Ann. Occup. Hyg., 2014, Vol. 58, No. 3, 380–396
doi:10.1093/annhyg/met074
Advance Access publication 8 January 2014

The Chartered Society for Worker Health Protection

REVIEW

Use of the Finnish Information System on Occupational Exposure (FINJEM) in Epidemiologic, Surveillance, and Other Applications

Timo Kauppinen[1], Sanni Uuksulainen[1*], Anja Saalo[1], Ilpo Mäkinen[1] and Eero Pukkala[2,3]

1. Surveillance and Reviews, Finnish Institute of Occupational Health (FIOH), Topeliuksenkatu 41aA, FI-00250 Helsinki, Finland;
2. Finnish Cancer Register (FCR), Institute for Statistical and Epidemiological Cancer Research, Pieni Roobertinkatu 9, FI-00130 Helsinki, Finland;
3. School of Health Sciences, FI-33014 University of Tampere, Finland
*Author to whom correspondence should be addressed. Tel: +358 30 4741; fax: +358 30 4742779; e-mail: sanni.uuksulainen@ttl.fi
Submitted 5 August 2013; revised 22 November 2013; revised version accepted 27 November 2013.

ABSTRACT

This paper reviews the use of the Finnish Information System on Occupational Exposure (Finnish job-exposure matrix, FINJEM) in different applications in Finland and other countries. We describe and discuss studies on FINJEM and studies utilizing FINJEM in regard to the validity of exposure estimates, occupational epidemiology, hazard surveillance and prevention, the assessment of health risks and the burden of disease, the assessment of exposure trends and future hazards, and the construction of job-exposure matrices (JEMs) in countries other than Finland. FINJEM can be used as an exposure assessment tool in occupational epidemiology, particularly in large register-based studies. It also provides information for hazard surveillance at the national level. It is able to identify occupations with high average exposures to chemical agents and can therefore serve the priority setting of prevention. However, it has only limited use at the workplace level due to the variability of exposure between workplaces. The national estimates of exposure and their temporal trends may contribute to the assessment of both the recent and future burden of work-related health outcomes. FINJEM has also proved to be useful in the construction of other national JEMs, for example in the Nordic Occupational Cancer study in the Nordic countries. FINJEM is a quantitative JEM, which can serve many purposes and its comprehensive documentation also makes it potentially useful in countries other than Finland.

KEYWORDS: burden of disease; epidemiology; Finland; hazard surveillance; job-exposure matrix; trend

INTRODUCTION

The Finnish Information System on Occupational Exposure (Finnish job-exposure matrix, FINJEM) was constructed in the 1990s (Kauppinen *et al.*, 1998). FINJEM was prompted by the need to translate occupational histories into quantitative estimates of exposure to carcinogens for a census-based epidemiological study on occupational cancer risks, but it was designed to also serve other purposes in the field of occupational health. It is a job-exposure matrix (JEM) that contains occupation- and time-specific estimates of exposure to various agents or factors, which occur in Finnish workplaces. It includes comprehensive documentation on exposure estimates in a database, which facilitates its use in hazard surveillance, risk assessment, and as a general exposure information system for various other purposes. The transparent nature of FINJEM also makes it potentially useful as a source of data in applications outside Finland.

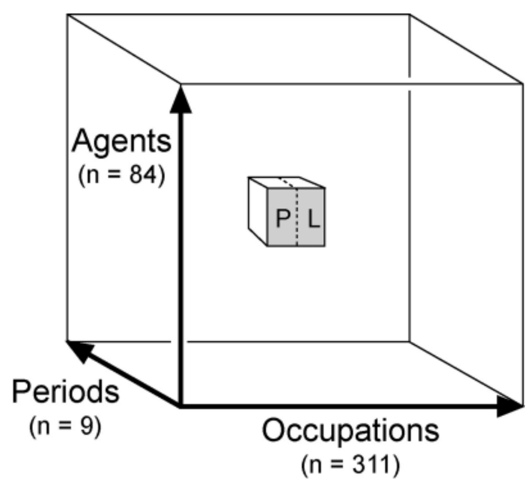
The aim of the present paper is to review the use of FINJEM in different applications in Finland and other countries. The strengths, weaknesses, and future potential of FINJEM and the generic JEM methodology overall is discussed from different perspectives, such as occupational epidemiology, the surveillance of hazards, the prevention of hazards, the assessment of risks and the burden of disease, the assessment of exposure trends, the prediction of future exposures, and the construction of JEMs for other countries.

DESCRIPTION OF FINJEM

FINJEM covers the major occupational exposures that have occurred in Finland since 1945. The basic dimensions with which exposure is assessed in FINJEM are agents, occupations, and calendar periods. The exposure to each agent is characterized by the proportion of the exposed (*P*, as % of the employed) and the mean level of exposure among the exposed (*L*, in agent-specific units) by occupation and period. The basic structure of FINJEM is presented in Fig. 1.

The exposure estimates of FINJEM are based on the evaluations of ~20 experts at Finnish Institute of Occupational Health (FIOH) and data from the Finnish Database of Occupational Exposure Measurements (Heikkilä *et al.*, 2005), the Finnish Register on Occupational Exposure to Carcinogens (Kauppinen *et al.*, 2007), and the national Work and Health surveys (Perkiö-Mäkelä *et al.*, 2010). FIOH biomonitoring data and data from the Finnish Register of Occupational Diseases were also used to estimate some exposures. The total number of measurements used to assess chemical exposures was 157035 (as of September 2013). The number of measurement results of the following agents exceeded 1000: asbestos (3161), benzene (2413), lead and lead in blood (61023), carbon monoxide (5358), chromium, chromium VI, and chromium in urine (8888), dust (5514), formaldehyde (9001), man-made mineral fibers (1905), nickel and nickel in urine (3060), other mineral dusts (8109), silica/quartz (3852), combined effect of solvents (2551), styrene (9683), toluene (2709), wood dust (5277), and xylene (2296). The basis of the estimates, definitions of agents, and aggregated measurement and survey data are documented in the FINJEM database.

The first version of FINJEM was developed in 1992–1993 for a large epidemiological linkage study on cancer (Pukkala, 1995). The second version came in 1994–1995, for a large occupational mortality study. It included 74 chemical, physical, microbiological, ergonomic, and psychosocial factors. The occupational dimension was divided into 311 categories (Longitudinal Occupational Classification of Finnish Censuses, unpublished data) and this version covered



1 Basic structure of Finnish Information System on Occupational Exposure (FINJEM). Exposure to each agent is characterized by the prevalence of exposure (*P*, as % of the employed) and average level of exposure among the exposed (*L*, in agent-specific units) by occupation and period.

the periods 1945–1959, 1960–1984, and 1985–1994. Since then, a substantial part of exposure estimates has been updated for the periods 1995–1997, 1998–2000, 2001–2003, 2004–2006, 2007–2009, and 2010–2012, mainly for surveillance purposes. The period 1960–1984 was assessed with particular care by dividing individual occupations into subgroups (e.g. full-time stainless steel welders, occasional stainless steel welders), by estimating the effect of the intermittency of exposure (annual mean exposure at work), and by reviewing a substantial amount of measurement data. The other periods were assessed mainly based on identified changes of exposure over time (new measurement data, changes in technology, regulations, or in the use of chemicals).

The occupation-specific numbers of workers exposed to chemical agents have also been divided into exposure classes based on the estimated mean level of exposure *L* (arithmetic mean) and the log-normal distribution of exposures. The geometric standard deviation of the distribution was assumed to be 2.5 but was changed whenever available data allowed. The exposure classes were <10, 10–50, and >50% of the Finnish occupational exposure limit (OEL) (HTP-arvot, 2009). This procedure also allows one to calculate the prevalence and number of workers exposed to a 'high' level (>50% of OEL). The calculation requires assuming that the distribution of workers' exposures within an occupation is equal to the distribution of exposure levels within this occupation. In 2001, the industrial dimension (223 classes, Finnish Classification of Industries 1995) (Statistics Finland, 1993) was added to FINJEM for the period 1995–1997. Exposure estimates were mechanically calculated on the basis of occupation-specific estimates and the distribution of occupations within industries.

