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Prevalence of occupational co-exposure to biomechanical factors and neurotoxic chemicals in French workers

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Abstract

Objectives. Little is known about occupational co-exposure. The objective was to assess the prevalence of exposure and co-exposure to biomechanical factors and neurotoxic chemicals in French workers in 2017.

Methods. Data from the French representative survey SUMER 2017 (SURveillance Médicale des Expositions aux Risques professionnels) were analysed. A total of 25,118 workers were included. Exposure to four biomechanical factors (manual handling of loads, forceful joint exertion, repetitive movements, hand-arm transmitted vibrations) and 18 neurotoxic chemicals (n-hexane, perchloroethylene, trichloroethylene, etc.) were assessed using a questionnaire during face-to-face interviews with occupational physicians.

Results. Among men, 22.9% were exposed to at least one biomechanical factor and 10.2% were exposed to at least one neurotoxic chemical, mainly single exposures. Among women, 10.8% were exposed to at least one biomechanical factor and 3.1% were exposed to at least one neurotoxic chemical, also mainly single exposures. Occupational co-exposure to biomechanical factors and neurotoxic chemicals was observed among 4.8% of men and 0.7% of women. Workers under 30 years old, blue-collar workers and those working in small companies were more co-exposed than other workers. In men, prevalence of co-exposure was higher in the construction sector compared to other economic activities.

Discussion. This study stresses the importance of considering multiple occupational exposures while the current prevention measures are designed to focus on preventing occupational factors individually.

Keywords: Occupational exposure, Co-exposure, Biomechanical factors, Neurotoxic chemicals

What's Important About This Paper?

Little is known about co-exposure to occupational biomechanical factors and neurotoxic chemicals, although it may be associated with musculoskeletal disorders. This study showed that 5% of French men and 1% of French women were co-exposed in 2017, slightly lower than in 2010. Upset plots were used to present single and co-exposure in order to clearly show the combination of exposures.

Introduction

Occupational biomechanical factors, e.g., repetition and force, have been identified as risk factors for musculoskeletal disorders (MSD) (da Costa and Vieira, 2010; Kozak *et al.*, 2015; Keir *et al.*, 2019). A few studies have shown a potential effect of biomechanical and chemical co-exposure on the onset of MSDs, particularly carpal tunnel syndrome (CTS) (Ophir *et al.*, 2014; Roquelaure *et al.*, 2020). Certain chemical agents encountered in the workplace possess neurotoxic properties that can alter the functioning of the central nervous system (CNS) (e.g., trichlorethylene) and/or the peripheral nervous system (e.g., n-hexane) and increase the risk of MSDs (Roquelaure *et al.*, 2020; Dib *et al.*, 2021). Repetitive or forceful work not only cause mechanical stress on musculoskeletal structures but also elevates cardiac and respiratory output, as well as perspiration, potentially leading to increased respiratory or cutaneous absorption of toxic substances (Ophir *et al.*, 2014). Extended occupational exposure to neurotoxic chemical agents can heighten biomechanical stress through to two mechanisms: (1) Neurotoxic exposure can induce diffuse microlesions in the median, ulnar, or radial nerves, making them more susceptible to compression at the elbow or wrist (peripheral mechanism) (LoPachin and Gavin, 2015; Roquelaure *et al.*, 2020); (2) Neurotoxic chemical agents cause nonspecific lesions in the CNS affecting sensory-motor coordination (van Valen *et al.*, 2009; Li *et al.*, 2015). Reduced coordination of the upper limbs and lower dexterity may result in decreased mechanical efficiency and increased biomechanical overuse during repetitive manual tasks, contributing to heightened risk of MSDs in co-exposed workers (Freivalds, 2011).

A growing number of articles deal with the concept of exposome (Wild, 2012; Neufcourt *et al.*, 2022). However, there are still very few studies on occupational exposome (Roquelaure *et al.*, 2022). A French report stated that 97% of French workers were exposed to multiple exposures considering chemical, physical, biological, organisational and/or psychosocial

hazards (Anses, Dares, and Santé publique France, 2021), but little is known about occupational co-exposure to biomechanical factors and neurotoxic chemicals in particular. In a previous study, we showed that approximately 5% of male and 1% of female French workers were co-exposed to biomechanical factors and neurotoxic chemicals in 2010 (Bertin *et al.*, 2020).

