Short Communication

Occupational Exposure Assessment Tools in Europe: A Comprehensive Inventory Overview

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Abstract

Objectives: The Network on the Coordination and Harmonisation of European Occupational Cohorts (OMEGA-NET) was set up to enable optimization of the use of industrial and general population cohorts across Europe to advance aetiological research. High-quality harmonized exposure assessment is crucial to derive comparable results and to enable pooled analyses. To facilitate a harmonized research strategy, a concerted effort is needed to catalogue available occupational exposure information. We here aim to provide a first comprehensive overview of exposure assessment tools that could be used for occupational epidemiological studies.

Methods: An online inventory was set up to collect meta-data on exposure assessment tools. Occupational health researchers were invited via newsletters, editorials, and individual e-mails to provide details of job-exposure matrices (JEMs), exposure databases, and occupational coding systems and their associated crosswalks to translate codes between different systems, with a focus on Europe.

Results: Meta-data on 36 general population JEMs, 11 exposure databases, and 29 occupational coding systems from more than 10 countries have been collected up to August 2021. A wide variety of exposures were covered in the JEMs on which data were entered, with dusts and fibres (in 14 JEMs) being the most common types. Fewer JEMs covered organization of work (5) and biological factors (4). Dusts and fibres were also the most common exposures included in the databases (7 out of 11), followed by solvents and pesticides (both in 6 databases).
Conclusions: This inventory forms the basis for a searchable web-based database of meta-data on existing occupational exposure information, to support researchers in finding the available tools for assessing occupational exposures in their cohorts. This inventory remains open for further additions, to enlarge its coverage and include newly developed tools.

Keywords: epidemiology; exposure assessment; exposure databases; harmonization; job-exposure matrix

Introduction

Prospective cohort studies are considered the strongest design in occupational epidemiology, as it often allows for obtaining information directly from individuals and updating information over time (Blair et al., 2015). Although many large cohorts with occupational information exist in Europe (Kogevinas et al., 2020), these are not yet used to their full potential in the study of occupational risks. Pooling these data would increase statistical power, offering opportunities such as looking at rare outcomes and interactions between risk factors, as well as enabling the exploration of between-countries differences (Turner and Mehlum, 2018). A major limiting factor is the lack of large-scale systematic and harmonized exposure assessment that is required for coordinated occupational health research (Peters et al., 2020). Good quality exposure assessment is essential to detect and characterize relevant exposure–disease associations.

The first step in the exposure assessment process often involves translating narrative descriptions of occupational histories into occupational codes, either manually or by using (semi-)automated systems to code such free text. These codes then offer the opportunity to link a study to a job-exposure matrix (JEM), i.e. a cross-tabulation between occupational title and workplace hazards.

JEMs are an important tool in large-scale and systematic exposure assessment (Kromhout and Vermeulen, 2001; Peters, 2020). JEMs are often based on expert judgement, but exposure (measurement) data can also be used to develop a JEM (Ge et al., 2018). Numerous JEMs have been developed and described over the years, all with their own coding systems and definitions of exposure. However, many different coding systems exist, and vary between countries and over time. Due to these differences in coding systems, a preliminary step using crosswalks that represent correspondence between systems may be required to link a study to a specific JEM (‘t Mannetje and Kromhout, 2003).

Occupational exposure measurements of a wide range of occupations have been collected in several national exposure databases during recent decades (Peters et al., 2012). Based on these data, exposure levels for all types of jobs and time periods could potentially be estimated by statistical modelling. Although several large occupational exposure databases exist, their use in population-based research has been limited due to a lack of FAIR (findable, accessible, interoperable, and re-useable) principles.

Although comparisons between individual JEMs have been published (e.g. Offermans et al., 2012), JEMs have not been systematically compiled and compared. Additionally, a clear overview of all available JEMs, exposure databases, job coding systems, and crosswalks has been lacking, and knowledge about these tools is not easily available. More accessible information on job coding systems and crosswalks between different systems will also support harmonization of exposure data and tools across countries.

Our aim was to collate regional (i.e. continental) and country-specific exposure assessment tools, with an initial focus on Europe, that can be applied to large general population cohorts to allow for risk analyses and to facilitate health impact analyses.

Methods

OMEGA-NET (the Network on the Coordination and Harmonisation of European Occupational Cohorts, http://omeganetcohorts.eu/) is an EU COST Action that started in 2017 and will continue into 2022 (Turner and Mehlum, 2018). OMEGA-NET includes members from
over 40 countries, including European and neighbouring countries (Belarus, Morocco, Palestinian Authority, Russian Federation) as well as international partner countries Australia, the United States, and the United Arab Emirates. The project was set up to enable optimization of the use of industrial and general population cohorts across Europe to advance aetiological research (Turner and Mehlm, 2018).

Within the scope of OMEGA-NET, an online inventory was created to collect meta-data on various exposure assessment tools (https://occupationalexposuretools.net). Occupational health researchers were invited to provide details on JEMs, exposure databases, occupational coding systems, and the associated crosswalks, with a focus on Europe. The inventory was promoted, and contributions were sought, by mailings within consortia with a focus on occupational health research [OMEGA-NET, and the EU-H2020 ExpoSeme Project for Health and Occupational Research (EPHOR) (Pronk et al., unpublished data) including representatives from 12 European countries], the newsletter of the International Commission on Occupational Health, an editorial in this journal (Peters et al., 2020), conference presentations, and by directly approaching individual researchers that were identified via searches in PubMed and Google.

