organic dusts (%):								
Contact with animals, cereal dusts, textile dusts, wood dusts, other organic dusts	3·92	5·21	8·36	3·92	1·94	8·40	15·64	7·22
Mineral dusts (%):								
Asbestos, coal dusts, other inorganic dusts	2·02	0·79	15·62	2·10	0·22	0·00	18·46	0·44
Combustion products (%):								
Polycyclic aromatic hydrocarbons (PAHs), soot, tar, mineral oil, diesel fumes	3·98	1·45	4·86	0·71	2·44	0·06	1·92	0·04
Heavy metals (%):								
Arsenic, beryllium, cadmium, chromium, lead, mercury, and their compounds	4·04	1·98	5·43	0·40	3·98	0·28	6·62	0·04
Welding/soldering (%):								
Welding fumes, soldering fumes	2·64	0·63	1·80	1·29	0·18	0·00	0·70	0·02
Solvents (%):								
Antiknock agents, benzene, carbon tetrachloride, degreasing agents, styrene, other organic solvents, synthetic adhesives, dyestuffs, epoxy resins, paints, printing inks	17·86	4·34	8·34	5·17	35·68	3·88	17·78	1·26
Other chemical products (%):								
Acrylonitrile, natural adhesives, aromatic amines, chlorophenols, cutting oils, detergents, ethylene oxide, formaldehyde, herbicides, nitrates, polychlorinated biphenyls (PCB), waxes and polishes	25·82	2·72	10·52	2·44	44·20	11·56	4·22	12·48

Results

Twenty three per cent of the men and 19% of the women reported an exposure to dusts, gases, or chemical fumes in their current job. According to the three job exposure matrices 35% of the men were exposed to dusts, gases, and chemical fumes (about 12% with high exposure), but for women the proportion varied from 30% to 60% (7% to 20% with high exposure). The percentages of subjects exposed to solvents and other chemical products were higher according to the British job exposure matrix than according to the French job exposure matrix (table 1). The reverse was found for exposure to dusts. For combustion products, heavy metals, and welding and soldering, the percentages were similar in both the British and French job exposure matrices, although estimated exposure of the subjects was not the same (table 1). Exposure to each hazard group was closely related between both sexes. Women were more often non-smokers

Table 2 Mean (SEM) FEV_1 scores according to the level of exposure to dusts, gases, and chemical fumes estimated by three job exposure matrices (JEM)

	Men				Women			
	No	Low	High	P value	No	Low	High	P value
British JEM	0·03 (0·02)	−0·02 (0·03)	−0·10 (0·04)	**	0·05 (0·02)	0·02 (0·02)	−0·15 (0·03)	***
	3228	1167	630		1917	2041	1014	
French JEM	0·01 (0·02)	0·00 (0·03)	−0·08 (0·04)	p = 0·06†	0·03 (0·02)	−0·03 (0·03)	−0·07 (0·04)	*
	3215	1175	635		3076	1099	797	
Italian JEM	0·03 (0·02)	−0·07 (0·03)	−0·09 (0·04)	***	0·03 (0·02)	−0·01 (0·03)	−0·23 (0·06)	***
	3182	1096	564		3348	1201	375	

*P ⩽ 0·05; **P ⩽ 0·01; ***P ⩽ 0·001; test for trend.
† P = 0·04 for men with no or low exposure *v* highly exposed men (high approach).
FEV_1 scores adjusted for age, height, city, and smoking.
FEV_1 scores, in men with no exposure to dusts, gases, and chemical fumes according to all three JEMs, was 0·06 (n = 2,032) and for highly exposed men 0·03 (n = 186) respectively.
FEV_1 scores, in women with no exposure to dusts, gases, and chemical fumes according to all three JEMs, was 0·10 (n = 878) and for highly exposed women 0·27 (n = 237).
The most common occupations in each exposure category (⩾ 10% of the subjects) were for:
high exposure; men: butchers (British (B) and French (F)), warehousemen (Italian (I)), draughtsmen (F); women: cleaning ladies (B,F,I), hospital orderlies (B,F), hairdressers (I), clothing workers (B), nurses (F);
low exposure; men: warehousemen (B,F), physicians (B,F), shop salesmen (F,I), office workers (B); women: shop saleswomen (F,I), nurses (I), clothing workers (F), primary school teachers (F), office workers (B), secretaries (B);
no exposure; men: sale managers (B,F,I), office workers (F,I); women: office workers (F,I), secretaries (F,I), shop saleswomen (B), primary school teachers (B).

(70% *v* 27%) and had a lower education level (13% *v* 26% with university level) than men. The FEV_1 significantly decreased with smoking and low education level. For both sexes and according to the British and French job exposure matrices, 75% of the subjects highly exposed to dusts, gases, and chemical fumes had only primary education.

DUSTS, GASES, AND CHEMICAL FUMES

For the three job exposure matrices and both sexes, FEV_1 was significantly related to exposure to dusts, gases, and chemical fumes (table 2). Subjects highly exposed to dusts, gases, and chemical fumes had a lower FEV_1 than non-exposed subjects and those with low exposure had intermediate FEV_1 levels. The decrease in FEV_1 score between non-exposed and highly exposed subjects was larger for women than for men. No interaction between occupational exposures and smoking habits was found (exsmokers were excluded from that analysis). In men, the differences in FEV_1 score found by the three job exposure matrices between no and high exposure to dusts, gases, and chemical fumes corresponded with the differences in FEV_1 found between non-smokers and moderate smokers. No interaction between occupational exposures and air pollution (SO_2) was found. Significant associations found for exposure to dusts, gases, and chemical fumes and FEV_1 persisted after exclusion of asthmatic people.