The objective of this study was to update the prevalence of exposure and co-exposure to biomechanical factors of MSDs of the upper limb and back and neurotoxic chemicals in French workers in 2017, incorporating Dib *et al.*'s recent neurotoxic classification for chemicals at work (Dib *et al.*, 2021).

Methods

Study sample

Data from the French representative survey SUMER 2017 (Surveillance médicale des expositions aux risques professionnels (SUMER) - 2017, DARES - Ministère du Travail et de l'Emploi [producteur], ADISP [diffuseur]) were analysed (Coutrot *et al.*, 2018). SUMER is a periodical national cross-sectional survey conducted by the French Ministry of Labor. Its main objective is to describe the occupational exposures of French salaried workers. The survey is based on a two-level sampling involving 1243 voluntary occupational physicians who randomly selected 26 494 workers (20 and 30 interviews by occupational physician) between April 2016 and September 2017 (Havet and Penot, 2022).

The occupational physicians rely on the worker's statements during the medical examination in face-to-face and their expertise based on their knowledge of the field and the work processes specific to the position, the company or the workers' occupational categories to collect information about occupational exposures (physical, organizational and psychosocial factors, chemicals products and biological agents) within the previous week of work (Memmi

et al., 2019a). Occupational physicians have received a collection guide specifying how to fill in biomechanical and chemical exposures (guide available online in French (Dares, 2016)). Occupational physicians could use information from safety data sheets and labelling to identify the chemical agents used by the worker.

Workers aged 67 years old or younger were selected. Workers with missing data for the duration of biomechanical exposure per week were excluded; there were no missing data for chemical exposure (Supplementary material 1).

The SUMER survey was approved by the French Ethics Committees, the Commission Nationale de l'Informatique et des Libertés—CNIL- and the Conseil National de l'Information Statistique—CNIS.

Occupational exposure to biomechanical factors

Four biomechanical exposures were retained for their associations with MSDs in the epidemiological literature (da Costa and Vieira, 2010; Kozak *et al.*, 2015; Keir *et al.*, 2019): manual handling of loads ≥ 10 hours/week, forceful joint exertion ≥ 10 hours/week, repetitive movements ≥ 20 hours/week, hand-arm transmitted vibrations ≥ 2 hours/week, within the previous week of work. The thresholds of duration per week were retained following the recommendations of the European consensus for the surveillance of musculoskeletal disorders (Sluiter, Rest, and Frings-Dresen, 2001).

Occupational exposure to neurotoxic chemicals

The questionnaire included a list of 94 chemicals or groups of chemicals. Among them, 18 were retained for their neurotoxicity (Grandjean and Landrigan, 2006; Dib *et al.*, 2021): formaldehyde, acrylamide, arsenic and arsenic compounds, aluminum, lead and lead compounds, other metals and derivatives, pesticides, methanol, ketones, benzene, n-hexane,

styrene, toluene, white-spirit, dichloromethane, perchloroethylene, trichloroethylene and tetrahydrofuran. Occupational exposure to neurotoxic chemicals was defined by the presence or absence of exposure within the previous week of work.

Socio-professional factors

Four age categories were studied (<30 years old, 30-39 years old, 40-49 years old and 50 or more years old). Occupations were coded using the French national classification of occupations (PCS 2003 by the National Institute of Statistics and Economic Studies - INSEE) and studied in four categories: professionals/managers, associate professionals/technicians, clerks/service workers, and blue collar workers. Industry sectors were coded using the French national classification of economic activities (NAF 2008 by INSEE) and grouped into four categories: agriculture, manufacturing, construction, and services. The number of workers in the company was studied in five categories (1 to 9, 10 to 49, 50 to 199, 200 to 499, ≥ 500).