Occupation- and gender-specific information of lifestyle factors (smoking, alcohol, diet, physical exercise, overweight) for the period 1995–1997 were added to FINJEM in 2005. The data came from the 1993–1999 surveys on the health behavior of adult Finns (data provided by the Finnish Public Health Institute, currently the National Institute for Health and Welfare). These estimates address the prevalence of each category of lifestyle factors. Direct prevalence data were used when the number of respondents representing a given occupation (three-digit occupation) in the surveys was at least 20. In cases with fewer respondents, the prevalence of a larger occupational group (two-digit occupation) was used.

The FINJEM estimates for 16 agents were reviewed in a Nordic expert team during the construction of JEMs for the Nordic Occupational Cancer study (NOCCA), which is a cohort study based on entire employed populations in one or several censuses in Denmark, Finland, Iceland, Norway, and Sweden. As a consequence of this review, many exposure estimates in FINJEM were modified to better match the measurement data and the experience of the expert team. The team also assessed and added eight new agents, not included in FINJEM (six individual solvents, sulphur dioxide, and welding fumes), to the NOCCA JEMs and FINJEM (Kauppinen *et al.*, 2009).

The present version of FINJEM (FINJEM 2012) has been updated up to the period 2007–2009. Almost all chemical exposures have been updated completely, but some other exposures are only partly updated or not at all (see Table 1). FINJEM data and the background documentation are saved in the MS Access database (presently in the 2010 version). The exposure estimates are available for collaborative purposes as an MS Excel file if the conditions of use are agreed with FIOH. FINJEM can also be purchased and used for non-collaborative purposes. Further information may be obtained from S.U. (sanni.uuksulainen@ttl.fi).

COMPARISON OF FINJEM WITH OTHER JEMS

The exposure estimates of FINJEM were compared with the semi-quantitative and expert-based estimates generated from the data of a large case–control study on occupational cancer in Montreal, Canada (Lavoué *et al.*, 2012). Canadian data on exposure prevalences and levels were processed to allow valid comparisons with FINJEM estimates. The comparison of exposure prevalences could be made for 27 agents, covering the time period 1945–1995. The agent-specific prevalences were found to be consistently higher in the Montreal JEM, suggesting that it is more sensitive than FINJEM. The Montreal JEM records lower exposures than FINJEM, which is more specific by requiring a certain minimum level of exposure and by excluding all exposures whose prevalence in an occupation is <5%. The authors concluded that information concerning several agents (e.g. metals, welding fumes)

Table 1. Agents and time periods included in FINJEM, as of August 2013.

Agent or stress factor	Period covered[a]
Physical agents (*N* = 12)	
Noise (two indicators), noise impulses, hand vibration	1985–2000 (–2012)
Low-frequency ultrasound, high-frequency ultrasound	1985–1994
Cold	1945–2003 (–2012)
Heat, ultraviolet radiation	1985–2012
Radio frequency radiation, low-frequency magnetic fields	1985–2012
Ionizing radiation	1960–2003 (–2012)
Chemical agents (*N* = 48)	
Organic solvents	
Aliphatic/alicyclic hydrocarbon solvents, aromatic hydrocarbon solvents, benzene, toluene, chlorinated hydrocarbon solvents, methylene chloride, perchloroethylene, 1,1,1-trichloroethane, trichloroethylene	1945–2009 (–2012)
Other organic solvents	1945–1994
Organic dusts	
Animal dust, flour dust, leather dust, plant dust, pulp/paper dust, synthetic polymer dust, textile dust, wood dust, softwood dust, hardwood dust	1945–2009 (–2012)
Petroleum-based products	
Bitumen fumes, gasoline, oil mist	1945–2009 (–2012)
Inorganic mineral dusts	
Asbestos, man-made mineral fibers, quartz (silica) dust	1945–2009 (–2012)
Other mineral dusts	1945–1994
Metals	
Cadmium, chromium, iron, lead, nickel, welding fumes	1945–2009 (–2012)
Engine exhaust	
Diesel exhaust, gasoline engine exhaust	1945–2009 (–2012)
Pesticides	
Herbicides, insecticides	1960–2009 (–2012)
Fungicides	1945–2009 (–2012)
Formaldehyde, arsenic, carbon monoxide, PAHs, benzo(a)pyrene	1945–2009 (–2012)
Environmental tobacco smoke	1985–2009 (–2012)

Table 1. ***Continued***

Agent or stress factor	Period covered[a]
Volatile sulphur compounds, sulphur dioxide, detergents (dermal exposure)	1960–2009 (–2012)
Isocyanates	2001–2009 (–2012)
Microbiological agents ($N = 2$)	
Mold spores, gram-negative bacteria of non-human origin	1945–1994
Physiological and ergonomic factors ($N = 8$)	
Inconvenient and difficult work postures, manual handling of burdens, perceived physical workload, repetitive work movements, high accident risk	1945–1985, 1998–2003 (–2012)
Sedentary work, standing work	1945–1994
Work with video display units	1960–1985, 1998–2003 (–2012)
Psychosocial factors ($N = 9$)	
Challenge at work, social climate at work, control possibilities at work, perceived workload, perceived risks at work, social demands at work, supervisor support at work,	1985–1994
Working time arrangements (shift work), night work	1945–1994
Lifestyle factors ($N = 5$)	
Daily smoking, substantial alcohol use, poor diet, insufficient physical exercise, overweight	1995–2000 (–2012)

[a]Range of years for which exposure estimates exist, often as divided into shorter periods. The end year in brackets refers to unchecked estimates (i.e. estimates only copied from previous checked period).

can be transported from Finland to Canada and probably other countries. For other agents compared, there was significant disagreement and their transportability across countries as such cannot be assumed by default. The comparison was also methodologically difficult. The sources of disagreement between FINJEM and the Montreal data set included the actual exposure differences between Finland and the Montreal region, the conversion of occupational classifications, the different exposure metrics used, differences in the inclusion of low exposures (minimum criteria), and different ways of using available data.

The exposure estimates of FINJEM and two other JEMs (Dutch DOMJEM and Asbestos JEM) were compared through case-by-case expert assessment of a subcohort of 1630 men included in The Netherlands Cohort Study (NLCS) (Offermans *et al.*, 2012). DOMJEM has three exposure classes (no/low/high). Asbestos JEM has four semi-quantitative classes for the prevalence of exposure and seven for the level of exposure. The assessment concerned exposure to asbestos, polycyclic aromatic hydrocarbons (PAHs), and welding fumes. The expert assessment revealed the lowest prevalence of exposure for all three exposures. DOMJEM showed the highest level of agreement with the expert assessment for asbestos and PAHs, closely followed by FINJEM. For welding fumes, concordance between the expert assessment and FINJEM was high. Asbestos JEM showed poor agreement with the expert asbestos assessment. The authors concluded that DOMJEM and FINJEM proved to be rather similar in agreement compared with the expert assessment, while Asbestos JEM appeared to be less appropriate for use in the NLCS.

The agreement between the FINJEM estimates, self-reported exposures, and a panel of occupational hygienists was studied in a community-based case–control study in Australia (Benke *et al.*, 2001). The panel assessed exposure to chemicals for 5620 jobs. The agreement among the panel, FINJEM, and self-reported exposures was found to be only poor to fair. The use of FINJEM for some exposures, for example insecticides, was considered to provide good results at very low cost in future epidemiological studies but some results indicated that there may be significant differences between the exposure profiles of Finland and Australia.