Airflow limitation was significantly associated with high exposure to dusts, gases, and chemical fumes according to the British job exposure matrix for both men and women. According to the British matrix with non-exposed subjects as the control group, the odds ratios (ORs) for highly exposed men were 1·30 (95% confidence interval (95 % CI) 1·06–1·60) for $FEV_1 < 80\%$ and 1·56 (1·00–2·44) for $FEV_1 < 60\%$ of predicted value, respectively, and 1·82 (1·50–2·19) and 1·75 (1·21–2·52) for highly exposed women. Intermediate ORs were found for men (1·12

Table 3 Mean (SEM) FEV_1 scores by level of exposure estimated by the British and French matrices: analysis of exposure groups

	British JEM				French JEM			
	No	Low	High	P value	No	Low	High	P value
Men:								
Organic dusts	0·00 (0·01)	0·21 (0·07)	−0·12 (0·06)	NS†	0·02 (0·02)	−0·12 (0·05)	−0·13 (0·07)	**
Mineral dusts	0·00 (0·01)	0·13 (0·09)	0·00 (0·15)	NS	0·00 (0·02)	−0·01 (0·03)	0·08 (0·08)	NS
Combustion products	0·00 (0·01)	−0·01 (0·07)	−0·26 (0·14)	°	0·01 (0·01)	−0·12 (0·07)	−0·03 (0·18)	NS
Heavy metals	0·00 (0·01)	−0·03 (0·08)	−0·03 (0·09)	NS	0·00 (0·01)	0·01 (0·06)	−0·07 (0·17)	NS
Welding and soldering	0·00 (0·01)	0·11 (0·09)	−0·09 (0·18)	NS	0·01 (0·01)	0·05 (0·09)	−0·06 (0·13)	NS
Solvents	0·02 (0·02)	−0·07 (0·03)	−0·09 (0·08)	**	0·02 (0·02)	−0·13 (0·05)	−0·05 (0·06)	*
Other chemical products	0·02 (0·02)	−0·03 (0·03)	−0·24 (0·09)	**	0·00 (0·02)	0·00 (0·04)	−0·13 (0·08)	NS
Women:								
Organic dusts	0·02 (0·01)	0·03 (0·09)	−0·20 (0·05)	***	0·02 (0·02)	−0·04 (0·03)	−0·17 (0·06)	***
Mineral dusts	0·00 (0·01)	−0·53 (0·32)	—	°	0·02 (0·02)	−0·08 (0·03)	0·09 (0·18)	*
Combustion products	0·01 (0·01)	−0·29 (0·10)	0·06 (0·42)	**‡	0·00 (0·01)	−0·23 (0·11)	−0·08 (0·73)	*
Heavy metals	0·01 (0·01)	−0·01 (0·07)	0·31 (0·25)	NS	−0·01 (0·01)	0·10 (0·05)	0·46 (0·23)	*‡
Welding/soldering	0·00 (0·01)	−0·64 (0·33)	—	*	0·00 (0·01)	0·09 (0·17)	0·18	NS
Solvents	0·00 (0·02)	0·00 (0·02)	0·00 (0·07)	NS‡	0·01 (0·02)	−0·05 (0·04)	−0·24 (0·11)	*
Other chemical products	0·03 (0·02)	0·01 (0·02)	−0·13 (0·04)	**	0·01 (0·02)	−0·05 (0·07)	−0·06 (0·04)	°

°P ⩽ 0·10; *P ⩽ 0·05; **P ⩽ 0·01; ***P ⩽ 0·001; test for trend.
†P = 0·04 men with no or low *v* high exposure to organic dusts (high approach); men with low exposure to organic dusts were exclusively exposed to contact with animals (all physicians).
‡ A single (or very similar) occupation (s) represent more than 70% of exposure groups in the low category (>100 subjects in the category) for combustion products (waiters, café or restaurant owners), heavy metals (nurses and hospital orderlies exposed to mercury) and solvents (secretaries and office workers).
FEV_1 scores adjusted for age, height, city and smoking.
JEM = job exposure matrix.

(NS) and 1·40 (NS), respectively) and women (1·22 (1·03–1·44) and 1·14 (NS), respectively) with low exposure. No relation was found for exposure in men according to the French job exposure matrix. Women highly exposed to dusts, gases, and chemical fumes according to the French job exposure matrix had an OR (95% CI) significantly greater than one for $FEV_1 < 80\%$ (1·47 (1·22–1·77)), but not significant for $FEV_1 < 60\%$ (1·23). Intermediate but not significant ORs were found for women with low exposure.

HAZARD GROUPS

Both known and not previously recognised hazard groups were significantly associated with FEV_1 (table 3). In men, FEV_1 was significantly decreased in relation to the level of exposure to organic dusts estimated by the French job exposure matrix. Men exposed to solvents according to both job exposure matrices, or to other chemical products according to the British job exposure matrix, had a significant decrease in FEV_1. In women, FEV_1 was significantly decreased in relation to the level of exposure to organic dusts and combustion products assessed by the British and French job exposure matrices. The FEV_1 significantly decreased with exposure to mineral dusts and solvents estimated by the French job exposure matrix and to other chemical products and welding and soldering estimated by the British job exposure matrix. Unexpectedly, FEV_1 significantly increased with increasing exposure to heavy metals estimated by the French job exposure matrix. Based on the consistency of the relation (see methods), associations of hazards with FEV_1 were classified as very likely for organic dusts, combustion products, and for other chemical products, and as possible for solvents and mineral dusts.