Statistical analyses

Weighting was carried out in several stages by the Dares (French Ministry of Labor and Employment): adjustment accounted for the characteristics of occupational physicians, the periodicity of medical visits, the characteristics of non-respondents and finally the data were weighted by gender, age, nationality, working time, occupational category, company size and economic activity to ensure the representativeness of the survey sample (Havet and Penot, 2022). Descriptive analyses were performed using weighted data to provide estimates that were nationally representative of the French working population .

Upset plots were used to describe the single and co-exposure to biomechanical and neurotoxic chemicals according to gender. Upset plots are a visualization technique for the quantitative analysis of sets and their intersections, more powerful than Venn diagrams which can only

take into account a limited number of variables (Lex *et al.*, 2014; Ballarini *et al.*, 2020; Gomez, Goponenko, and Soulakova, 2023). The weighted percentages were presented in the plots if at least 30 workers were exposed (unweighted frequency).

Differences in the prevalence of co-exposure according to covariates were tested using the Rao-Scott chi-squared test, which accounts for sampling weights to compare observed proportions. Unweighted frequencies and weighted percentages are presented (Niedhammer *et al.*, 2018).

Statistical analyses were performed using SAS V.9.4 and R 4.3.0.

Results

The study sample included 25,118 workers aged 67 or under and without missing values for the duration of biomechanical exposure (14,139 men and 10,979 women). Among men, 22.9% were exposed to at least one of the four biomechanical factors studied (Supplementary material 2). The most frequent exposures were single biomechanical exposures: 6.3% were exposed only to hand-arm transmitted vibrations (≥ 2 h/week) and 5.7% only to manual handling of loads (≥ 10 h/week) (Fig. 1). Two percent of men were co-exposed to hand-arm transmitted vibrations and manual handling of loads. Almost ten percent of men (10.2%) were exposed to at least one of the 18 neurotoxic chemicals studied (Supplementary Material 2), mainly single chemical exposures: 1.5% were exposed only to white-spirit, 1.1% only to ketones, 0.8% only to pesticides, 0.7% only to lead and lead compounds and 0.7% only to aluminum (Fig. 2), 0.4% were co-exposed to ketones and white-spirit

Among women, 10.8% were exposed to at least one biomechanical factor (Supplementary material 2), also mainly single biomechanical exposures: 3.3% were exposed only to manual handling of loads (≥ 10 h/week), 2.4% only to forceful joint exertion (≥ 10 h/week) and 2.1% only to repetitive movements (≥ 20 h/week) (Fig. 3). Almost three percent of women (3.1%)

were exposed to at least one neurotoxic chemical (Supplementary Material 2): 0.9% were exposed only to ketones, 0.4% only to pesticides, 0.3% to methanol and 0.3% to formaldehyde (Fig. 4).

Occupational co-exposure to biomechanical factors and neurotoxic chemicals was observed among 4.8% of men (about 560,000 salaried workers) and 0.7% of women (about 83,000 salaried workers, Fig. 5 and 6 and Supplementary Material 2). Workers under 30 years old, blue-collar workers and workers in small companies were more co-exposed than other workers (Fig. 5 and 6). In men, the prevalence of co-exposure was higher in the construction sector compared to other economic activities (Fig. 5). Upset plots of co-exposure were shown in Supplementary Material 3 for men and Supplementary Material 4 for women.

Discussion

Among the French working population, 5% of male and 1% of female were co-exposed to biomechanical factors and neurotoxic chemicals.

Few studies have investigated the co-exposure to biomechanical factors and neurotoxic chemicals in the working population. Using the same list of neurotoxic chemicals as Bertin *et al.* (Bertin *et al.*, 2020), the prevalence of co-exposure to biomechanical factors and neurotoxic chemicals in 2017 was slightly lower than in 2010: 4.4% in men (vs. 4.9% in 2010) and 0.7% in women (vs. 0.9% in 2010). Between both studies, less workers were exposed to biomechanical factors, in particular repetitive movements and manual handling of loads. This could be explained by the more frequent use of job rotation observed over the period in the same population (Memmi *et al.*, 2019b), as well as by the preventive effects of the new French law on arduous work (order no. 2017-1389) (Bertin *et al.*, 2019). Manual handling of loads decreased between 2010 and 2017, this could be explained by the increased use of mechanized aids (Memmi *et al.*, 2019b). In addition, the differences could be explained

by the evolution of the structure of the salaried population between 2010 and 2017: more professionals/managers and service workers, fewer associate professionals/technicians and unskilled blue-collar workers, and more workers in the services sector and fewer in manufacturing (Memmi *et al.*, 2019b).