FINJEM AS EXPOSURE ASSESSMENT TOOL IN OCCUPATIONAL EPIDEMIOLOGY

The epidemiological studies utilizing FINJEM as an exposure assessment tool are summarized in Table 2. The majority of studies are on cancer and based on the linkage of the Finnish 1970 Census cohort with the cancer incidence data of the Finnish Cancer Registry from 1971 onwards. The risk estimate most commonly calculated in these studies is the risk ratio (RR) in different classes of estimated cumulative exposure (CE), expressed in concentration–time units (e.g. in p.p.m.–years). The potentially confounding factors (occupational and non-occupational) are adjusted for by multivariate analysis.

The health outcomes studied in Finland include coronary heart diseases, metabolic syndrome, and musculoskeletal disorders. These studies have been based on cohorts, for example the participants of the Helsinki Heart Study. In addition to the peer-reviewed articles in Table 2, a large national study report on occupational mortality and work-disability displays risk estimates by major causes of death or disability and by many of the FINJEM exposures listed in Table 1 (Notkola and Pajunen, 1996).

FINJEM has been applied in epidemiological studies in Sweden, The Netherlands, Australia, Spain, and Germany. Most of these studies have been large case–control studies based on general populations, occupational histories of which cover the whole occupational spectrum, and a long time period. The health outcomes include various cancers, sleep apnea, and dementia. Different chemical agents have been frequently studied but only a few studies exist on physical, microbiological, physiological-ergonomic, and psychosocial factors (Table 2).

In a meta-analysis of pancreatic cancer, FINJEM was used to classify chemical exposures of epidemiological studies, followed by the calculation of meta-relative risks by simple random models (Ojajärvi *et al.*, 2000) and by hierarchical Bayesian models (Ojajärvi *et al.*, 2007). FINJEM was also used in the pooled analysis of 11 case–control studies on bladder cancer among men in Western Europe (Kogevinas *et al.*, 2003).

Table 2 suggests that FINJEM can be used in large epidemiological studies on occupational risks, particularly when other methods of exposure assessment are not feasible. Studies based on crude information on occupation in one or several national censuses are examples of these. Extensive population-based case–control studies covering a large amount of different occupations and a long observation period may also gain from using the JEM approach. Industry-based cohort studies and nested case–control studies usually allow more detailed data on exposure to be collected. They thus enable a more accurate exposure assessment for individuals or groups of workers. The use of generic JEMs, such as FINJEM, should be avoided when applying these study designs.

The performance of FINJEM has been comprehensively tested with Finnish data on exposure to crystalline silica and the risk of lung cancer (Pukkala *et al.*, 2005). Different metrics of exposure with and without allowance for a latency period, as well as with and without possibly confounding occupational and non-occupational factors were tested. The use of CE with a latency allowance and the inclusion of possibly confounding factors in statistical models were recommended for studies on chronic diseases. Cumulative exposure in this context is the sum over exposed years and occupations of the product of the prevalence (probability) of exposure and the level of exposure (e.g. in p.p.m.–years). The simplification of the exposure metric resulted usually in lower observed risk, particularly when the level of exposure was not included in the metric. Cumulative exposure is the most commonly used metric in studies presented in Table 2 but also some other metrics have been used, e.g. the prevalence of exposure after excluding occupations with low prevalences.

Generic JEMs have been criticized for misclassifying exposure at the level of individual subjects, as this

Table 2. FINJEM in peer-reviewed epidemiological studies on occupational risks.

Health outcome	Exposures	Study design	Country	Reference
Cancer by site				
Respiratory tract, lung	Silica	Census, cohort	Finland	Pukkala *et al.* (2005)
	Silica	Case–cohort	The Netherlands	Preller *et al.* (2010)
	Diesel and gasoline engine exhaust	Census, cohort	Finland	Guo *et al.* (2004a)
	Welding fumes, iron fumes	Census, cohort	Finland	Siew *et al.* (2008)
	Eight different organic dusts	Census, cohort	Finland	Laakkonen *et al.* (2006)
Nose, nasopharynx	Wood dust, formaldehyde	Census, cohort	Finland	Siew *et al.* (2012)
Mouth, pharynx	Various chemical agents	Census, cohort	Finland	Tarvainen *et al.* (2008)
Oesophagus	Various chemical agents	Case–control	Spain	Santibañez *et al.* (2008)
Pancreas	Various chemical, physical, and ergonomic factors	Case–control	Spain	Alguacil *et al.* (2000)
	Various chemical, physical, and ergonomic factors	Case–control	Spain	Santibañez *et al.* (2010)
	Various chemical agents	Meta-analysis	Finland	Ojajärvi *et al.* (2000, 2007)
Pancreas/K-ras activation	Organic solvents	Case–control	Spain	Alguacil *et al.* (2002)
	Various chemical, physical, and ergonomic factors	Case–control	Spain	Alguacil *et al.* (2003)
Liver	Various solvents, gasoline	Census, cohort	Finland	Lindbohm *et al.* (2009)
Bladder	PAHs	Pooled analysis	Six European countries	Kogevinas *et al.* (2003)
Bladder, urinary tract	Various solvents, gasoline	Census, cohort	Finland	Lohi *et al.* (2008)
Non-Hodgkin lymphoma	Various chemical and physical agents	Case–control	Sweden	Dryver *et al.* (2004)
	Night work	Census, cohort	Finland	Lahti *et al.* (2008)
	Ionizing and non-ionizing radiation	Case–control	Australia	Karipidis *et al.* (2007b)

Table 2. ***Continued***

Health outcome	Exposures	Study design	Country	Reference
Leukaemia	Various chemical agents, electromagnetic fields	Case–control	Sweden	Björk *et al.* (2001)
Breast	Various chemical, physical, and ergonomic factors	Census, cohort	Finland	Weiderpass *et al.* (1999)
Endometrium and cervix uteri	Various chemical, physical, and ergonomic factors	Census, cohort	Finland	Weiderpass *et al.* (2001)
Ovary	Various chemical, physical, and ergonomic factors	Census, cohort	Finland	Vasama-Neuvonen *et al.* (1999)
Brain, nervous system	Various chemical and physical agents	Census, cohort	Finland	Wesseling *et al.* (2002)
	Ionizing and non-ionizing radiation	Case–control	Australia	Karipidis *et al.* (2007a)
Gastrointestinal, stomach	Various chemical, physical, and ergonomic factors	Census, cohort	Finland	Weiderpass *et al.* (2003)
	Various chemical agents	Case–control	Spain	Santibañez *et al.* (2012)
Testicles	Various chemical agents	Census, cohort	Finland	Guo *et al.* (2005)
Multisite	Diesel and gasoline engine exhaust	Census, cohort	Finland	Guo *et al.* (2004b)
	Mold spores, bacteria	Census, cohort	Finland	Laakkonen *et al.* (2008)
Coronary heart diseases	Noise	Cohort	Finland	Virkkunen *et al.* (2005)
	Noise, shift work, physical workload	Cohort	Finland	Virkkunen *et al.* (2006, 2007)
Metabolic syndrome	Noise, physical workload	Cohort	Finland	Koskinen *et al.* (2011)
Sleep apnea	Various solvents	Case–control	Germany	Heiskel *et al.* (2002)
Dementia	Various psychosocial factors	Case–control	Germany	Seidler *et al.* (2004)
	Magnetic fields	Case–control	Germany	Seidler *et al.* (2007)
Lumbar disc disorders	Various physiological and psychosocial factors	Census, cohort	Finland	Leino-Arjas *et al.* (2004)

leads to the tendency to mask the actual risk, if there is one. The prevalence of exposure to most chemical agents in the employed population is low, <10%. The observed risk may be seriously underestimated if even a small proportion of subjects of a large unexposed population is misclassified as exposed, i.e. if the specificity of exposure assessment is decreased. The bias is much weaker if a part of the exposed subjects is missed, i.e. the sensitivity of exposure assessment is decreased (Flegal *et al.*, 1986). If all the subjects in an occupation are given the same estimate of exposure, as in the JEM approach, the situation is slightly different. Statistical simulation tests have indicated that with a reasonable assumption (log-normal distribution of exposure within the exposed in an occupation), the observed risk may in some cases be higher than the actual risk when CE is used as the metric of exposure. This bias, however, tends to be negligible when the prevalence of exposure in the studied population is either very low or very high (Burstyn *et al.*, 2013). The median prevalence of exposure to chemical agents in FINJEM is ranging from 0.4 to 1.9% among the Finnish employed population in 1950–2008 (Kauppinen *et al.*, 2013). In addition to possible bias, the random error may provide results that are either higher or lower than the actual risk (or the lack of risk).