Combining all meta-data, an open resource for occupational exposure assessment tools has been built. Data entries were checked for inconsistencies and clarifications were sought where necessary. Here, we describe the characteristics of the meta-data available as of August 2021. As we focus on tools that can be used in general population cohorts, we have excluded data that were provided on industry-specific JEMs \((n = 3)\) for current descriptive analysis.

Results

Meta-data on 36 general population JEMs, 11 exposure databases, and 29 occupational coding systems have been collected from individual researchers up to August 2021.

A wide variety of exposures were covered, with dusts and fibres (in 14 JEMs) being the most common types (Table 1). Among dusts and fibres, asbestos was the most assessed exposure, with presence in 10 JEMs, followed by quartz and wood dust (both in 7 JEMs). Fewer JEMs covered organization of work including working time (5) or biological factors (4). Other exposures that were relatively often covered included benzene, chromium, nickel, and physical workload (each in seven JEMs). Many JEMs were originally developed for the Nordic countries, with FINJEM being the earliest JEM in our inventory (Kauppinen et al., 1998). There was also overlap in development of JEMs: FINJEM formed the basis for three later JEMs (i.e. NOCCA, INTEROCC, and MatEmEsp), whereas SYN-JEM used DOM-JEM as input. Furthermore, 27 JEMs were based on expert assessment, 17 included direct measurements, and 13 relied on self-reported data, with many reporting a combination of these sources. Five JEMs had an industry axis, 13 were time varying, and 7 were sex specific.

Meta-data were provided for exposure databases covering the Netherlands \((n = 3)\), France \((n = 3)\), UK \((n = 2)\), Norway \((n = 1)\), and multinational \((n = 2)\) (Supplementary Table 1, available at Annals of Work Exposures and Health online). The earliest data are included in ExpoSYN (1951–2009). For six databases (Colchic, EV@LUTIL, EXPO, HSE-BMDB, NECID, and SCOLA), data collection is still ongoing. Dusts and fibres were also the most common exposures in the databases (7 out of 11), followed by solvents and pesticides (both included in 6 databases).

Information on the occupational coding systems included international (i.e. ISCO), as well as national coding systems from more than 10 countries. Their relation to other coding systems and the availability of crosswalks and/or automated coding systems is shown in Table 2.

Discussion

Existing occupational exposure assessment tools, including JEMs, exposure databases, coding systems, and crosswalks have been collated in an inventory. Although many different types of exposures have been covered by the 36 JEMs, the most common exposure group was dusts and fibres, while biological factors and employment conditions were much less frequent. This distribution may partly represent the major research focus in occupational epidemiology over the last decades. On the other hand, not all exposure types are equally appropriate for assessment by JEMs (Peters, 2020), which may also be reflected by our inventory. The availability of multiple JEMs on the same exposure allows for studying method uncertainty and to study if associations are method dependent (e.g. Offermans et al., 2012). The geographical coverage showed that most JEMs were developed in Western and Northern Europe. Based on the current inventory, it would appear that JEMs developed for Eastern and Southern Europe, in particular, could be a major improvement on the current toolbox for occupational exposure assessment in large cohorts.

While the OMEGA-NET team actively made contacts and sought contributions from researchers, our
Table 1. Overview of the 36 JEMs entered in the OMEGA-NET inventory of exposure assessment tools by August 2021.