SPECIFIC HAZARDS

In men, FEV_1 was significantly decreased by increasing exposure to detergents estimated by the British and French job exposure matrices (table 4). The FEV_1 significantly decreased with the level of exposure to diesel fumes or waxes and polishes estimated by the British job exposure matrix, and to PAHs estimated by the French job exposure matrix. Unexpectedly, FEV_1 significantly increased with exposure to formaldehyde estimated by the British job exposure matrix. There were also more significant relations between specific hazards and a decrease in FEV_1 for women than for men (table 5). In women, FEV_1 significantly decreased with the level of exposure to PAHs, textile dusts, detergents, and waxes and polishes estimated by the French and British job exposure matrices. The significant relations found for PAHs remained significant after adjustment for three hazard groups generally associated with industrial exposure to PAHs (heavy metals, welding and soldering, mineral dusts). The significant decrease in FEV_1 found for women exposed to waxes and polishes according to both job exposure matrices did not remain significant after adjustment for detergents. The FEV_1 significantly decreased with exposure to welding fumes estimated by the British job exposure matrix. The FEV_1 was significantly higher among women exposed to formaldehyde than those not exposed, according to the French job exposure matrix. Significant associations found for exposure to detergents remained after exclusion of subjects with asthma. No significant interaction between hazard groups

Table 4 Mean (SEM) FEV_1 scores for men by level of specific exposures estimated by the British and French matrices

	British JEM				*French JEM*			
	No	*Low*	*High*	*P value*	*No*	*Low*	*High*	*P value*
Contact with animals	0·00 (0·01)	0·21 (0·07)	−0·15 (0·08)	NS†	0·00 (0·01)	0·39 (0·41)	−0·11 (0·11)	NS
	4672	195	158		4931	10	84	
Textile dusts	0·00 (0·01)	—	−0·07 (0·21)	NS	0·00 (0·01)	−0·02 (0·08)	−0·47 (0·39)	NS
	4995	0	30		4920	92	13	
Asbestos	0·00 (0·01)	0·10 (0·08)	0·04 (0·34)	NS	0·00 (0·01)	0·01 (0·07)	−0·25 (0·62)	NS
	4900	113	12		4787	232	6	
Diesel fumes	0·00 (0·01)	−0·02 (0·12)	−0·27 (0·14)	*	0·00 (0·01)	−0·20 (0·14)	0·01 (0·18)	NS
	4918	40	67		4925	70	30	
PAHs	0·00 (0·01)	−0·13 (0·10)	0·04 (0·34)	NS	0·01 (0·01)	−0·13 (0·06)	−0·06 (0·30)	*
	4905	108	12		4752	255	18	
Chromates	0·00 (0·01)	0·04 (0·10)	−0·01 (0·17)	NS	0·00 (0·01)	0·14 (0·08)	—	NS
	4895	108	22		4915	110	0	
Welding fumes	0·00 (0·01)	0·07 (0·09)	—	NS	0·00 (0·01)	−0·05 (0·11)	−0·09 (0·28)	NS
	4908	117	0		4925	85	15	
Soldering fumes	0·00 (0·01)	0·05 (0·13)	−0·09 (0·18)	NS	0·00 (0·01)	0·06 (0·10)	−0·06 (0·14)	NS
	4933	60	32		4914	61	50	
Epoxy resins	0·00 (0·01)	0·07 (0·09)	0·04 (0·34)	NS	0·00 (0·01)	−0·09 (0·07)	−0·01 (0·21)	NS†
	4900	113	12		4831	175	19	
Paints	0·00 (0·01)	−0·22 (0·15)	0·00 (0·12)	NS	0·00 (0·01)	−0·11 (0·08)	0·00 (0·12)	NS†
	4948	43	34		4827	164	34	
Formaldehyde	−0·01 (0·01)	0·24 (0·07)	−0·03 (0·32)	**†	−0·01 (0·01)	0·20 (0·06)	−0·16 (0·12)	NS†
	4858	164	3		4767	197	61	
Waxes and polishes	0·01 (0·01)	−0·30 (0·08)	0·09 (0·43)	***	0·00 (0·01)	−0·03 (0·12)	−0·02 (0·22)	NS
	4884	136	5		4969	39	17	
Detergents	0·01 (0·01)	−0·12 (0·06)	−0·26 (0·10)	**	0·01 (0·01)	−0·13 (0·06)	−0·17 (0·13)	*
	4680	246	99		4775	214	36	

*$P \leqslant 0·05$; **$P \leqslant 0·01$; ***$P \leqslant 0·001$; test for trend.
FEV_1 scores adjusted for age, height, city and smoking.
JEM = job exposure matrix.
†A single occupation represents more than 70% of exposure groups in the low category (>100 subjects in the category) for formaldehyde and contacts with animals (physicians), epoxy resins and paints (draughtsmen). The same phenomenon also occurs for high exposure to contact with animals (butchers).

Table 5 Mean (SEM) FEV_1 scores for women by level of specific exposures estimated by the British and French matrices