Another factor to consider when using a generic JEM is the exposure contrast between the exposed and unexposed. If exposure is distributed between the exposed occupations in such a way that a group of highly exposed subjects can be distinguished, the possibilities to observe an actual risk are favourable. In the opposite case, in which the prevalence or the level of exposure, or both, are low in all exposed occupations, the chances of finding a true risk are poor. FINJEM provides quantitative estimates of average exposure among exposed subjects, which can be compared with OELs and background exposures to assess the exposure contrast. To avoid the 'dilution' of exposure and of possible risk, an exposure–response analysis is recommended to be included in studies utilizing FINJEM.

FINJEM AS A HAZARD SURVEILLANCE TOOL AND IN THE PREVENTION OF HAZARDS

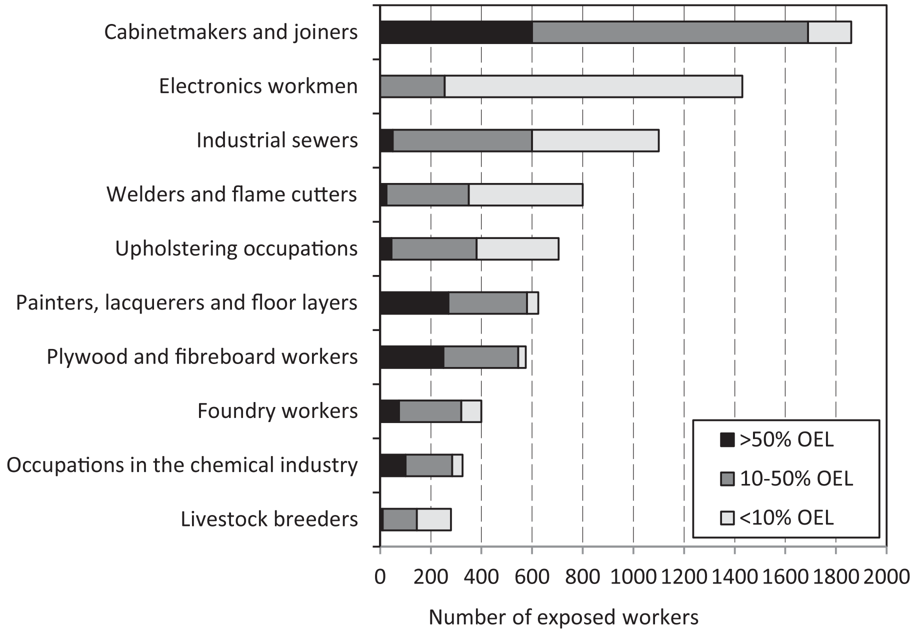
For surveillance purposes, FINJEM provides an overview of the extent and level of exposure to chemical and physical agents. FINJEM estimates are updated every 3 years for most of the chemical agents included (Table 1). The numbers of exposed workers and distributions of exposure levels by agent are regularly used in the national surveillance of chemical hazards in Finland. A large special report on occupational exposure to chemical agents was published in 2005 (Vainio *et al.*, 2005).

In addition to cross-sectional data, FINJEM provides data on exposure trends over time and exposure profiles by occupation and agent. Two examples of chemical exposure profiles are presented in Figs 2 and 3. The estimated levels of exposure are compared with the Finnish OEL, which enables the identification of possibly hazardous exposures by agent and occupation for preventive purposes.

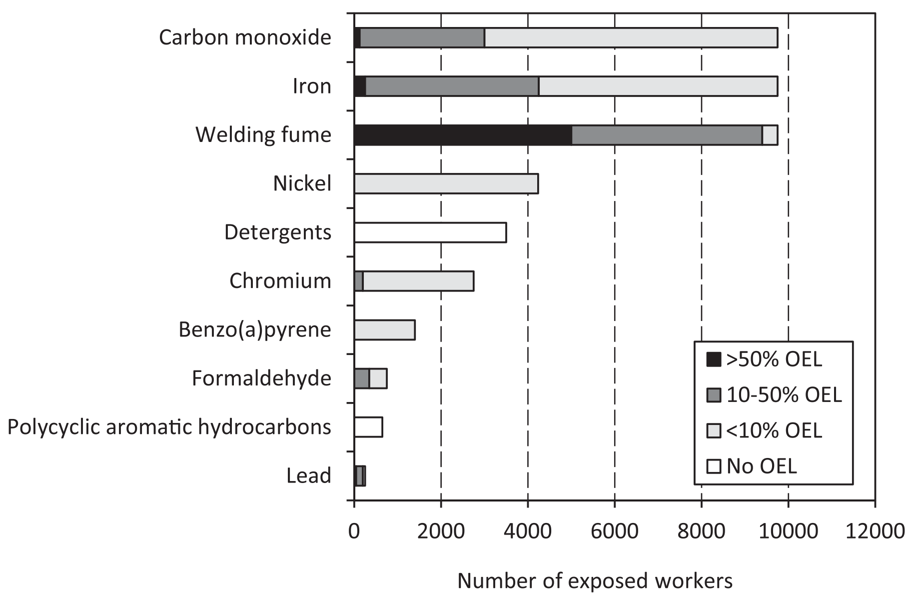
The benefit of using FINJEM at the workplace level for the prevention of chemical and physical hazards is limited. Exposures and health risks vary between workplaces, between workers performing different tasks, and even between workers performing similar tasks (Kromhout *et al.*, 1993). The reliable identification of workers or worker groups experiencing high exposure requires other methods, such as exposure measurements, or the use of exposure models based on the control banding concept. The FINJEM estimates for different occupations are long-term average figures, which are helpful mainly in the planning of national or regional preventive measures.

From the point of view of hazard surveillance, it is also worth noting that FINJEM covers only a limited set of agents. Most dermal exposures and many harmful inhalation exposures are not included. The minimum threshold of the prevalence of exposure (5% of the employed in an occupation) may also exclude a substantial amount of exposed workers, particularly if the occupation is common.

An industry-based exposure matrix is often a better alternative for an occupation-based matrix (such as FINJEM) in international surveillance projects. The reason for this is the better availability of comparable labor force data by industry than that by occupation. If the labor force in different countries is expressed uniformly, for example according to an international classification of the United Nations, the preliminary (default) estimates of the prevalence and level of exposure are transportable across countries without any complicated code conversions. These default estimates can then be refined by national experts to correspond



2 Occupational exposure profile for formaldehyde in Finland in 2007–2009. The numbers of workers exposed to formaldehyde by occupation and average level of exposure compared with Finnish OEL in 2009 (0.3 p.p.m.). Occupations with the 10 highest numbers of exposed workers are shown in the figure.



3 Occupational exposure profile for welders and flame cutters in Finland in 2007–2009. Numbers of workers exposed to chemical agent and average level of exposure compared with the Finnish OELs in 2009. Chemical agents with the 10 highest numbers of exposed workers are shown in the figure.

to national exposure circumstances. This procedure has been followed in the construction of international matrices on occupational exposure to carcinogens (CAREX) (Kauppinen *et al.*, 2000), carcinogens and pesticides (Central-American matrices) (see, e.g. Partanen *et al.*, 2003), and wood dust (WOODEX) (Kauppinen *et al.*, 2006). The newest of these matrices is CAREX Canada, which includes the regional dimension and also covers environmental exposures (see the CAREX Canada website). At least in principle, a global industry-based exposure matrix can be constructed to cover all countries and all important occupational exposures by applying industry-based approach, which is based on transportable preliminary (default) estimates and their refinement by an international community of occupational hygienists.