| JEM name                       | Job coding | Exposure metrics                  |
|--------------------------------|------------|-----------------------------------|
| ALOHA + JEM (Skorge et al., 2009) | ISCO 1988  | Intensity; semi-quantitative      |
| Asbestos JEM<sup>a,b</sup> (Swast et al., 2008) | ISCO 1968  | Intensity: semi-quantitative; probability |
| AshJEM<sup>a,b</sup> (van Oyen et al., 2015) | N/A        | Intensity: quantitative           |
| BEN-JEM<sup>1</sup> (Spycher et al., 2017)   | ISCO 1998  | Intensity: quantitative; probability |
| CANJEM<sup>a</sup> (Sauvé et al., 2018)       | ISCO 1968  | Intensity: semi-quantitative; probability; frequency |
| Constances JEM (Yung et al., 2020)            | PCS        | Intensity                          |
| COVID-19-JEM (Oude Hengel et al., 2021)       | ISCO 2008  | Probability                        |
| dBAR-JEM<sup>a</sup> (Stokholm et al., 2020) | ISCO 1988  | Intensity: quantitative            |
| DEE-JEM (Ge et al., 2020)                    | ISCO 1968  | Intensity: quantitative; probability |
| DOM-JEM (Peters et al, 2011)                 | ISCO 1968  | Intensity: semi-quantitative      |
| Time period covered (time intervals) | Exposures | Data source(s) | Region for which the JEM was originally developed |
|-------------------------------------|-----------|----------------|-----------------------------------------------|
| n.s. | *Dusts and fibres: mineral dust; organic dust*  
*Solvents: chlorinated solvents; aromatic solvents; other solvents*  
*Metals: metals (n.s.)*  
*Pesticides: fungicides; herbicides; insecticides*  
*Other chemicals: gas and fumes (n.s.)* | Expert assessment | Europe, North America |
| 1945–1994 (5-year intervals) | Asbestos | Expert assessment | The Netherlands |
| 1943–present  
(1943–1966, 1967–1986, 1987–2003, 2004+)  
1945–2009  
(1945–1959, 1960–1984, 1985–1994, 1995–1997, 1998–2000, 2001–2003, 2004–2006, 2007–2009) | Asbestos  
Benzene | Expert assessment  
Direct measurements | Australia  
Europe, North America |
| 1930–2000  
(varying intervals) | CANJEM included 258 agents from the selected categories (*not further specified in online inventory*) | Expert assessment | North America |
| n.s. | Awkward work postures; physical work load; repetitive work movements; sedentary work; standing work; work with video display units (VDU) | Expert assessment  
Self-reported data | France |
| 2020 | *Biological factors: infection risk*  
(number of contacts; type of contacts; indirect contact; location; social distancing; face covering)  
*Organization of work: job insecurity; migrants* | Expert assessment | Denmark, The Netherlands, UK |
| n.s. | Noise | Expert assessment  
Direct measurements | Denmark |
| n.s. | Diesel engine exhaust | Expert assessment  
Direct measurements | Europe, North America |
| n.s. | *Dusts and fibres: asbestos; biological dust; quartz*  
*Metals: chromium; nickel*  
*Other chemicals: diesel engine exhaust; PAHs (n.s.)*  
*Biological factors: animal contact; endotoxins* | Expert assessment | Europe |
| JEM name                          | Job coding | Exposure metrics                  |
|----------------------------------|------------|-----------------------------------|
| FINJEM\(^a\) (Kauppinen et al., 1998) | ISCO 1958  | *Intensity*: quantitative; *probability* |
| INTEROCC Chemical-JEM (van Tongeren et al., 2013) | ISCO 1968 ISCO 1988 | *Intensity*: quantitative; *probability* |
| INTEROCC ELF-JEM (Turner et al., 2014) | ISCO 1968 ISCO 1988 | *Intensity*: quantitative |
| Lower Body JEM (Rubak et al., 2014) | ISCO 1988  | *Intensity*: quantitative; *probability*; *duration*; *frequency* |
| LUXAR-JEM\(^a\) (Vested et al., 2019) | ISCO 1988  | *Intensity*: quantitative (lux), *peaks* |
| Time period covered (time intervals) | Exposures                                                                 | Data source(s)                      | Region for which the JEM was originally developed |
|-------------------------------------|---------------------------------------------------------------------------|------------------------------------|-----------------------------------------------|
| 1945–1997 (1945–1959, 1960–1984, 1985–1994, 1995–1997) | Dusts and fibres: asbestos; man-made mineral fibres; inorganic dust (n.s.); quartz; animal dust; flour dust; plant dust; pulp or paper dust; synthetic polymer dust; textile dust; wood dust (hardwood); wood dust (softwood); wood dust (n.s.); leather dust  
Solvents: alphatic and alicyclic hydrocarbon solvents (n.s.); benzene; styrene and styrene oxide; toluene; xylene; aromatic solvents (n.s.); methylene chloride; perchloroethylene; trichloroethanes; trichloroethylene; chlorinated hydrocarbon solvents (n.s.); formaldehyde; organic solvents (n.s.)  
Pesticides: fungicides; herbicides; insecticides  
Metals: arsenic; cadmium; chromium; iron; lead; nickel  
Other chemicals: diesel engine exhaust; gasoline engine exhaust; isocyanates; benzo(a)pyrene; bitumen fumes; oil mist; PAHs (n.s.); environmental tobacco smoke; sulphur dioxide and trioxide; welding fumes (n.s.)  
Biological factors: Gram-negative bacteria of human origin; moulds  
Physical agents: cold; hand-arm vibration; heat; noise; ionizing radiation; non-ionizing radiation; solar and ultraviolet radiation; ultrasound; noise; impulsiveness; hand vibration  
Ergonomics, physical workload, and injury related: accident risk  
Psychosocial domains: psychological job demands; social support at work from supervisors  
Organization of work: night (permanent or rotating) | Expert assessment  
Self-reported data  
Direct measurements | Finland |
| n.s. | Dusts and fibres: asbestos; quartz; animal dust; wood dust (n.s.)  
Solvents: gasoline; benzene; toluene; methylene chloride; perchloroethylene; trichloroethanes; trichloroethylene  
Metals: cadmium; chromium; iron; lead; nickel  
Other chemicals: diesel engine exhaust; benzo(a)pyrene; bitumen fumes; sulphur dioxide and compounds; welding fumes | Expert assessment FINJEM | International |
| n.s. | Non-ionizing radiation | Expert assessment  
Direct measurements | Europe, North America |
| n.s. | Awkward work postures; physical workload; standing work; whole-body vibration | Expert assessment | Denmark |
| n.s. | Light at day | Expert assessment  
Direct measurements | Southern Scandinavia |
| JEM name                      | Job coding | Exposure metrics                                      |
|-------------------------------|------------|-------------------------------------------------------|
| MatEmESp<sup>a</sup> (García et al., 2013) | CNO-94     | Intensity: qualitative, quantitative; probability; frequency; peaks |
| Matgé<sup>ab</sup> (Marant Micallef et al., 2021) | ISCO 1968 PCS 1994 | Intensity: semi-quantitative; probability |
| Time period covered (time intervals) | Exposures | Data source(s) | Region for which the JEM was originally developed |
|-------------------------------------|-----------|----------------|-----------------------------------------------|