The study of the associations between occupational co-exposures to biomechanical and neurotoxic chemical exposures and CTS is original (Ophir *et al.*, 2014). Many studies have investigated the effects of biomechanical factors on CTS (van Rijn *et al.*, 2009; Barcenilla *et al.*, 2012; Kozak *et al.*, 2015), but few have looked at the effect of neurotoxic chemicals. Exposure to chemicals may generate diffuse subtle nerve damage, rendering the median nerve more prone to entrapment at the carpal tunnel (Roquelaure *et al.*, 2020). The SUMER survey did not contain information on CTS or musculoskeletal disorders more generally, so the association between co-exposure and CTS could not be studied. However, it enables to estimate the prevalence of biomechanical and neurotoxic chemical co-exposures in the French working population with a large number of neurotoxic chemicals.

The study has several strengths: it included a large national and representative sample of the French working salaried population and a high response rate (81%). Weights were used to provide prevalence estimates for the entire French salaried working population. Information on biomechanical and chemical exposure was collected during face-to-face interviews carried out by occupational physicians based on workers' descriptions of their jobs and occupational physicians' knowledge of the workers' working environment. Upset plots were used to present single exposure, multi-exposure, and co-exposure. These plots are an alternative to the Venn diagram to visualize sets, their intersections, and aggregates of intersections (Lex *et al.*, 2014). This study had some limitations that should be mentioned. No duration and intensity were explored for chemical exposure due to many missing data. Exposure and co-exposure during the preceding week were studied. This method can lead to an over- or underestimation

of the number of exposed workers due to occasional or unusual activities during the previous week. It would have been interesting to study exposure and co-exposure over workers' entire working lives using more objective methods such as job-exposure matrices (JEM), but the workers' careers were not available.

Co-exposure to biomechanical factors and neurotoxic chemicals is more common among workers under 30 years old, blue-collar workers and those working in small companies. In men, prevalence of co-exposure was also higher in the construction sector compared to other economic activities. Co-exposure is a major occupational health issue, as most prevention measures target occupational factors individually. For preventers, it is essential to take a holistic approach to MSD risk assessment from an exposome perspective, rather than assessing risk categories such as biomechanical factors separately. This approach allows for a comprehensive consideration of the synergistic effects arising from the co-exposure to both biomechanical and chemical agents.

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Conflict of interest

The authors declare no conflict of interest.

Data Availability

The dataset used and analyzed during the current study is available from the corresponding author on reasonable request.