FINJEM IN THE ASSESSMENT OF HEALTH RISKS AND THE BURDEN OF DISEASES

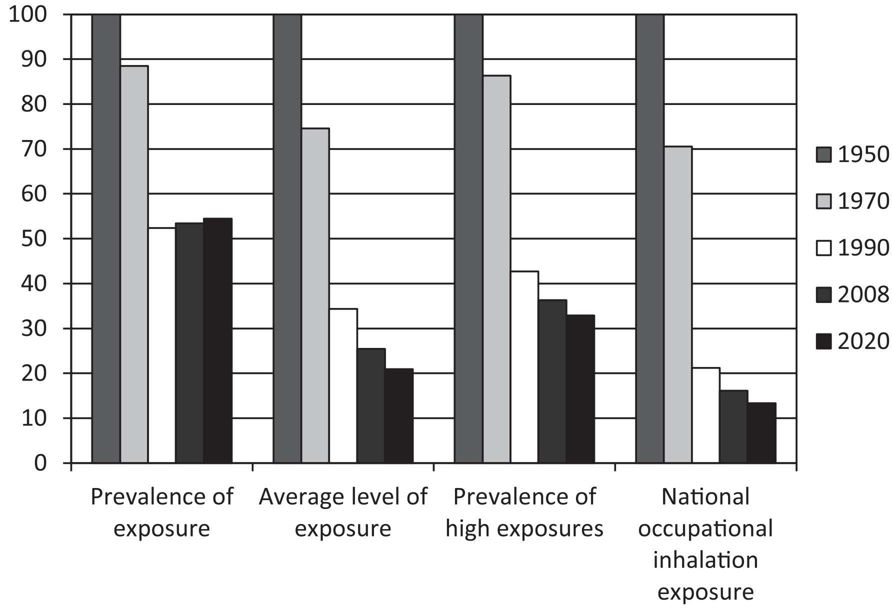
FINJEM has been used as the source of national estimates of exposure in quantitative risk assessment. The burden of occupational factors in mortality in Finland in 1996 due to past exposures was studied on the basis of epidemiological RRs and national exposure data (Nurminen and Karjalainen, 2001). The calculation of the numbers of cases attributable to exposure required figures of the size of the exposed population at risk, and in most cases, these were derived from FINJEM. This study provided only crude estimates of the burden. The uncertainty of the results in this study is mainly due to two factors. First, the relationships between fatal diseases and occupational exposures were assumed to be causative although the evidence on this was in some cases questionable. On the other hand, some actually causative relationships were definitely missing from the calculations. Second, the estimates of the numbers of workers exposed to a comparable dose of an agent as in the epidemiological study, whose RR was used in the calculation of attributable cases, were subjective judgments and thus uncertain. However, FINJEM was considered to be the most feasible source of national exposure data available for the burden assessment, and the procedure and estimates used were documented in a transparent way to enable re-evaluations, if more accurate data became available.

FINJEM estimates and trend data have also been used in the assessment of future numbers of attributable cases in Finland (Priha *et al.*, 2010) and in a European project aiming to assess the consequences of changing the OELs of some carcinogens. This European project mainly applied the assessment method developed in the UK and the industry-based CAREX approach (Rushton *et al.*, 2008). Because CAREX did not include temporal trend data on exposures, the predictions of the future burden gained from the trend data of FINJEM. If trend data are used as default for other countries, care must be taken to assess the similarity or dissimilarity of exposure circumstances between Finland and the country of application because the economic structure and the phase of technological development influence the prevalence and level of exposure.

FINJEM IN THE ASSESSMENT OF EXPOSURE TRENDS AND FUTURE EXPOSURES

The trends of occupational exposure to 41 chemical agents in Finland in 1950–2020 have been assessed on the basis of FINJEM data (Kauppinen *et al.*, 2013). Four different metrics of national exposure were calculated by agent: the prevalence of exposure, the prevalence of high exposure (at least 50% of the Finnish OEL), the average level of exposure among exposed workers, and the national occupational inhalation exposure (NOIE), which takes into account both the prevalence and level of exposure. Dermal exposure was estimated on the basis of statistics on occupational skin diseases. An example of trends for one agent is presented in Fig. 4. Although there was much variability by chemical agent, the general pattern was an increase of exposure (with the exception of high exposures) in 1950–1970, followed by a decrease in 1970–2008, which is expected to continue in 2008–2020. Diesel exhaust is an example of an agent whose exposure has not decreased along with the general trend.

This trend analysis of chemical exposures based on FINJEM proved a feasible project, which produced national estimates of exposure in terms of the prevalence of exposure, the prevalence of high exposure, the average level of exposure, and NOIE. Trend data have previously mainly been reported as the level of exposure based on exposure measurements. A large review of the trends of exposure measurements (Creely *et al.*, 2007) reported a median annual decrease of exposure of 8%, which is higher than the 1% reported by the FINJEM trend analysis. The reason for this difference



4 Occupational inhalation exposure to crystalline silica (quartz dust) in Finland in 1950, 1970, 1990, 2008, and 2020, as measured by four different metrics of exposure. Proportional values compared with 1950 (=100).

may be that the measurements are often directed to workers whose exposure is expected to be higher than the average exposure of all exposed workers. Measurements also tend to be carried out more frequently in medium-size and large companies, which have enough resources and the knowledge to prevent high exposures than in small companies whose resources are more limited. The FINJEM analysis also provided higher figures of annual decrease (e.g. median 7% in 1990–2008) for the subgroup of workers at 'high' exposure. However, there is much agent-specific variability in trends and some exposures do not follow the general pattern. On the other hand, small decreases of exposures among workers whose exposure is low are easily missed in judgment-based approaches. It is worth noting also that different exposure metrics show different temporal patterns and that they have different fields of use: NOIE is useful in the burden assessment, the prevalence of high exposures in the priority setting of prevention, and the prevalence and level of exposure in various occupations mainly in occupational epidemiology.

The same FINJEM-based trend analysis also included the prediction of exposures in 2020 by using the same metrics of exposure as in 1950–2008. This was a challenging task. The changes in the economic structure and distribution of occupations could be taken into account, but no reliable models were available to estimate agent-specific changes within occupations. The trend analysis of past exposures indicates that regulations, technology, and labor safety measures may strongly influence both the prevalence and the level of exposure, and that the influence is agent specific. The prediction for the year 2020 was therefore based on the extrapolation of the trends of exposure observed for the previous period of 1990–2008, which experts assessed agent by agent and occupation by occupation. The resulting estimates for 2020 should be considered crude figures, the reliability of which is not very high.

FINJEM AS A SOURCE OF INFORMATION FOR OTHER JEMS

FINJEM was the base for constructing JEMs for the NOCCA study (Kauppinen *et al.*, 2009). The Nordic JEMs include estimates of the prevalence and level of exposure to 28 agents (mainly chemical agents) in >300 occupations per country (from the national classifications of occupations) during four time periods covering 1945–1994. A team of Nordic occupational hygienists modified the FINJEM estimates to take into account the major differences of occupational exposure between the Nordic countries.