| 1996–2005                           | Dusts and fibres: asbestos; man-made mineral fibres; quartz; animal dust; flour dust; wood dust (n.s.) Solvents: gasoline; aliphatic and alicyclic hydrocarbon solvents (n.s.); benzene; aromatic hydrocarbon solvents (n.s.); methylene chloride; perchloroethylene; trichloroethanes; trichloroethylene; chlorinated hydrocarbon solvents (n.s.); formaldehyde; organic solvents (n.s.) Pesticides: thiram; captam; 2,4-D or 2,4,5-T; atrazine; diquat; diuron; chloropyriphos; endosulfan; methomyl; pyrethrins Metals: arsenic; cadmium; chromium; iron; lead; nickel Other chemicals: benzo(a)pyrene; bituminous fumes; PAHs (n.s.); oil mist; sulphur dioxide; isocyanates; welding fumes (n.s.) Physical agents: heat; noise Ergonomics, physical workload, and injury related: awkward work postures; physical work load; repetitive work movements; sedentary work; standing work; work with video display units (VDU); vibrations; safety hazards Psychosocial domains: violence; job control, autonomy; psychological job demands; role conflict/ambiguity/clarity; social support at work from supervisors; skill use opportunities; work engagement; job insecurity; esteem; sociodemographic characteristics of working force Organization of work: contract duration; job insecurity; low pay; work contract type; night (permanent or rotating); duration; regular/variable working hours; shift work; working weekends; employment situation | Expert assessment Self-reported Spain data FINJEM | Matgéné, Marant Micallef, 2021 |
| 1950–2010 (varying intervals)      | Dusts and fibres: asbestos; ceramic fibres; mineral woods; cement; quartz; flour dust; leather dust Solvents: aliphatic and alicyclic hydrocarbon solvents (n.s.); aromatic solvents (n.s.); benzene; gasoline; methylene chloride; perchloroethylene; trichloroethylene; carbon tetrachloride; chloroform; formaldehyde; ketones; ethers; alcohols; ethylene and propylene glycols Other chemicals: PAHs | Expert assessment France | MatEmESpb, García et al., 2013 |
| JEM name | Job coding | Exposure metrics |
|----------|------------|------------------|
| NOCCA-JEM\(^b\) \((\text{Kauppinen et al., 2009})\) | NYK | Intensity: semi-quantity; probability |
| NORJEM—mechanical\(^c\) \((\text{Hanvold et al., 2019})\) | ISCO 1988 STYRK-98 | Intensity: qualitative |
| NORJEM—psychosocial\(^c\) \((\text{Hanvold et al., 2019})\) | ISCO 1988 STYRK-98 | Intensity |
| OAsJEM \((\text{Le Moual et al., 2018})\) | ISCO 1988 | Intensity: semi-quantitative |
| Physical workload factors JEM\(^c\) \((\text{Solovieva et al., 2012})\) | ISCO 1988 | Probability, duration, frequency |
| POLLEK \((\text{Szemik et al., 2020})\) | N/A | Intensity, probability, duration, frequency |
| Psychosocial JEM\(^c\) \((\text{Solovieva et al., 2012})\) | ISCO 1988 | Intensity: quantitative |
| RF-JEM \((\text{Migault et al., 2019})\) | ISCO 1988 | Intensity: quantitative, probability |
| Shiftwork JEM \((\text{Fernandez et al., 2014})\) | ISCO 1968 | Probability |
| SHOCK-JEM \((\text{Huss et al., 2013})\) | ISCO 1988 | Intensity |
| Shoulder JEM \((\text{Dalboege et al., 2016})\) | ISCO 1988 | Intensity, duration, frequency |
| Time period covered (time intervals) | Exposures                                                                 | Data source(s)            | Region for which the JEM was originally developed |
|-------------------------------------|---------------------------------------------------------------------------|---------------------------|-----------------------------------------------|
| 1945–1994 (1945–1959, 1960–1974, 1975–1984, 1985–1994) | **Dusts and fibres:** asbestos; quartz; animal dust; wood dust (n.s.)  
**Solvents:** gasoline; benzene; toluene; chloroform; methylene chloride; perchloroethylene; trichloroethanes; trichloroethylene; formaldehyde  
**Metals:** chromium; iron; lead; nickel  
**Other chemicals:** diesel engine exhaust; gasoline engine exhaust; benzo(a)pyrene; bitumen fumes; sulphur dioxide and compounds; welding fumes  
**Physical agents:** light at night; ionizing radiation; solar and UV radiation  
**Ergonomics, physical workload, and injury related:** physical work load  
**Organization of work:** night (permanent or rotating) | Expert assessment  
Direct measurements | Nordic countries |
| n.s.                                | Awkward work postures; physical work load; standing work; hands above shoulder height; standing/walking | Self-reported data | Norway |
| n.s.                                | Job control, autonomy; psychosocial job demands; social support at work from supervisors; skill use opportunities; monotonous work; job strain | Self-reported data | Norway |
| n.s.                                | **Dusts and fibres:** animal dust; flour dust; plant dust; textile dust; wood dust (n.s.)  
**Solvents:** organic solvents  
**Pesticides:** fungicides; herbicides  
**Metals:** metal (n.s.)  
**Other chemicals:** detergents and cleaning products; isocyanates | Expert assessment  
Literature data | France |
| n.s.                                | Awkward work postures; physical work load; repetitive work movements; standing work | Self-reported data | Finland |
| n.s.                                | Career advancements opportunities; psychological job demands; work–family interface | Self-reported data | Poland |
| n.s.                                | Job control, autonomy; psychosocial job demands; social support at work from supervisors; skill use opportunities | Self-reported data | Finland |
| n.s.                                | Non-ionizing radiation | Expert assessment  
Self-reported data  
Direct measurements  
Literature data | Europe, North America, Oceania |
| n.s.                                | Exposure to light at night; phase shift; sleep disruption; poor diet; lack of physical activity; lack of vitamin D; graveyard shifts; early morning shifts | Expert assessment  
Self-reported data | Australia |
| n.s.                                | Electric shock | Expert assessment  
Direct measurements | Europe, North America |
| n.s.                                | Awkward work postures; physical work load; repetitive work movements; hand-arm vibration; computer work | Expert assessment  
Direct measurements | Denmark |
| Table 1. Continued |
|-------------------|-------------------|-------------------|
| JEM name           | Job coding        | Exposure metrics |
| SIOPS-JEM (Behrens et al., 2016) | ISCO 1968, ISCO 1988 | Intensity: quantitative |
| Swedish noise JEM* (Sjöström et al., 2013) | ISCO 1958, ISCO 1988 | Intensity |
| Swedish physical workload JEMb,c,d | ISCO 1988, SSYK 96 | Duration |
| Swedish psychosocial JEMb,c,d | ISCO 1988, SSYK 96 | Duration |
| SWEJEM Chemicals and Particlesd | FOB 80, SSYK 96 | Intensity: quantitative (mg/m³); probability |
| SYN-JEM* (Peters et al., 2016) | ISCO 1968 | Intensity: quantitative |
| US Pesticide JEM (Liew et al., 2014) | IPUM-USA 2000 | Intensity: semi-quantitative |
| Wood dust JEM* (Basinas et al., 2016) | ISCO 1988 | Intensity: quantitative |