Figures

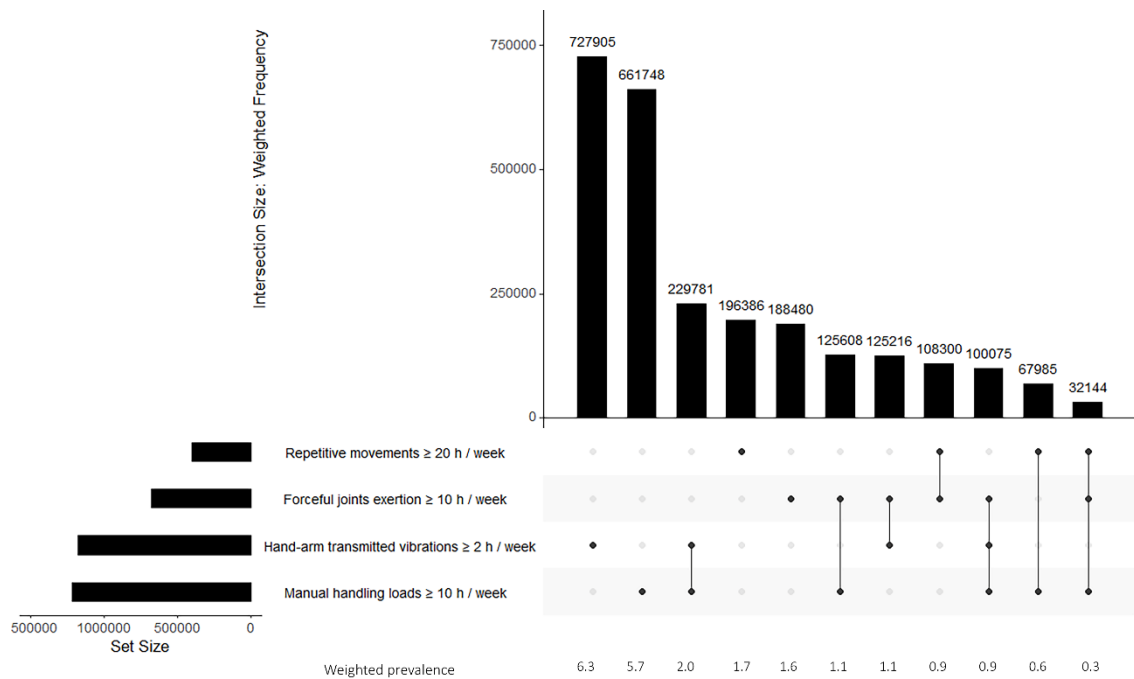


Fig. 1: Upset plot of biomechanical exposure in men: weighted frequency and percentage (SUMER 2017, France; Combinations of variables with an unweighted frequency of less than 30 are not shown)

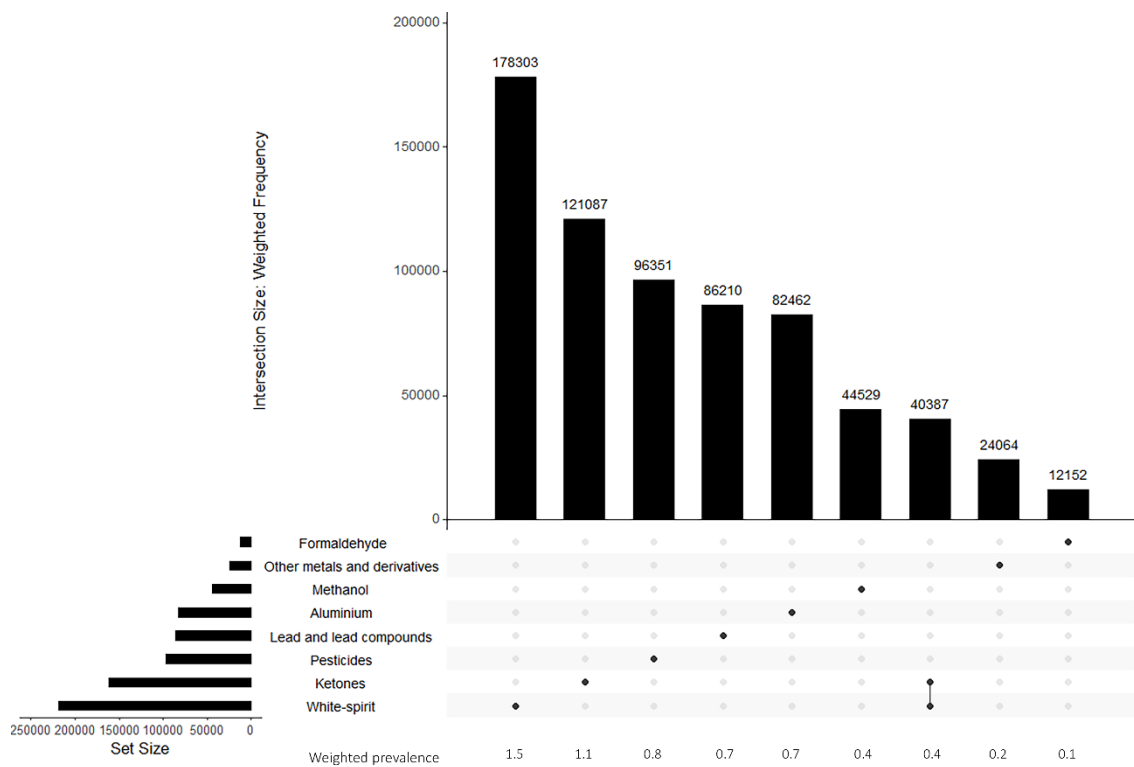


Fig. 2 Upset plot of neurotoxic chemical exposure in men: weighted frequency and percentage (SUMER 2017, France; Combinations of variables with an unweighted frequency of less than 30 are not shown)