	British JEM				*French JEM*			
	No	*Low*	*High*	*P value*	*No*	*Low*	*High*	*P value*
Contact with animals	0·00 (0·01)	0·03 (0·09)	−0·18 (0·09)	°	0·00 (0·01)	0·70 (1·07)	0·07 (0·16)	NS
	4734	97	141		4983	2	37	
Textile dusts	0·01 (0·01)	—	−0·20 (0·06)	**†	0·02 (0·01)	−0·18 (0·05)	−0·14 (0·18)	***
	4742	0	230		4456	488	28	
Asbestos	0·00 (0·01)	−0·53 (0·32)	—	°	0·00 (0·01)	−0·22 (0·14)	—	NS
	4962	10	0		4923	49	0	
Diesel fumes	0·00 (0·01)	−0·08 (0·73)	−0·74	NS	0·00 (0·01)	−0·62 (0·46)	−0·08 (0·73)	NS
	4969	2	1		4962	8	2	
PAHs	0·00 (0·01)	−0·24 (0·11)	—	*†	0·01 (0·01)	−0·26 (0·11)	—	*
	4873	99	0		4875	97	0	
Chromates	0·00 (0·01)	−0·13 (0·18)	0·56 (0·29)	NS	0·00 (0·01)	0·02 (0·17)	—	NS
	4950	20	2		4951	21	0	
Welding fumes	0·00 (0·01)	−0·81 (0·33)	—	*	0·00 (0·01)	0·07 (0·18)	—	NS
	4964	8	0		4938	34	0	
Soldering fumes	0·00 (0·01)	0·69	—	NS	0·00 (0·01)	0·19 (0·27)	0·18	NS
	4971	1	0		4963	8	1	
Epoxy resins	0·00 (0·01)	−0·17 (0·15)	—	NS	0·00 (0·01)	−0·13 (0·15)	0·12 (0·31)	NS
	4935	37	0		4937	28	7	
Paints	0·00 (0·01)	−0·15 (0·17)	−0·04 (0·23)	NS	0·00 (0·01)	−0·04 (0·18)	−0·04 (0·23)	NS
	4946	13	13		4940	19	13	
Formaldehyde	0·00 (0·01)	0·12 (0·12)	−0·10 (0·76)	NS	−0·01 (0·01)	0·15 (0·11)	0·10 (0·06)	*‡
	4924	46	2		4613	65	294	
Waxes and polishes	0·02 (0·01)	−0·14 (0·04)	−0·30 (0·23)	***	0·01 (0·01)	−0·19 (0·07)	—	**
	4399	559	14		4733	239	0	
Detergents	0·03 (0·02)	−0·19 (0·07)	−0·14 (0·04)	***	0·02 (0·01)	−0·15 (0·07)	−0·18 (0·06)	***†
	4213	205	554		4436	213	323	

°P ≤ 0·10; *P ≤ 0·05; **P ≤ 0·01; ***P ≤ 0·001; test for trend.
FEV_1 scores adjusted for age, height, city and smoking.
JEM = job exposure matrix.
†A single (or very similar) occupation (s) represent more than 70% of exposure groups in the low category (>100 subjects in the category) for PAHs (waiters, café or restaurant owners). For high exposure category, it occurs for textile dusts (seamstresses, machine sewers), formaldehyde (nurses, hospital orderlies) and detergents (cleaning ladies).

or specific hazards and smoking habits was found. Based on the consistency of the relations (see methods) associations of specific hazards with decreased FEV_1 were classified as very likely for detergents, PAHs, textile dusts, and as possible for diesel fumes and waxes and polishes.

Analyses carried out on FEV_1/FVC or FEF_{25-75} showed similar results to those carried out on FEV_1 except for asbestos, for which the association with FEV_1/FVC was classified as very likely whereas the association with FEF_{25-75} was classified as possible. The application of the Italian matrix gave for both sexes similar results for PAHs and solvents but different findings for formaldehyde (table 6) than with the French and British job exposure matrices.

EDUCATIONAL LEVEL

Adjustment for education level was performed only in retrospect, through adjustment and stratification, because of potential over adjustment, and overall the associations already described decreased. For women, the associations remained significant (French and Italian job exposure matrices) or of borderline significance (British job exposure matrix) for dusts, gases, and chemical fumes after adjustment for education. The FEV_1 scores adjusted for education level were 0·07, 0·06, −0·05 (British job exposure matrix) and 0·07, 0·01, 0·02 (French job exposure matrix) in women with no, low, and high exposure to dusts, gases, and chemical fumes, respectively. Associations were significant and strongest in women with only primary education, according to the three job exposure matrices. Similar results were found for hazard groups and specific hazards, with significant associations in women with only primary education. For example, significant FEV_1 scores adjusted for education level were 0·06, −0·10, −0·02 (British job exposure matrix) and 0·06, −0·03, −0·06 (French job exposure matrix) in women with no, low, and high exposure to detergents, respectively.

Table 6 Mean (SEM) FEV_1 scores according to the level of specific exposures estimated by the Italian matrix

	Men				*Women*			
	No	*Low*	*High*	*P value*	*No*	*Low*	*High*	*P value*
Asbestos	0·00 (0·02)	−0·04 (0·03)	0·01 (0·14)	NS	0·02 (0·02)	−0·16 (0·04)	−1·05 (0·34)	***
	3881	932	29		4334	584	6	
PAHs	0·01 (0·02)	−0·03 (0·03)	−0·18 (0·08)	*	0·02 (0·02)	−0·08 (0·04)	−0·37 (0·18)	**
	3711	986	145		4066	830	28	
Chromates	0·00 (0·02)	0·04 (0·07)	−0·10 (0·07)	NS†	0·00 (0·01)	−0·11 (0·11)	−0·20 (0·21)	NS
	4436	227	179		4816	87	21	
Formaldehyde	0·01 (0·02)	−0·05 (0·03)	—	NS	0·02 (0·02)	−0·06 (0·03)	—	*
	3964	878	0		3726	1198	0	
Organic solvents	0·02 (0·02)	−0·10 (0·04)	−0·09 (0·05)	**	0·01 (0·02)	−0·04 (0·03)	−0·27 (0·11)	*
	3763	809	270		3672	1188	64	

*P ≤ 0·05; **P ≤ 0·01; ***P ≤ 0·001; test for trend.
FEV_1 scores adjusted for age, height, city and smoking.
JEM = job exposure matrix.
†A single occupation represents more than 70% of exposure groups in the high category (> 100 subjects in the category) for chromates (warehousemen).