The process to modify FINJEM for other Nordic countries was more laborious than its direct use but provided more credible estimates. It is therefore recommended instead of the direct use or the construction of a completely new JEM, which is the most time-consuming alternative. The selection of priority agent–occupation combinations and the adoption of general principles at the beginning of the work were necessary because of the high number of estimates to be evaluated (>50 000 per country). Priority was given to large occupations and high exposures, which contribute significantly to the results of epidemiological studies. Additional exposure measurement data (reported to be 'thousands' of measurements) from Norway and Sweden were used but proved to be scanty at the level of occupations, difficult to interpret, and time consuming to work with. In the NOCCA project, changes were made to the estimates of 140 of the 6220 agent–occupation combinations of the original FINJEM. The driver for many of these changes was industrial hygiene measurement data available from Sweden and Norway. The modifications concerned levels of exposure to silica and diesel exhaust in particular. However, most of the original estimates (97%) in FINJEM were considered accurate enough to be used as the basis to modify estimates for the JEMs of other Nordic countries.

The risk estimates of 49 different cancers by 53 occupational categories in five countries have been published (Pukkala *et al.*, 2009) but the JEMs of Nordic countries enable now the comprehensive cancer incidence data of NOCCA to be analyzed also by exposure (see, e.g. Vlaanderen *et al.*, 2013). The NOCCA project has a website, and collaborative studies on occupational cancer by using NOCCA data and JEMs are encouraged.

Another large cancer study that has used FINJEM as the base for constructing a JEM is INTEROCC (van Tongeren *et al.*, 2013). The INTEROCC project is a multi-center case–control study on brain cancer and occupational exposure to chemical agents and electromagnetic fields. The exposure estimates of 29 FINJEM agents (mainly solvents and metal fumes) were modified by an international team of experts. A crosswalk was developed between the Finnish occupational codes used in FINJEM and the 1968 International Standard Classification of Occupations (ISCO68). Whenever necessary, the exposure estimates of FINJEM were modified to fit the ISCO occupations either by mathematically combining estimates of several FINJEM occupations or by splitting the estimates of one FINJEM occupation into multiple ISCO occupations. As in the NOCCA study, one long period in FINJEM (1960–1984) was split into two periods (1960–1974 and 1975–1984). In addition, the estimates of benzene, hydrocarbon solvents, engine exhausts, PAHs, and benzo(a)pyrene were modified to achieve consistency between the definitions of agents and their minimum exposures in FINJEM and INTEROCC-JEM. The modifications generally increased the prevalence of exposure in the lowest categories of CE, but in some cases, this was also seen in other levels of exposure. The INTEROCC-JEM has been used to study the risk of different types of brain cancer by exposure (Lacourt *et al.*, 2013).

The modification process of FINJEM in the INTEROCC project differed from that of NOCCA. The emphasis was on the internal consistency of the estimates. For example, exposure to PAHs from environmental tobacco smoke was added because it was not included by definition in the PAH estimates in FINJEM. The use of different occupational classification, as in FINJEM, also required splitting FINJEM estimates into several occupations of the ISCO classification used in the INTEROCC study. The conversions between occupational classifications are a potential source of bias ranging from negligible to significant. Care should be taken particularly with conversions of high exposures in large occupations. Although occupational coding systems often differ substantially ('t Mannetje and Kromhout, 2003), crosswalks can be established and they seem to be as efficient as manual recoding (Koeman *et al.*, 2013).

A Spanish JEM (MatEmESp) has been constructed for national surveillance and prevention purposes partially based on FINJEM data. The FINJEM estimates of prevalence and the level of exposure to physical, chemical, and microbiological agents were adapted to the Spanish classification of occupations. These preliminary estimates were then improved by a team of Spanish hygienists on the basis of available Spanish data. The assessment of safety risks (not included in FINJEM), ergonomic factors, and psychosocial factors was based on Spanish surveys and other national sources. For some factors, the estimates were also provided for men and women separately and for three age categories (Garcia *et al.*, 2013).

JEMs that are based on other JEMs tend to resemble their 'parent' JEMs. The changing of estimates of the 'parent' JEM requires good knowledge on exposure circumstances in two countries or populations, which is often missing. Even if data were available, it is difficult to conclude, for example that the level of exposure in two countries actually differs significantly, and that the observed difference in the measurement data is not due to methodological factors. However, large qualitative differences should be identified and taken into account. For example, if a part of miners are exposed to asbestos in one country and there is no asbestos mining in another country, the exposure estimates of asbestos need to be corrected to be in accordance with this fact.

Examples of the use of FINJEM estimates or data as one source of information among others in the construction of other JEMs are the French MATGENE matrix (Fevotte *et al.*, 2011), the New Zealand JEM ('t Mannetje *et al.*, 2011), and the Swedish particle matrix PARCC-JEM (Wiebert *et al.*, 2012).

OTHER USES OF FINJEM

FINJEM has been used for miscellaneous other purposes. It is a general databank, which is able to provide data on the numbers of exposed workers and their exposure levels to various agents, for the planning of studies and training, for example. It may be useful in the evaluation of the impact and cost of changing OELs, and it has also been considered as a source of information for the assessment of exposures of people suspected of having an occupational disease. For example, chemical exposures of patients with chronic solvent encephalopathy have been surveyed with FINJEM (Keski-Säntti *et al.*, 2010).

VALIDITY OF FINJEM AND RECOMMENDATIONS

The overall validity of FINJEM remains unknown, although there is evidence that FINJEM is able to replicate the results of some known risk factors (see, e.g. Pukkala *et al.*, 2005). No alternative data of good quality are available in Finland to directly test the validity of FINJEM. A practical complication is that FINJEM covers almost 50 chemical exposures, >300 occupations, and a long period of time (1945–2012). Although FINJEM's actual validity is unknown, efforts have been taken during its history to improve it. Knowledge of experts, comprehensive Finnish measurement data, accurate definitions of exposure, and systematic assessment methods were applied in the construction of the original FINJEM. The documentation of the FINJEM database has also enabled re-evaluations that have resulted in improvements to FINJEM in the NOCCA (Kauppinen *et al.*, 2009) and INTEROCC projects (Lavoué *et al.*, 2012; van Tongeren *et al.*, 2013). Further improvements are possible when new exposure measurement data become available, and when the Bayesian methods of integrating data and prior views of the assessors will be more widely applied in the future. It is also worth noting that the validity of any JEM depends on its context of application. A JEM that sensitively assigns exposure to occupations with a low level of exposure is likely to be more useful for assessing the burden of diseases, but a specific JEM tends to be more useful in occupational epidemiology aimed at the identification or quantification of risks.

When FINJEM is applied outside Finland or used as the basis to construct a JEM for another country, we recommend checking and modifying the estimates of at least large occupations with potentially heavy exposure to correspond to national exposure circumstances. In epidemiological studies of chronic diseases, we recommend analyzing risks quantitatively (exposure–response analysis) because the misclassification of exposure particularly in low exposure classes may mask the risk in the qualitative (exposed versus unexposed) analysis. Cumulative exposure with the allowance for a latency period is often the preferable metric of exposure in studies of chronic diseases but the use of several alternative exposure metrics may be still better because the validity of the metric may depend on the outcome and on the distribution of exposure in the population under study. A good practice is also to check the exposure contrast, i.e. to assess if the number of substantially exposed workers is sufficient for the detection of the risk under study. The use of available measurement data is recommended but the representativeness of data needs to be judged before use. Bayesian approaches that combine exposure data and subjective judgments are a promising new way to improve the validity of JEMs. In hazard surveillance, industry-based approaches should be considered as alternatives to occupation-based JEMs. A good documentation of exposure estimates is recommended when constructing new JEMs. JEMs should also be used more than in the past for the assessment of risks, burdens of disease, exposure trends, and future exposures.

FUNDING

Finnish Institute of Occupational Health; Finnish Cancer Register; Finnish work Environment fund.

ACKNOWLEDGEMENTS

We gratefully acknowledge the valuable contribution of Dr Pirjo Heikkilä (retired, main assessor of exposures), Mr Jouni Toikkanen (planning and construction of the FINJEM database), and all assessors and users of FINJEM in Finland and abroad, who are too many to be listed here (see the list of references). The authors do not have any conflicts of interests.