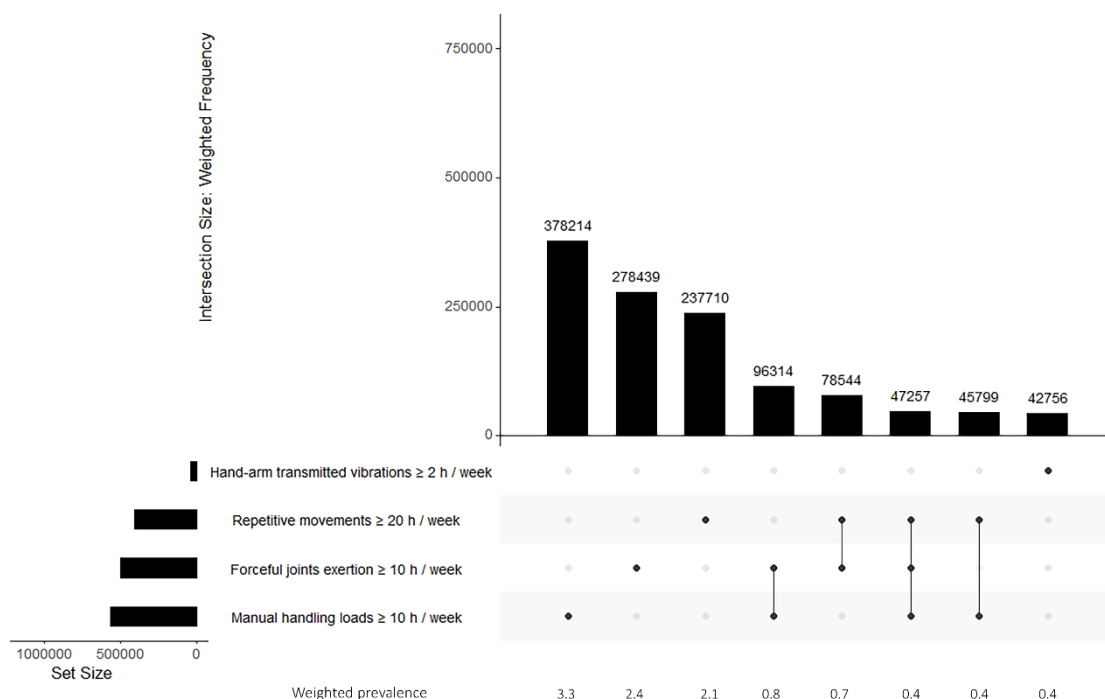


Fig. 3: Upset plot of biomechanical exposure in women: weighted frequency and percentage (SUMER 2017, France; Combinations of variables with an unweighted frequency of less than 30 are not shown)