ns, not specified; PAH, polycyclic aromatic hydrocarbons.

*aIndustry axis.

*bTime varying.

*cSex specific.

*dNo scientific publications identified.
| Time period covered (time intervals) | Exposures                                                                 | Data source(s)                   | Region for which the JEM was originally developed |
|--------------------------------------|---------------------------------------------------------------------------|---------------------------------|--------------------------------------------------|
| n.s.                                 | Social prestige                                                          | Expert assessment               | Europe, North America                            |
| 1970–2004 (5-year intervals)         | Noise                                                                     | Expert assessment               | Sweden                                           |
|                                      |                                                                          | Direct measurements             |                                                   |
| 1989–2013 (1989–1997, 1997–2013)      | Heavy lifting (at least 15 kg); physically strenuous work; fast breathing; forward bent position; twisted position; hands above shoulder level; repetitive work; frequent bending or twisting; physical load index | Self-reported data               | Sweden                                           |
| 1989–2013 (1989–1997, 1997–2013)      | Job control, autonomy; psychosocial job demands; social support at work from supervisors; skill use opportunities; job strain | Self-reported data               | Sweden                                           |
| n.s.                                 | Dusts and fibres: asbestos; man-made mineral fibres; quartz; stone and concrete; animal dust; flour dust; plant dust; pulp or paper dust; synthetic polymer dust; textile dust; wood dust (hardwood); wood dust (softwood); wood dust (n.s.); leather dust Solvents: gasoline; aliphatic and alicyclic hydrocarbon solvents (n.s.); benzene; styrene and styrene oxide; toluene; aromatic solvents (n.s.); methylene chloride; perchloroethylene; trichloroethylene; chlorinated hydrocarbon solvents (n.s.); formaldehyde Pesticides: fungicides; herbicides; insecticides Metals: arsenic; cadmium; chromium; iron; lead; nickel Other chemicals: carbon monoxide; detergents; diesel engine exhaust; gasoline engine exhaust; isocyanates; synthetic metal processing or drilling oils or fluids; benzo(a)pyrene; bitumen fumes; PAHs (n.s.); sulphur dioxide and trioxide; welding fumes (n.s.) | Expert assessment               | Sweden                                           |
|                                      |                                                                          | Direct measurements             | FIN-JEM                                          |
| 1960–2010 (1-year intervals)         | Dusts and fibres: asbestos; quartz Metals: chromium VI; nickel Other chemicals: benzo(a)pyrene | Direct measurements             | Europe, Canada                                   |
| n.s.                                 | Pesticides (n.s.)                                                        | Self-reported data              | North America                                    |
| 1978–2004 (1-year intervals)         | Wood dust (n.s.)                                                         | Expert assessment               | Europe                                           |
|                                      |                                                                          | Direct measurements             |                                                   |
inventory was largely dependent on the person(s) responsible for each tool to enter meta-data in the online system. This approach ensured the relevant information was collected as accurately as possible. Particularly for older exposure assessment tools, institutional knowledge may be lost if the responsible persons are no longer active in the research area. We, therefore, focussed on more recent and currently cited exposure tools, which we also considered to be most relevant. The downside of this dependency on individual researchers was that not all identified exposure tools have been included. For example, meta-data on a major national exposure database [i.e. MEGA from Germany (Gabriel et al., 2010)] were not entered by August 2021.