REFERENCES

Alguacil J, Kauppinen T, Porta M *et al.* (2000) Risk of pancreatic cancer and occupational exposures in Spain. PANKRAS II Study Group. *Ann Occup Hyg*; **44**: 391–403.

Alguacil J, Porta M, Kauppinen T *et al.*; PANKRAS II Study Group. (2003) Occupational exposure to dyes, metals, polycyclic aromatic hydrocarbons and other agents and K-ras activation in human exocrine pancreatic cancer. *Int J Cancer*; **107**: 635–41.

Alguacil J, Porta M, Malats N *et al.* (2002) Occupational exposure to organic solvents and K-ras mutations in exocrine pancreatic cancer. *Carcinogenesis*; **23**: 101–6.

Benke G, Sim M, Fritschi L *et al.* (2001) Comparison of occupational exposure using three different methods: hygiene panel, job exposure matrix (JEM), and self reports. *Appl Occup Environ Hyg*; **16**: 84–91.

Björk J, Albin M, Welinder H *et al.* (2001) Are occupational, hobby, or lifestyle exposures associated with Philadelphia chromosome positive chronic myeloid leukaemia? *Occup Environ Med*; **58**: 722–7.

Burstyn I, Lavoué J, Van Tongeren M. (2012) Aggregation of exposure level and probability into a single metric in job-exposure matrices creates bias. *Ann Occup Hyg*; **56**: 1038–50.

Creely KS, Cowie H, Van Tongeren M *et al.* (2007) Trends in inhalation exposure–a review of the data in the published scientific literature. *Ann Occup Hyg*; **51**: 665–78.

Dryver E, Brandt L, Kauppinen T *et al.* (2004) Occupational exposures and non-Hodgkin's lymphoma in Southern Sweden. *Int J Occup Environ Health*; **10**: 13–21.

Fevotte J, Dananché B, Delabre L *et al.* (2011) Matgéné: a program to develop job-exposure matrices in the general population in France. *Ann Occup Hyg*; **55**: 865–78.

Flegal KM, Brownie C, Haas JD. (1986) The effects of exposure misclassification on estimates of relative risk. *Am J Epidemiol*; **123**: 736–51.

Garcia AM, González-Galarzo MC, Kauppinen T *et al.* (2013) A job-exposure matrix for research and surveillance of occupational health and safety in Spanish workers: MatEmESp. *Am J Ind Med*; **56**: 1226–38.

Guo J, Kauppinen T, Kyyrönen P *et al.* (2004a) Occupational exposure to diesel and gasoline engine exhausts and risk of lung cancer among Finnish workers. *Am J Ind Med*; **45**: 483–90.

Guo J, Kauppinen T, Kyyrönen P *et al.* (2004b) Risk of esophageal, ovarian, testicular, kidney and bladder cancers and leukemia among finnish workers exposed to diesel or gasoline engine exhaust. *Int J Cancer*; **111**: 286–92.

Guo J, Pukkala E, Kyyrönen P *et al.* (2005) Testicular cancer, occupation and exposure to chemical agents among Finnish men in 1971-1995. *Cancer Causes Control*; **16**: 97–103.

Heikkilä P, Saalo A, Kauppinen T. (2005) Finnish database of occupational exposure measurements (FDOEM). In IOHA 6th International Scientific Conference, Proceedings, Paper R3-1, 19–23 September 2005, Pilanesberg, South Africa.

Heiskel H, Gunzenhäuser D, Seidler A *et al.* (2002) Sleep apnea and occupational exposure to solvents. *Scand J Work Environ Health*; **28**: 249–55.

HTP-arvot. (2009) *Haitalliseksi tunnetut pitoisuudet: julkaisuja 11/2009 (Occupational exposure limits: publication 11/2009)*. Helsinki: Ministry of Social Affairs and Health.

Karipidis KK, Benke G, Sim MR *et al.* (2007a) Occupational exposure to ionizing and non-ionizing radiation and risk of glioma. *Occup Med (Lond)*; **57**: 518–24.

Karipidis KK, Benke G, Sim MR *et al.* (2007b) Occupational exposure to ionizing and non-ionizing radiation and risk of non-Hodgkin lymphoma. *Int Arch Occup Environ Health*; **80**: 663–70.

Kauppinen T, Heikkilä P, Plato N *et al.* (2009) Construction of job-exposure matrices for the Nordic Occupational Cancer Study (NOCCA). *Acta Oncol*; **48**: 791–800.

Kauppinen T, Saalo A, Pukkala E *et al.* (2007) Evaluation of a national register on occupational exposure to carcinogens: effectiveness in the prevention of occupational cancer, and cancer risks among the exposed workers. *Ann Occup Hyg*; **51**: 463–70.

Kauppinen T, Toikkanen J, Pedersen D *et al.* (2000) Occupational exposure to carcinogens in the European Union. *Occup Environ Med*; **57**: 10–8.

Kauppinen T, Toikkanen J, Pukkala E. (1998) From cross-tabulations to multipurpose exposure information systems: a new job-exposure matrix. *Am J Ind Med*; **33**: 409–17.

Kauppinen T, Uuksulainen S, Saalo A *et al.* (2013) Trends of occupational exposure to chemical agents in Finland in 1950-2020. *Ann Occup Hyg*; **57**: 593–609.

Kauppinen T, Vincent R, Liukkonen T *et al.* (2006) Occupational exposure to inhalable wood dust in the member states of the European Union. *Ann Occup Hyg*; **50**: 549–61.

Keski-Säntti P, Kaukiainen A, Hyvärinen HK *et al.* (2010) Occupational chronic solvent encephalopathy in Finland 1995-2007: incidence and exposure. *Int Arch Occup Environ Health*; **83**: 703–12.

Koeman T, Offermans NS, Christopher-de Vries Y *et al.* (2013) JEMs and incompatible occupational coding systems: effect of manual and automatic recoding of job codes on exposure assignment. *Ann Occup Hyg*; **57**: 107–14.

Kogevinas M, 't Mannetje A, Cordier S *et al.* (2003) Occupation and bladder cancer among men in Western Europe. *Cancer Causes Control*; **14**: 907–14.

Koskinen HL, Kauppinen T, Tenkanen L. (2011) Dual role of physical workload and occupational noise in the association of the metabolic syndrome with risk of coronary heart disease: findings from the Helsinki Heart Study. *Occup Environ Med*; **68**: 666–73.

Kromhout H, Symanski E, Rappaport SM. (1993) A comprehensive evaluation of within- and between-worker components of occupational exposure to chemical agents. *Ann Occup Hyg*; **37**: 253–70.

Laakkonen A, Kyyrönen P, Kauppinen T *et al.* (2006) Occupational exposure to eight organic dusts and respiratory cancer among Finns. *Occup Environ Med*; **63**: 726–33.

Laakkonen A, Verkasalo PK, Nevalainen A *et al.* (2008) Moulds, bacteria and cancer among Finns: an occupational cohort study. *Occup Environ Med*; **65**: 489–93.

Lacourt A, Cardis E, Pintos J *et al.* (2013) INTEROCC case-control study: lack of association between glioma tumors and occupational exposure to selected combustion products, dusts and other chemical agents. *BMC Public Health*; **13**: 340.

Lahti TA, Partonen T, Kyyrönen P *et al.* (2008) Night-time work predisposes to non-Hodgkin lymphoma. *Int J Cancer*; **123**: 2148–51.

Lavoué J, Pintos J, Van Tongeren M *et al.* (2012) Comparison of exposure estimates in the Finnish job-exposure matrix FINJEM with a JEM derived from expert assessments performed in Montreal. *Occup Environ Med*; **69**: 465–71.

Leino-Arjas P, Kaila-Kangas L, Kauppinen T *et al.* (2004) Occupational exposures and inpatient hospital care for lumbar intervertebral disc disorders among Finns. *Am J Ind Med*; **46**: 513–20.