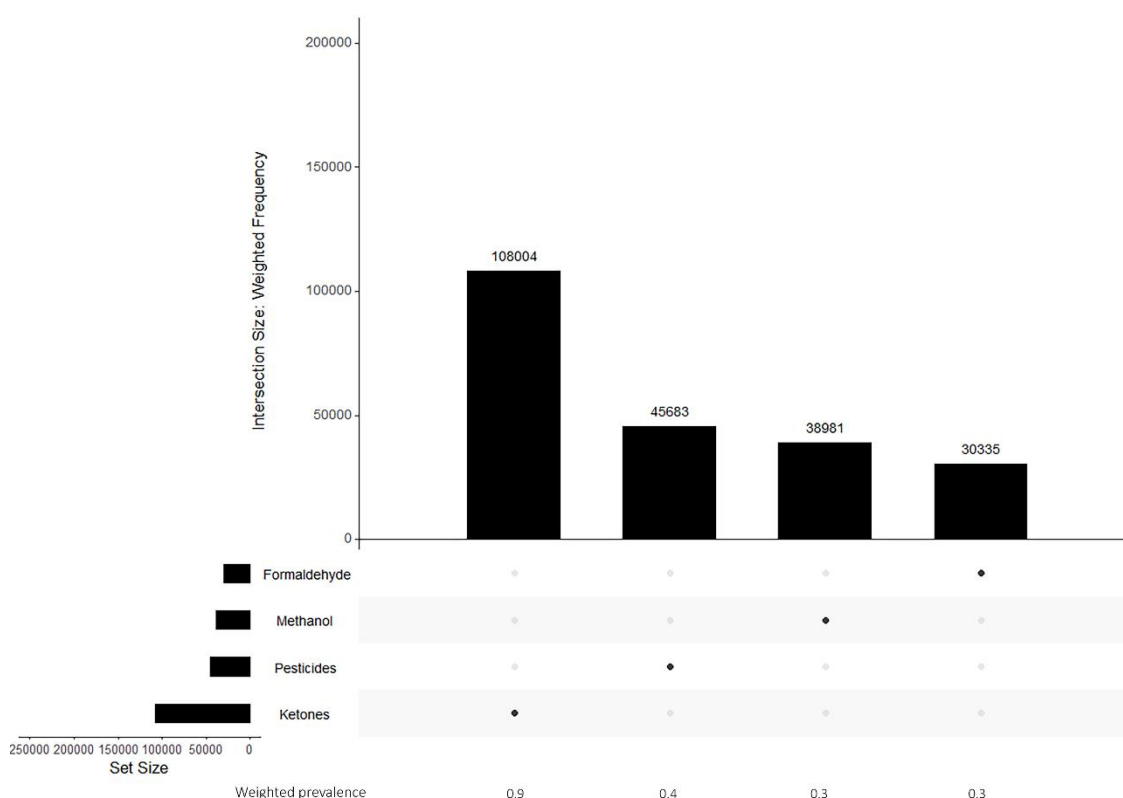


Fig. 4: Upset plot of neurotoxic chemical exposure in men: weighted frequency and percentage (SUMER 2017, France; Combinations of variables with an unweighted frequency of less than 30 are not shown)