We further focussed our efforts on collecting information on JEMs and databases that are active and could potentially be used in the exposure assessment of general population cohorts. Hence, tools that were highly specific for one type of occupation or one study population were not our main priority. For example, although we know there are many exposure measurements collected in specific industries (Peters et al., 2012), we did not actively approach their database custodians, as many such databases are not available for use outside their intended scope [e.g. the Dust Monitoring Program of the European Industrial Minerals Association (Zilaout et al., 2017)]. There were also JEMs developed for one specific population, e.g. the Matex-JEM that was specifically

### Table 2. Meta-data on the 29 occupational coding systems in OMEGA-NET inventory by August 2021.

| System name | Version year | Country/region | Related coding system | Crosswalk available to related system/version | Semi-automated coding |
|-------------|--------------|----------------|-----------------------|-----------------------------------------------|-----------------------|
| CH-ISCO-19  | 2019         | Switzerland    | SSCO 2000             | No                                             |                       |
| CITP-08     | 2008         | France         | ISCO-08               | Yes                                           |                       |
| CNO-94      | 1994         | Spain          | ISCO-88               | Yes                                           |                       |
| CNO-11      | 2011         | Spain          | ISCO-08               | Yes                                           |                       |
| DISCO-88    | 1996         | Denmark        | ISCO-88               | Yes                                           |                       |
| DISCO-08    | 2010         | Denmark        | ISCO-08               | Yes                                           |                       |
| FOB 80      | 1980         | Sweden         | ISCO-58               | Yes                                           |                       |
| ISCO-58     | 1958         | International  |                       | Yes                                           |                       |
| ISCO-68     | 1968         | International  |                       | Yes                                           |                       |
| ISCO-88     | 1988         | International  |                       | Yes                                           |                       |
| ISCO-08     | 2008         | International  |                       | Yes                                           |                       |
| NOC 2006    | 2006         | Canada         |                       | Yes                                           |                       |
| NOC 2011    | 2011         | Canada         |                       | Yes                                           |                       |
| NOC 2016    | 2016         | Canada         |                       | Yes                                           |                       |
| NUP06       | 2006         | Italy          | ISCO-88               | Yes                                           |                       |
| NYK83       | 1983         | Sweden         | FOB80                 | Yes                                           |                       |
| PCS         | 2003         | France         |                       | No                                             | SICORE                |
| SBC 1992    | 1992         | Netherlands    | ISCO-88               | Yes                                           |                       |
| SSCO 2000   | 2000         | Switzerland    | CH-ISCO-19            | No                                             |                       |
| SSYK 1996   | 1996         | Sweden         | ISCO-88               | Yes                                           |                       |
| SSYK 2012   | 2014         | Sweden         |                       | Yes                                           |                       |
| STYRK-08    | 2011         | Norway         | ISCO-08               | Yes                                           |                       |
| UK SOC 1990 | 1990         | United Kingdom |                       | Yes                                           | CASCOT                |
| UK SOC 2000 | 2000         | United Kingdom |                       | Yes                                           | OSCAR                 |
| UK SOC 2010 | 2010         | United Kingdom |                       | Yes                                           | CASCOT                |
| UK SOC 2020 | 2020         | United Kingdom |                       | Yes                                           | CASCOT                |
| US SOC 2000 | 2000         | United States  |                       | Yes                                           |                       |
| US SOC 2010 | 2010         | United States  |                       | Yes                                           | SOCeer                |
| US SOC 2018 | 2018         | United States  |                       | Yes                                           | O*Net                 |

CAPS: https://ssl3.isped.u-bordeaux2.fr/CAPS-CA/Langue.aspx; CASCOT: https://warwick.ac.uk/fac/soc/ier/software/cascot/; O*Net: https://www.onetonline.org/; OSCAR: https://pubmed.ncbi.nlm.nih.gov/27973677/; SICORE: https://www.census.gov/prod/2/gen/96arc/ixbschuh.pdf; SOCeer: https://doi.org/10.1136/oemed-2015-103152.
developed for one company, using its internal job classification, and as such is not applicable to other settings (Imbernon et al., 1991).

Furthermore, we initially focussed on European tools, fitting with the initial objectives of OMEGA-NET. However, the inventory and its website remain open for new entries and a more global coverage would certainly be preferable to support the broader objectives to promote collaborative and harmonized research in the area of occupational epidemiology.

To have an easy entry point into finding these important exposure tools was one of the goals of OMEGA-NET. Therefore, all collected meta-data on exposure assessment tools have been made publicly available via a searchable web-based database (https://occupationalexposuretools.net/inventory/). With this effort we have brought together a wealth of information on available exposure assessment tools, that will aid the exposure assessment process in many occupational cohorts.

Supplementary Data

Supplementary data are available at Annals of Work Exposures and Health online.

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Conflict of interest

None declared.

Data availability

The data were derived from sources in the public domain: https://occupationalexposuretools.net/inventory/.