For men, the pattern was less clear. After adjustment for education level, the associations of dusts, gases, and chemical fumes, hazard groups, or specific hazards with FEV_1 did not remain significant. The FEV_1 scores adjusted for education level were 0·03, 0·03, −0·03 (British job exposure matrix) and 0·03, 0·02, 0·00 (French job exposure matrix) in men with no, low, and high exposure to dusts, gases, and chemical fumes, respectively. Significant associations were found in those with a secondary education. In men with primary education, men not currently exposed seemed to have rather low FEV_1 scores. Men not currently exposed to dusts, gases, and chemical fumes according to both job exposure matrices reported exposure in previous jobs in 18%, 8%, and 4% of cases among men with primary, secondary, and university education level, respectively.

Discussion

In the non-industrial population based PAARC survey, both men and women exposed to dusts, gases, or chemical fumes according to three job exposure matrices had significantly lower FEV_1 levels after adjustment for age, height, city, and smoking than those not exposed. Furthermore significant exposure-response relations were found with the three independent job exposure matrices. We found associations of exposure to already known risk factors such as organic dusts or textile dusts with reduced FEV_1. Exposure to detergents, PAHs, and solvents showed consistent associations with reduced FEV_1 for both sexes in the various job exposure matrices. To a lesser extent associations of exposure to waxes and polishes, diesel fumes, and asbestos and lung function were also found.

DUSTS, GASES, AND CHEMICAL FUMES

To our knowledge, this study is the first to analyse the relation of lung function to occupational exposures estimated by job exposure matrices. The consistent associations according to three independent job exposure matrices and in sub-populations (men or women, smokers or non-smokers) found between lung function and exposure to dusts, gases, and chemical fumes are in agreement with findings already reported both in community[4–14] and workforce based studies.[1–3] The relation of lung function with self reported exposure to dusts, gases, and chemical fumes was significant[4–6 10] in four out of six community based studies in which it was analysed. In the PAARC survey, significant relations with lung function were found for exposure to dusts, gases, and chemical fumes assessed by job exposure matrices but not for self reported exposure.[6] This is probably explained by the very limited information on self reported exposure (only one question) in the PAARC survey. No interaction between occupational exposures and smoking was found, which confirms results from most other studies.[5–11 14]

Exposure-response relations found for both sexes by three different job exposure matrices support the hypotheses of a causal role of dusts, gases, and chemical fumes on lung function. Exposure-effect relations of dusts, gases, and chemical fumes with symptoms and impairment of lung function have already been reported in the general population of Tucson[4] within exposed subjects and for gases and fumes in a heavily exposed general Chinese population.[12] No effect of low exposure was found in the Zutphen[7] or the Norwegian[11] studies, which used job exposure matrices.

The PAARC survey, the primary aim of which was to assess the role of air pollution,[19] excluded by design households of manual workers to avoid heavy occupational exposures. The present results from the PAARC survey provide an opportunity to assess the role of exposure encountered mostly in intermediate occupations, which now concern an increasing proportion of the working force. There are some limitations in the study related to the very small numbers of manual workers. Results cannot be generalised to the population as a whole. If a relation is found in the moderately exposed PAARC population, it could be expected in a general population with a higher proportion of exposed subjects. In the PAARC survey the clearer relation in women (less affected by the exclusion of manual worker heads of households) than in men supports this hypothesis.

SPECIFIC HAZARDS

Whereas exposure to dusts, gases, and chemical fumes in relation to respiratory diseases was analysed in a few community based studies, specific hazards have not been commonly studied.[4 7 9 11] In the PAARC survey, known relations were found and some new hypotheses suggested.

DUSTS

The significant relation of exposure with lung function found in the PAARC survey for women exposed to mineral dusts according to the French job exposure matrix (with an association of borderline significance for the British job exposure matrix) supports results from workforce[3 27 28] and population based studies.[12] The lack of relation among men is likely to be explained by the absence of manual worker men in the PAARC survey. Exposure to asbestos seems to have an effect especially on FEV_1/FVC, and to a lesser extent on FEF_{25-75}. This is in agreement with the lower lung function found in workers exposed to asbestos in occupational group studies.[3] In the general population of Tucson subjects exposed (*v* non-exposed) to asbestos had higher prevalences of dyspnoea or wheezing but no relation with lung function was reported.[4]

The significant decrease in FEV_1 found in the PAARC survey, for women exposed to textile dusts (clothing workers) supports findings in workforce based studies.[3 29] Exposure to textile fibres, especially cotton, is associated with byssinosis in textile mill workers and with a decline in FEV_1,[3 29] but no population based study had analysed the relation of textile dust exposure and respiratory outcomes. Besides subjects working in textile mills, further investigation of the risk factors encountered by clothing workers would be interesting.

Consistent associations of exposure to organic dusts and lung function were found in the PAARC survey. As well as for textile dusts, the association of exposure to grain dusts with respiratory symptoms or with a decrease in lung function has been described in cross sectional[3] and longitudinal studies[28] conducted in workforce based populations. In population based studies Lebowitz *et al* found an association between self reported exposure to sawdust and lung function.[4] Heederick *et al*, in the Zutphen survey,[7] as well as Hsairi *et al*,[13] in the PAARC survey, found an association between exposure to organic dust assessed with the British job exposure matrix, and symptom prevalence.