Lindbohm ML, Sallmén M, Kyyrönen P *et al.* (2009) Risk of liver cancer and exposure to organic solvents and gasoline vapors among Finnish workers. *Int J Cancer*; **124**: 2954–9.

Lohi J, Kyyrönen P, Kauppinen T *et al.* (2008) Occupational exposure to solvents and gasoline and risk of cancers in the urinary tract among Finnish workers. *Am J Ind Med*; **51**: 668–72.

Notkola V, Pajunen A. (1996) *Socio-demographic factors, working conditions and inter-occupational differences in mortality and work disability in Finland in 1981–1994 (in Finnish). Final report*. Helsinki: Helsinki University and Finnish Institute of Occupational Health.

Nurminen M, Karjalainen A. (2001) Epidemiologic estimate of the proportion of fatalities related to occupational factors in Finland. *Scand J Work Environ Health*; **27**: 161–213.

Offermans NS, Vermeulen R, Burdorf A *et al.* (2012) Comparison of expert and job-exposure matrix-based retrospective exposure assessment of occupational carcinogens in The Netherlands Cohort Study. *Occup Environ Med*; **69**: 745–51.

Ojajärvi IA, Partanen TJ, Ahlbom A *et al.* (2000) Occupational exposures and pancreatic cancer: a meta-analysis. *Occup Environ Med*; **57**: 316–24.

Ojajärvi A, Partanen T, Ahlbom A *et al.* (2007) Estimating the relative risk of pancreatic cancer associated with exposure agents in job title data in a hierarchical Bayesian meta-analysis. *Scand J Work Environ Health*; **33**: 325–35.

Partanen T, Chaves J, Wesseling C *et al.* (2003) Workplace carcinogen and pesticide exposures in Costa Rica. *Int J Occup Environ Health*; **9**: 104–11.

Perkiö-Mäkelä M, Hirvonen M, Elo A *et al.* (2010) *Work and health interview survey 2009 (in Finnish)*. Helsinki: Finnish Institute of Occupational Health. Available at http://www.ttl.fi/fi/verkkokirjat/tyo_ja_terveys_suomessa/Documents/tyo_ja_terveys_haastattelututkimus_2009.pdf (Accessed 5 August 2013).

Preller L, van den Bosch LM, van den Brandt PA *et al.* (2010) Occupational exposure to silica and lung cancer risk in the Netherlands. *Occup Environ Med*; **67**: 657–63.

Priha E, Karjalainen A, Kauppinen T. (2010) The health effects of occupational exposures (in Finnish). *Ympäristö ja Terveys*; **41**: 36–41.

Pukkala E. (1995) *Cancer risk by social class and occupation. A survey of 109,000 cancer cases among Finns of working age*. Heidelberg: Karger.

Pukkala E, Guo J, Kyyrönen P *et al.* (2005) National job-exposure matrix in analyses of census-based estimates of occupational cancer risk. *Scand J Work Environ Health*; **31**: 97–107.

Pukkala E, Martinsen JI, Lynge E *et al.* (2009) Occupation and cancer - follow-up of 15 million people in five Nordic countries. *Acta Oncol*; **48**: 646–790.

Rushton L, Hutchings S, Brown T. (2008) The burden of cancer at work: estimation as the first step to prevention. *Occup Environ Med*; **65**: 789–800.

Santibañez M, Alguacil J, de la Hera MG *et al.* (2012) Occupational exposures and risk of stomach cancer by histological type. *Occup Environ Med*; **69**: 268–75.

Santibañez M, Vioque J, Alguacil J *et al.* (2010) Occupational exposures and risk of pancreatic cancer. *Eur J Epidemiol*; **25**: 721–30.

Santibañez M, Vioque J, Alguacil J *et al.*; PANESOES Study Group. (2008) Occupational exposures and risk of oesophageal cancer by histological type: a case-control study in eastern Spain. *Occup Environ Med*; **65**: 774–81.

Seidler A, Geller P, Nienhaus A *et al.* (2007) Occupational exposure to low frequency magnetic fields and dementia: a case-control study. *Occup Environ Med*; **64**: 108–14.

Seidler A, Nienhaus A, Bernhardt T *et al.* (2004) Psychosocial work factors and dementia. *Occup Environ Med*; **61**: 962–71.

Siew SS, Kauppinen T, Kyyrönen P *et al.* (2008) Exposure to iron and welding fumes and the risk of lung cancer. *Scand J Work Environ Health*; **34**: 444–50.

Siew SS, Kauppinen T, Kyyrönen P *et al.* (2012) Occupational exposure to wood dust and formaldehyde and risk of nasal, nasopharyngeal, and lung cancer among Finnish men. *Cancer Manag Res*; **4**: 223–32.

Statistics Finland. (1993) *Toimialaluokitus 1995. Käsikirjoja 4*. Helsinki: Tilastokeskus.

Tarvainen L, Kyyrönen P, Kauppinen T *et al.* (2008) Cancer of the mouth and pharynx, occupation and exposure to chemical agents in Finland [in 1971-95]. *Int J Cancer*; **123**: 653–9.

‘t Mannetje A, Kromhout H. (2003) The use of occupation and industry classifications in general population studies. *Int J Epidemiol*; **32**: 419–28.

‘t Mannetje AM, McLean DJ, Eng AJ *et al.* (2011) Developing a general population job-exposure matrix in the absence of sufficient exposure monitoring data. *Ann Occup Hyg*; **55**: 879–85.

Vainio H, Liesivuori J, Lehtola M *et al.* (2005) *Chemical agents and work (in Finnish)*. Helsinki: Finnish Institute of Occupational Health.

Vasama-Neuvonen K, Pukkala E, Paakkulainen H *et al.* (1999) Ovarian cancer and occupational exposures in Finland. *Am J Ind Med*; **36**: 83–9.

van Tongeren M, Kincl L, Richardson L *et al.* (2013) Assessing occupational exposure to chemicals in an international epidemiological study of brain tumours. *Ann Occup Hyg*; **57**: 610–26.

Virkkunen H, Härmä M, Kauppinen T *et al.* (2006) The triad of shift work, occupational noise, and physical workload and risk of coronary heart disease. *Occup Environ Med*; **63**: 378–86.

Virkkunen H, Härmä M, Kauppinen T *et al.* (2007) Shift work, occupational noise and physical workload with ensuing development of blood pressure and their joint effect on the risk of coronary heart disease. *Scand J Work Environ Health*; **33**: 425–34.

Virkkunen H, Kauppinen T, Tenkanen L. (2005) Long-term effect of occupational noise on the risk of coronary heart disease. *Scand J Work Environ Health*; **31**: 291–9.

Vlaanderen J, Straif K, Martinsen JI *et al.* (2013) Cholangiocarcinoma among workers in the printing industry: using the NOCCA database to elucidate the generalisability of a cluster report from Japan. *Occup Environ Med*; **70**: 828–30.

Weiderpass E, Pukkala E, Kauppinen T *et al.* (1999) Breast cancer and occupational exposures in women in Finland. *Am J Ind Med*; **36**: 48–53.

Weiderpass E, Pukkala E, Vasama-Neuvonen K *et al.* (2001) Occupational exposures and cancers of the endometrium and cervix uteri in Finland. *Am J Ind Med*; **39**: 572–80.

Weiderpass E, Vainio H, Kauppinen T *et al.* (2003) Occupational exposures and gastrointestinal cancers among Finnish women. *J Occup Environ Med*; **45**: 305–15.

Wesseling C, Pukkala E, Neuvonen K *et al.* (2002) Cancer of the brain and nervous system and occupational exposures in Finnish women. *J Occup Environ Med*; **44**: 663–8.

Wiebert P, Lönn M, Fremling K *et al.* (2012) Occupational exposure to particles and incidence of acute myocardial infarction and other ischaemic heart disease. *Occup Environ Med*; **69**: 651–7.