References

Basinas I, Liukkonen T, Sigsgaard T et al. (2016) Statistical modelling and development of a quantitative job exposure matrix for wood dust in the wood manufacturing industry. Occup Environ Med; 73 (Suppl. 1): P096.

Behrens T, Groß I, Siemiatycki J et al. (2016) Occupational prestige, social mobility and the association with lung cancer in men. BMC Cancer; 16: 395.

Blair A, Hines CJ, Thomas KW et al. (2015) Investing in prospective cohorts for etiologic study of occupational exposures. Am J Ind Med; 58: 113–22.

Dalbøge A, Hansson GA, Frost P et al. (2016) Upper arm elevation and repetitive shoulder movements: a general population job exposure matrix based on expert ratings and technical measurements. Occup Environ Med; 73: 553–60.

Fernandez RC, Peters S, Carey RN et al. (2014) Assessment of exposure to shiftwork mechanisms in the general population: the development of a new job-exposure matrix. Occup Environ Med; 71: 723–9.

Gabriel S, Koppisch D, Range D. (2010) The MGU—a monitoring system for the collection and documentation of valid workplace exposure data. Gefahrst Reinhalt Luft; 70: 43–79.

García 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.

Ge CB, Friesen MC, Kromhout H et al. (2018) Retrospective occupational exposure assessment to chemicals in case-control studies in the general population: past, present, and future. Ann Work Expos Health; 62: 1047–63.

Ge C, Peters S, Olsson A et al. (2020) Diesel engine exhaust exposure, smoking, and lung cancer subtype risks. A pooled exposure-response analysis of 14 case-control studies. Am J Respir Crit Care Med; 202: 402–11.

Hanvold TN, Sterud T, Kristensen P et al. (2019) Mechanical and psychosocial work exposures: the construction and evaluation of a gender-specific job exposure matrix (JEM). Scand J Work Environ Health; 45: 239–47.

Huss A, Vermeulen R, Bowman JD et al. (2013) Electric shocks at work in Europe: development of a job exposure matrix. Occup Environ Med; 70: 261–7.

Imbernon E, Goldberg M, Guenel P et al. (1991) MATEX: une matrice emplois-expositions destinée à la surveillance épidémiologique des travailleurs d’une grande entreprise (EDF-GDF). Arch Mal Prof Méd Trav Sécur Soc; 52: 559–66.

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.

Conflict of interest

None declared.

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References

Basinas I, Liukkonen T, Sigsgaard T et al. (2016) Statistical modelling and development of a quantitative job exposure matrix for wood dust in the wood manufacturing industry. Occup Environ Med; 73 (Suppl. 1): P096.

Behrens T, Groß I, Siemiatycki J et al. (2016) Occupational prestige, social mobility and the association with lung cancer in men. BMC Cancer; 16: 395.

Blair A, Hines CJ, Thomas KW et al. (2015) Investing in prospective cohorts for etiologic study of occupational exposures. Am J Ind Med; 58: 113–22.

Dalbøge A, Hansson GA, Frost P et al. (2016) Upper arm elevation and repetitive shoulder movements: a general population job exposure matrix based on expert ratings and technical measurements. Occup Environ Med; 73: 553–60.

Fernandez RC, Peters S, Carey RN et al. (2014) Assessment of exposure to shiftwork mechanisms in the general population: the development of a new job-exposure matrix. Occup Environ Med; 71: 723–9.

Gabriel S, Koppisch D, Range D. (2010) The MGU—a monitoring system for the collection and documentation of valid workplace exposure data. Gefahrst Reinhalt Luft; 70: 43–79.

García 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.

Ge CB, Friesen MC, Kromhout H et al. (2018) Retrospective occupational exposure assessment to chemicals in case-control studies in the general population: past, present, and future. Ann Work Expos Health; 62: 1047–63.

Ge C, Peters S, Olsson A et al. (2020) Diesel engine exhaust exposure, smoking, and lung cancer subtype risks. A pooled exposure-response analysis of 14 case-control studies. Am J Respir Crit Care Med; 202: 402–11.

Hanvold TN, Sterud T, Kristensen P et al. (2019) Mechanical and psychosocial work exposures: the construction and evaluation of a gender-specific job exposure matrix (JEM). Scand J Work Environ Health; 45: 239–47.

Huss A, Vermeulen R, Bowman JD et al. (2013) Electric shocks at work in Europe: development of a job exposure matrix. Occup Environ Med; 70: 261–7.

Imbernon E, Goldberg M, Guenel P et al. (1991) MATEX: une matrice emplois-expositions destinée à la surveillance épidémiologique des travailleurs d’une grande entreprise (EDF-GDF). Arch Mal Prof Méd Trav Sécur Soc; 52: 559–66.

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

Kogevinas M, Schlünssen V, Mehlm IS *et al.* (2020) The OMEGA-NET international inventory of occupational cohorts. *Ann Work Expo Health*; 64: 565–8.

Kromhout H, Vermeulen R. (2001) Application of job-exposure matrices in studies of the general population. Some clues to their performance. *Eur Respir Rev*; 11: 80–90.

Le Moal N, Zock JP, Dumas O *et al.* (2018) Update of an occupational asthma-specific job exposure matrix to assess exposure to 30 specific agents. *Occup Environ Med*; 75: 507–14.

Liew Z, Wang A, Bronstein J *et al.* (2014) Job exposure matrix (JEM)-derived estimates of lifetime occupational pesticide exposure and the risk of Parkinson’s disease. *Arch Environ Occup Health*; 69: 241–51.