GASES OR CHEMICAL FUMES

According to the three job exposure matrices, men and women exposed to PAHs had a decrease in FEV_1. Most of the exposed subjects had a low level of exposure to PAHs. The consistency of results for PAHs and diesel fumes are an argument for the effect of combustion products on lung function. In a workforce based population, a relation between exposure to non-halogenated hydrocarbons (including tars) and 12 year FEV_1 decline has been reported.[28] Similarly, in the Tucson general population, a higher rate of abnormal lung function in subjects exposed to vehicle exhaust compared with non-exposed subjects was found.[4] For now, there is no clear hypothesis to explain an effect of PAHs on lung function. The PAHs are formed by thermal decomposition, and therefore exposure to PAHs is never isolated, but associated with dusts or other exposures. Exposure to PAHs probably reflects associations with other respiratory hazards not characterised in the job exposure matrices. Consequently it is difficult to estimate the independent effect of PAHs.

Consistent results found for detergents, by both job exposure matrices, which remained significant among women after adjustment for waxes and polishes, suggest a role of detergents in decreased FEV_1. In workforce based studies, short term effects of exposure to detergents, such as a high percentage of pulmonary function abnormalities, asthma, and cutaneous reactivity, have been shown among detergent workers[30] and were attributed to the presence of enzymes. Our results suggest the effects of occupational exposure to detergents on lung function independently of asthma, such as experienced by cleaning ladies. Subjects exposed to detergents may more often also be exposed to chlorine, ammonia, chloramine, or other known respiratory irritants. Interestingly, analyses based on job titles conducted in two population based studies found increased prevalences of dyspnea for domestic service, cleaning, or handling employees[31] and of wheezing and attacks of breathlessness among housewives[32] possibly exposed to detergents. As the association of exposure to waxes and polishes and detergents was typical of cleaning work, it was tempting to delineate their specific effects. Further investigations, for example a follow up of cleaning ladies in workforce based populations, are warranted.

Consistent associations of exposure to solvents with lung function were found. The assessment of solvent exposure is difficult because of the complex nature and variety of solvents that makes it difficult to identify homogeneous groups,[33 34] and of frequent associations with other hazards. Our results are in agreement with results found with self reported exposure in the Tucson study[4] as well as in the Zutphen study with the British job exposure matrix[7] or a population based matrix.[35] In a 12 year follow up study conducted among workers in the Paris area,[28] oil of turpentine (and resins, varnishes, and paints based on turpentine) was significantly related to steeper FEV_1 slope, whereas no relation was found with alcohol, esters, or ketones. The intensity of exposure to solvents depends on many individual variables (safety device, spray painting) that are not possible to record in a job exposure matrix. Further research is needed to better characterise exposures to solvents and their potential effects.[34] Whereas an association of chronic non-specific lung disease with paints was reported in the Zutphen study[7] no relation was found with lung function in the PAARC survey. All the hypotheses generated for specific hazards need to be interpreted with caution before replication of the findings.

EDUCATION LEVEL

When taking education level into account, associations remained for women and were considerably weakened for men. The relevance of adjustment for sociocultural variables is debatable[36] and as recommended in the general case of potential over adjustment, analyses were performed before and after adjustment. Social class was directly derived from the present occupation and adjustment for it would really be a clear over adjustment. Education level, related to both present and past lifestyles, was considered in the analysis despite its very strong relation to current occupation. Most papers on the analysis of occupational exposures in general populations have not considered education and some have included an analysis before and after adjustment. Results are rarely given only after adjustment.[12] In the PAARC survey, results were, as in the Zutphen study,[7] less clear after taking education level into account, and most associations were weakened. Associations remained significant for women with only primary education, which is not surprising because most highly exposed women had a low education level. Therefore, results in women suggest that a poor background is unlikely to explain the associations found. In particular, the association between exposure to detergents (the main hypothesis generated) and FEV_1 remained significant after adjustment for education level. In men, however, the associations remained only in those with secondary education, but not in those with primary education, which seems initially surprising. In men with only primary education, the difference found between exposed and non-exposed may have been explained by low levels of FEV_1 in non-exposed men who often reported exposure in a previous job. The lack of relation of exposure with FEV_1 in men with primary education may reflect some healthy worker effect. It is difficult to evaluate the bias produced by the absence of manual workers among the men (most of them with only primary education) in the PAARC survey. Such design may have left under study an unhealthy selected group of men with primary education, in particular former manual workers in the non-exposed group. An alternative hypothesis may be that education did reflect the role of an unmeasured confounder, such as early childhood infections. The problem of an unmeasured confounder or other hazard is also a concern when a very high proportion of subjects in some exposure categories belong to a single occupation. In such cases, it is difficult to ascribe the difference in lung function (positive or negative) to that exposure. For example, it is difficult to interpret the relation between FEV_1 and formaldehyde because the exposed people were physicians in men and nurses in women, according to two job exposure matrices (British and French). Longitudinal studies from the time of first hiring are likely to be necessary in the design to delineate the roles of various sociocultural aspects on respiratory diseases, among which education and occupational conditions, although highly correlated, are separate variables.

METHODS

The validity of exposure generated by the job exposure matrices used is a key issue, nevertheless a true validation is difficult.[37] In the PAARC survey, there was no control estimate to study the validity of job exposure matrix. Kauppinenn *et al* concluded that the British job exposure matrix, compared with expert assessment, is an acceptably valid screening tool for specific agents with prevalences of 10% or more.[15] This suggests that caution is necessary in the interpretation of our results in the case of low prevalence of exposures. We did not study hazards for which less than 100 subjects (around 2%) were exposed among men or women. Results obtained for PAHs and diesel fumes should be viewed with particular caution as the prevalence of exposure was low. On the contrary a large proportion of subjects were exposed to detergents. Indirect validation of job exposure matrices has been provided by the demonstration of known association of exposures.[17 38] In the Zutphen cohort, known associations were found for chronic non-specific lung desease,[7] but not confirmed for lung cancer.[16] In the PAARC survey, known associations were found for textile dusts and organic dusts, which is an argument in favour of the validity of job exposure matrices. The known association of mineral dusts with low lung function was not confirmed, which may be related to the absence of manual worker men.