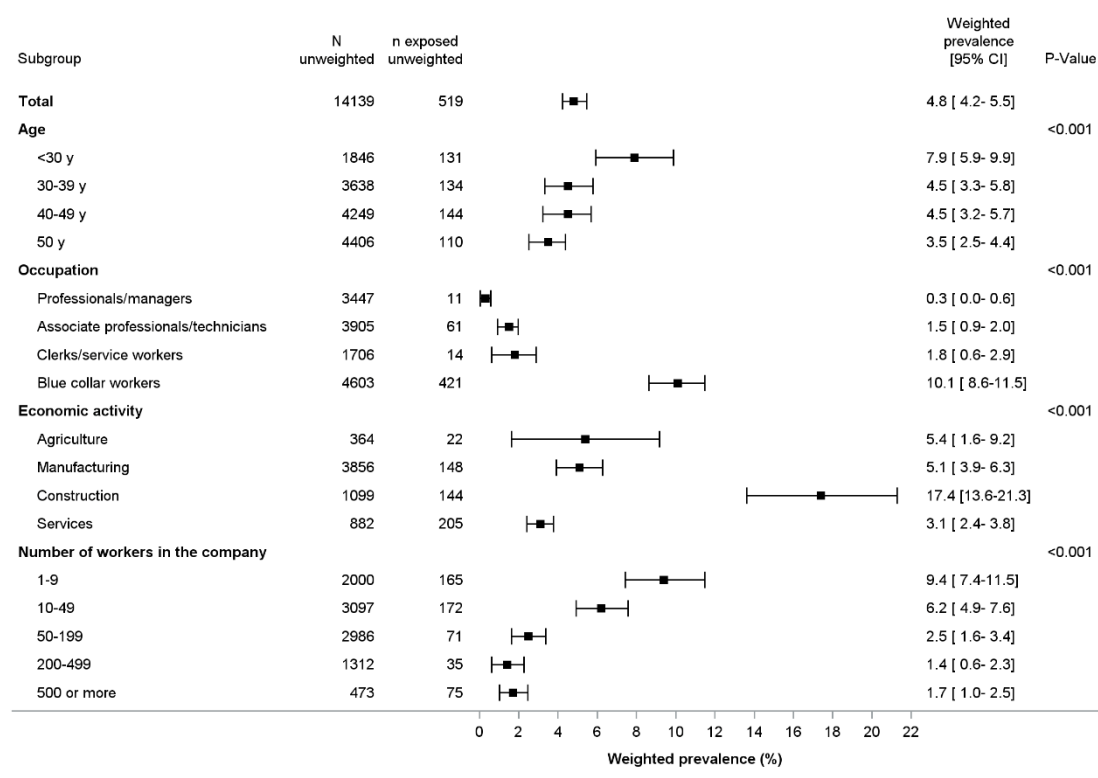


Fig. 5: Prevalence of co-exposure to at least one biomechanical factor and at least one neurotoxic chemical according to socio-professional characteristics in men (SUMER 2017, France)

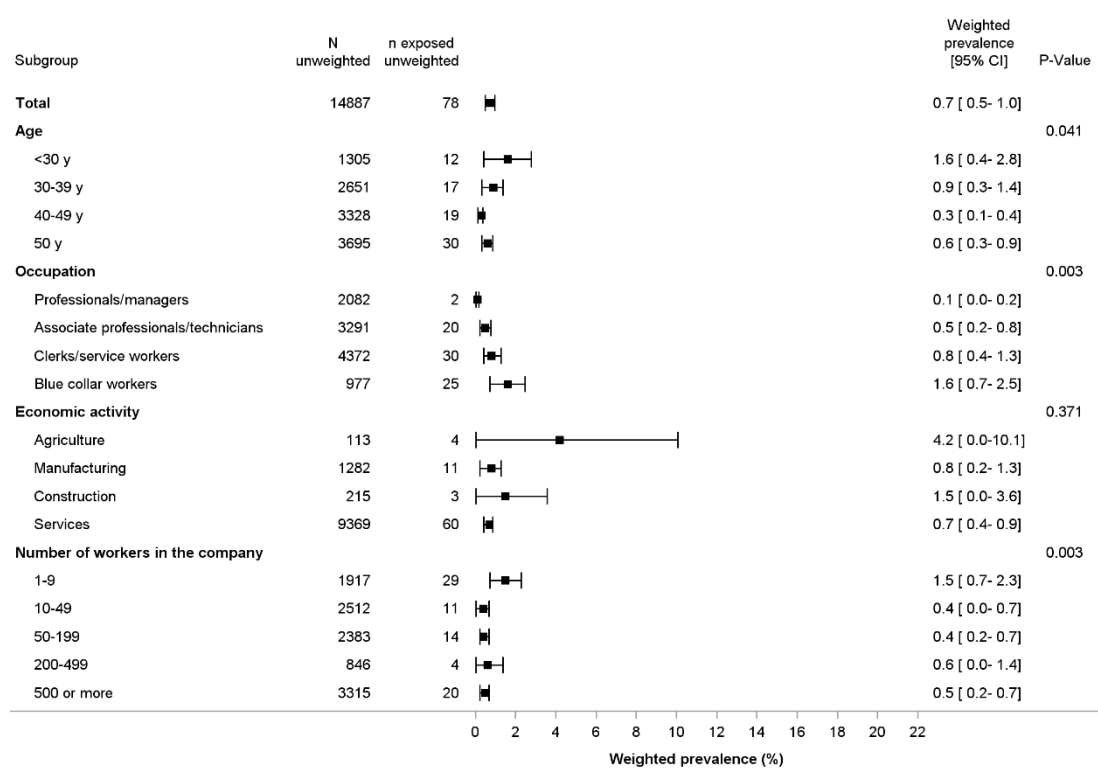


Fig. 6: Prevalence of co-exposure to at least one biomechanical factor and at least one neurotoxic chemical according to socio-professional characteristics in women (SUMER 2017, France)