Marant Micallef C, Charvat H, Houot MT *et al.* (2021) Estimated number of cancers attributable to quantitative occupational exposures in France in 2017: an update using a new method for improved estimates. *J Expo Sci Environ Epidemiol*. doi:10.1038/s41370-021-00353-1

Migault L, Bowman JD, Kromhout H *et al.* (2019) Development of a job-exposure matrix for assessment of occupational exposure to high-frequency electromagnetic fields (3 kHz–300 GHz). *Ann Work Expo Health*; 63: 1013–28.

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.

Oude Hengel KM, Burdorf A, Pronk A *et al.* (2021) Exposure to a SARS-CoV-2 infection at work: development of an international Job Exposure Matrix (COVID-19-JEM). *Scand J Work Environ Health*. doi:10.5271/sjweh.3998

Peters S. (2020) Although a valuable method in occupational epidemiology, job-exposure -matrices are no magic fix. *Scand J Work Environ Health*; 46: 231–4.

Peters S, Turner MC, Bugge MD *et al.* (2020) International Inventory of Occupational Exposure Information: OMEGA-NET. *Ann Work Expo Health*; 64: 465–7.

Peters S, Vermeulen R, Cassidy A *et al.*; INCO Group. (2011) Comparison of exposure assessment methods for occupational carcinogens in a multi-centre lung cancer case-control study. *Occup Environ Med*; 68: 148–53.

Peters S, Vermeulen R, Olsson A *et al.* (2012) Development of an exposure measurement database on five lung carcinogens (ExpoSYN) for quantitative retrospective occupational exposure assessment. *Ann Occup Hyg*; 56: 70–9.

Peters S, Vermeulen R, Portengen L *et al.* (2016) SYN-JEM: a quantitative job-exposure matrix for five lung carcinogens. *Ann Occup Hyg*; 60: 795–811.

Rubak TS, Svendsen SW, Andersen JH *et al.* (2014) An expert-based job exposure matrix for large scale epidemiologic studies of primary hip and knee osteoarthritis: the Lower Body JEM. *BMC Musculoskelet Disord*; 15: 204.

Sauvé JF, Siemiatycki J, Labrèche F *et al.* (2018) Development of and selected performance characteristics of CANJEM, a general population job-exposure matrix based on past expert assessments of exposure. *Ann Work Expo Health*; 62: 783–95.

Sjöström M, Lewné M, Alderling M *et al.* (2013) A job-exposure matrix for occupational noise: development and validation. *Ann Occup Hyg*; 57: 774–83.

Skorge TD, Eagan TM, Eide GE *et al.* (2009) Occupational exposure and incidence of respiratory disorders in a general population. *Scand J Work Environ Health*; 35: 454–61.

Solovieva S, Pehkonen I, Kausto J *et al.* (2012) Development and validation of a job exposure matrix for physical risk factors in low back pain. *PLoS One*; 7: e48680.

Spycher BD, Lupatsch JE, Huss A *et al.*; Swiss Paediatric Oncology Group; Swiss National Cohort Study Group. (2017) Parental occupational exposure to benzene and the risk of childhood cancer: a census-based cohort study. *Environ Int*; 108: 84–91.

Stokholm ZA, Erlandsen M, Schlünssen V *et al.* (2020) A quantitative general population job exposure matrix for occupational noise exposure. *Ann Work Expo Health*; 64: 604–13.

Swuste P, Dahman M, Burdorf A. (2008) Linking expert judgement and long-term trends in occupational exposure into a job-exposure matrix for historical exposure to asbestos in The Netherlands. *Ann Occup Hyg*; 52: 397–403.

Szemik S, Gajda M, Kowalska M. (2020) [The review of prospective studies on mental health and the quality of life of physicians and medical students]. *Med Pr*; 71: 483–91.

’t Mannetje A, Kromhout H. (2003) The use of occupation and industry classifications in general population studies. *J Epidemiol*; 32: 419–28.

Turner MC, Benke G, Bowman JD *et al.* (2014) Occupational exposure to extremely low-frequency magnetic fields and brain tumor risks in the INTEROCC study. *Cancer Epidemiol Biomarkers Prev*; 23: 1863–72.

Turner MC, Mehlm IS. (2018) Greater coordination and harmonisation of European occupational cohorts is needed. *Occup Environ Med*; 75: 475–6.

van Oyen SC, Peters S, Alfonso H *et al.* (2015) Development of a job-exposure matrix (AshJEM) to estimate occupational exposure to asbestos in Australia. *Ann Occup Hyg*; 59: 737–48.

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

Vested A, Schlünssen V, Burdorf A *et al.* (2019) A quantitative general population job exposure matrix for occupational daytime light exposure. *Ann Work Expo Health*; 63: 666–78.

Yung M, Dale AM, Buckner-Petty S *et al.* (2020) Musculoskeletal symptoms associated with workplace physical exposures estimated by a job exposure matrix and by self-report. *Am J Ind Med*; 63: 51–9.

Zilaout H, Vlaanderen J, Houba R *et al.* (2017) 15 years of monitoring occupational exposure to respirable dust and quartz within the European industrial minerals sector. *Int J Hyg Environ Health*; 220: 810–9.