In the PAARC survey job exposure matrices were not used in optimal conditions. Exposures were generated by job exposure matrices that took into account only the most recent occupation. Associations may have been underestimated by the healthy worker effect. The misclassification of exposure related to the use of job exposure matrices was worsened here by the translation of codes, but this bias is theoretically not differential.[39] Such misclassification reduces the strength of the associations but may not easily explain a significant relation. Subjects were exposed simultaneously to a lot of hazards, so it was difficult to estimate the effect of the hazards individually. It is never possible to eliminate the role of another unmeasured related hazard. Putting many exposures simultaneously in a model is not the optimal method,[39] because the various hazards are closely related. Although the French job exposure matrix was developed specially for the PAARC survey, the exposure assessment was hampered by the use of an inadequate job axis: jobs were defined only by occupations from the INSEE code[20] used in the PAARC study. Both the British and Italian job exposure matrices were built to assess hazards relevant for cancer. Building a job exposure matrix with adequate hazard axis for the study of respiratory diseases would be useful. Pooling under the same occupational title various workplaces differing in tasks and exposures remains an inherent limitation of job exposure matrices.[39]

In conclusion, the causal role of occupational exposure to dusts, gases, or chemical fumes on lung function is supported by the results obtained in the large non-industrial population based PAARC survey with three independent job exposure matrices. The validity of the job exposure matrix approach is sustained by the confirmation of already known associations. Furthermore, hypotheses have been generated for the potential deleterious respiratory effect of detergents, PAHs, and solvents. Caution is necessary in the interpretation of these results before replication. The question arose about the precise assessment of specific hazards, such as solvents or PAHs for which associations with FEV_1 could reflect the role of other respiratory hazards. Thus, job exposure matrices seem to be a useful method to estimate occupational exposure and generate hypotheses in large population surveys, in the absence of specific questionnaires about occupational exposures. Despite the expected limitations of job exposure matrices, the present results encourage further work to improve exposure assessment by job exposure matrix.

The PAARC study was supported by grants from the Ministères de l'Environnement et du Cadre de vie et de la santé et de la Sécurité Sociale, France and the present analysis in part by ECOJEM-COMAC grant (BMH1-CT92-0849). We thank the directors of the PAARC Cooperative group: R Bollinelli (deceased), D Brille, J Charpin, P Fréour, M Gervois, P Laval, JP Lemercier, and S Perdrizet; the coordinators: D Brille, P

Bourbon, and J Lellouch; and the other members of the PAARC group involved at different stages of the study, particularly E Patois who helped with data processing. We thank M Bollière for assistance in translation of French classifications to British classifications. We thank Drs D Coggon and B Pannet for providing us with the British job exposure matrix. We thank Dr F Berrino for providing us with the Italian job exposure matrix, developed at the Epidemiology Division of the Istituto Nazionale Tumori Milan (Italy) under contract CNR No 88.00524.44.

1 Becklake M. Occupational exposure: evidence for causal association with chronic obstructive pulmonary disease. *Am Rev Respir Dis* 1989;**140**:S85–91.
2 Heederick D, Taeke MP. Contribution of occupational exposures to the occurrence of chronic nonspecific lung disease. In: A Hirsch, M Goldberg, JP Martin, R Masse, eds. *Prevention of respiratory diseases.* New York: Marcel Dekker, 1993: 133–48.
3 Garshick E, Schenker MB. Occupation and chronic airflow limitation. In: M J Hensley, N A Saunders, eds. *Clinical epidemiology of chronic obstructive pulmonary disease.* New York: Marcel Dekker, 1989: 227–58.
4 Lebowitz MD. Occupational exposures in relation to symptomatology and lung function in a community population. *Environ Res* 1977;**14**:59–67.
5 Korn RJ, Dockery DW, Speizer FE, Ware JH, Ferris BG. Occupational exposures and chronic respiratory symptoms. *Am Rev Resp Dis* 1987;**136**:298–304.
6 Krzyzanowski M, Kauffmann F. The relation of respiratory symptoms and ventilatory function to moderate occupational exposure in a general population. Results from the French PAARC study among 16 000 adults. *Int J Epidemiol* 1988;**17**:397–406.
7 Heederik D, Pouwels H, Kromhout H, Kromhout D. Chronic non-specific lung disease and occupational exposures estimated by means of a job exposure matrix: the Zutphen study. *Int J Epidemiol* 1989;**18**:382–9.
8 Krzyzanowski M, Jedrychowski W. Occupational exposure and incidence of chronic respiratory symptoms among residents of Cracow followed for 13 years. *Int Arch Occup Environ Health* 1990;**62**:311–7.
9 Heederik D, Kromhout H, Burema J, Biersteker K, Kromhout D. Occupational exposure and 25-year incidence rate of non-specific lung disease: the Zutphen study. *Int J Epidemiol* 1990;**19**:945–52.
10 Viegi G, Prediletto R, Paoletti P, *et al.* Respiratory effects of occupational exposure in a general population sample in north Italy. *Am Rev Respir Dis* 1991;**143**:510–5.
11 Bakke S, Baste V, Hanoa R, Gulsvik A. Prevalence of obstructive lung disease in a general population: relation to occupational title and exposure to some airborne agents. *Thorax* 1991;**46**:863–70.
12 Xu X, Christiani DC, Dockery DW, Wang L. Exposure-response relationships between occupational exposures and chronic respiratory illness: a community-based study. *Am Rev Respir Dis* 1992;**146**:413–8.
13 Hsairi M, Kauffmann F, Chavance M, Brochard P. Personal factors related to the perception of occupational exposure: an application of a job exposure matrix. *Int J Epidemiol* 1992;**21**:972–80.
14 Xu X, Christiani DC. Occupational exposures and physician-diagnosed asthma. *Chest* 1993;**104**:1364–70.
15 Kauppinen TP, Mutanen PO, Seitsamo JT. Magnitude of missclassification bias when using a job-exposure matrix. *Scand J Work Environ Health* 1992;**18**:105–12.
16 Kromhout H, Heederik D, Dalderup LM, Kromhout D. Performance of two general job-exposure matrices in a study of lung cancer morbidity in the Zutphen cohort. *Am J Epidemiol* 1992;**136**:698–711.
17 Pannett P, Coggon D, Acheson ED. A job-exposure matrix for use in population based studies in England and Wales. *Br J Ind Med* 1985;**42**:777–83.
18 Macaluso M, Vineis P, Continenza D, Ferrario F, Pisani P, Andisio R. Job exposure matrices: experience in Italy. In: ED Acheson, ed. *Job exposure matrices.* Southampton: MRC Environmental Epidemiology Unit, 1983:22–30.
19 Groupe Coopératif PAARC. Pollution atmosphérique et affections respiratoires chroniques ou à répétition. I Méthodes et sujets. *Bulletin Europeen de Physiopatologie Respiratoire* 1982;**18**:87–99.
20 Institut National de la Statistique et des Etudes Economiques. *Code 2 du recensement de la population 1968. Code des métiers.* Paris: Imprimerie Nationale, 1968, 319.
21 General Register Office. *Classification of occupations (1966).* London: HMSO, 1966.
22 Ferrario F, Continenza D, Pisani P, Magnani C, Merletti F, Berrino F. Description of a job exposure matrix for sixteen agents which are or may be related to respiratory cancer. In: Hogstedt C, Reuterwall C, eds. *Progress in occupational epidemiology.* Amsterdam: Elsevier, 1988: 379–82.
23 International Labour Office: *International standard classification of occupations.* Revised edition. Geneva: ILO 1968.
24 Groupe Coopératif PAARC. Pollution atmosphérique et affections respiratoires chroniques ou à répétition. II Résultats et discussion. *Bulletin Europeen de Physiopatologie Respiratoire* 1982;**18**:101–11.
25 Quanjer P. Standardized lung function testing. *Bulletin Europeen de Physiopatologie Respiratoire* 1983;**19**(suppl 5):1–95.
26 Snedecor GW, Cochran WG. In: Ames IA, ed. *Statistical methods.* Iowa State University Press, 1967.
27 Becklake M. Epidemiology: prevalence and determinants. In: IL Berstein, M Chan-Yeung, JL Malo, DI Berstein, eds. *Asthma in the workplace.* New York: Marcel Dekker, 1993: 29–59.
28 Kauffmann F, Drouet D, Lellouch J, Brille D. Occupational exposure and 12-year spirometric changes among Paris area workers. *Br J Ind Med* 1982;**39**:221–32.
29 Merchant A, Bernstein IL. Cotton and other textile dusts. In: IL Berstein, M Chan-Yeung, JL Malo, DI Berstein, eds. *Asthma in the workplace.* New York: Marcel Dekker, 1993:551–76.
30 Bernstein DI, Malo JL. High molecular weight agents. In: IL Berstein, M Chan-Yeung, JL Malo, DI Berstein, eds. *Asthma in the workplace.* New York: Marcel Dekker, 1993:373–98.
31 Nejjari C, Tessier JF, Dartigues JF, Barberger-Gateau P, Letenneur L, Salamon R. The relationship between dyspnea and main lifetime occupation in the elderly. *Int J Epidemiol* 1993;**22**:848–54.
32 Stjernberg N, Lundbäck B, Jönsson E, Lindström M, Lundbäck K, Forsberg B, Sandström T. Chronic bronchitis, asthma and respiratory symptoms in relation to occupation and socio-economic group: report from the obstructive lung disease in northern Sweden study. *Scand J Work Environ Health* 1995 (in press).
33 Stengel B, Pisani P, Limasset JC, Bouyer J, Berrino J, Hemon D. Retrospective evaluation of occupational exposure to organic solvents: questionnaire and job exposure matrix. *Int J Epidemiol* 1993;**22**(suppl 2):S72–82.
34 Schenker MB, Jacobs JA. Respiratory effects of organic solvent exposure. *Tuber Lung Dis* 1995 (in press).
35 Post WK, Heederick D, Kromhout H, Kromhout D. Occupational exposures estimated by a population specific job exposure matrix and 25 year incidence rate of chronic nonspecific lung disease (CNSLD): the Zutphen study. *Eur Respir J* 1994;**7**:1048–55.
36 Brisson C, Loomis D, Pearce N. Is social class standardisation appropriate in occupational studies? *J Epidemiol Community Health* 1987;**41**:290–4.
37 Bouyer J, Hemon D. Studying the performance of a job exposure matrix. *Int J Epidemiol* 1993;**22**(suppl 2): S65–71.
38 Ahrens W, Jöckel K, Brochard P, Bolm-Audorff U, Grossgarten K, Iwatsubo Y, Orlowski E, Pohlabeln H, Berrino F. Retrospective assessment of asbestos exposure. I Case-control analysis in a study of lung cancer: efficiency of job-specific questionnaires and job exposure matrices. *Int J Epidemiol* 1993;**22**(suppl 2):S83–94.
39 Goldberg M, Goldberg P. Measurement of occupational exposure and prevention: principal approaches to research. In: A Hirsch, M Goldberg, JP Martin, R Masse, eds. *Prevention of respiratory diseases. Lung biology in health and disease.* New York: Marcel Dekker, 1993;**68**:167–92.