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## BRIEF REPORT

# Occupational co-exposure to biomechanical factors and neurotoxic chemicals in a representative sample of French employees

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## Abstract

**Objectives:** Musculoskeletal disorders, mainly carpal tunnel syndrome, represent a leading cause of compensation claims of workers worldwide. Despite this, and the fact that occupational exposures to biomechanical factors and neurotoxic chemicals have been individually associated with peripheral nerve damage, the prevalence of occupational co-exposure to biomechanical factors and neurotoxic chemicals has rarely been explored. Therefore, our aim was to assess the prevalence of occupational co-exposure to biomechanical factors and neurotoxic chemicals in a national representative sample of the French working population.

**Methods:** The study was based on the French representative cross-sectional survey SUMER 2010. A total of 47 983 employees who had worked in their current job for at least one year were included. Occupational exposure to biomechanical factors and neurotoxic chemicals within the previous week of work were assessed using a questionnaire during face-to-face interviews with occupational physicians.

**Results:** Approximately 5% of male employees and 1% of female employees were co-exposed to biomechanical factors and neurotoxic chemicals. This prevalence was up to 10% among male blue-collar workers and 13%, 8%, and 6%, respectively, among male employees in the construction, agriculture, and industry sectors. Male employees under 30 years old, in apprenticeships, and working in small companies were more co-exposed to biomechanical factors and neurotoxic chemicals than their counterparts.

**Conclusions:** Occupational co-exposure to biomechanical factors and neurotoxic chemicals was observed in a significant proportion of French male employees, suggesting that further studies are required to investigate its potential adverse effects on peripheral neuropathies.

## KEYWORDS

biomechanical factors, multiple exposures, neurotoxic chemicals, occupational exposure

## 1 | INTRODUCTION

Musculoskeletal disorders (MSDs) represent a leading cause of compensation claims by workers worldwide and the number-one cause in France with 42 349 new cases of occupational disease recognized in 2017, among which one third were carpal tunnel syndrome (CTS),<sup>1</sup> (ie, representing 12 792 cases). In the literature, biomechanical exposures, including repetitive movements, hand-arm transmitted vibrations, and forceful manual exertion, have been described as the principal risk factors of CTS at the workplace.<sup>2</sup> In addition, occupational exposure to neurotoxic chemicals have also been associated with an increased risk of neuropathies<sup>3,4</sup> including damage to peripheral nerves,<sup>5</sup> thus raising concerns about the potential adverse synergistic effects between mechanical stressors and chemicals on the risk of CTS.<sup>6</sup> The occupational co-exposure to biomechanical factors and neurotoxic chemicals may involve the development of CTS according to several putative pathophysiological mechanisms. As suggested for the diabetic polyneuropathy, exposure to chemicals may generate diffuse subtle nerve damage rendering the median nerve more prone to entrapment at the carpal tunnel thus potentiating the effect of mechanical stress during tasks exposing to both physical wrist stressors and chemicals.<sup>7</sup> Beside impairments of the peripheral nervous system, exposure to neurotoxic chemicals may involve subclinical changes in the central nervous system,<sup>8</sup> leading to lower dexterity and inefficient working performance generating higher medical stress of the median nerve.<sup>9,10</sup> While numerous studies have underlined the necessity of an integrative approach to assessing exposure,<sup>11</sup> this approach remains limited when it comes to assessing the whole-exposure spectrum at the workplace. In addition, the knowledge gap is even wider when it comes to documenting typical co-occurrence of different types of exposures, such as the combination of biomechanical and chemical factors.<sup>6</sup> And yet, to our knowledge, no study has explored the prevalence of occupational co-exposure to biomechanical factors and neurotoxic chemicals in a representative sample of the working population. In this context, our aim was to describe the prevalence of exposure and co-exposure to both biomechanical factors and neurotoxic chemicals in a national representative sample of the French working population.

## 2 | METHODS

### 2.1 | Study population

This study was based on the French representative survey SUMER 2010 (*SURveillance Médicale des Expositions aux Risques professionnels*), a periodical national cross-sectional survey conducted by the French Ministry of Labor.<sup>12</sup> Its main objective was to assess occupational

exposure among the French working population based on a voluntary network of occupational physicians who collect data for a random sample of employees from compulsory medical examinations. A total of 2400 occupational physicians included 47 983 employees who agreed to participate. The response rate was 89%. The SUMER survey was approved by the French Ethics Committees called Commission Nationale de l'Informatique et des Libertés—CNIL- and Conseil National de l'Information Statistique—CNIS. The notice of compliance was issued on October 10, 2008 (informed consent was not necessary for this survey).

### 2.2 | Occupational exposure assessment

Occupational exposures, including biomechanical and chemical exposures, were assessed during face-to-face interviews with the occupational physician during their regular compulsory medical examination. Physicians were also instructed to take into account passive exposures from the environment of the workstation. Biomechanical exposures were determined by an exposure to at least: manual handling of loads  $\geq 10$  hours, forceful joints exertion  $\geq 10$  hours, repetitive movements  $\geq 20$  hours, hand-arm transmitted vibrations  $\geq 2$  hours, within the previous week of work following the recommendations of the European consensus for the surveillance of MSDs.<sup>13</sup> Occupational exposure to neurotoxic chemicals was defined by at least one exposure (ie, presence/absence) within the previous week of work to chemicals or groups of chemicals known for their neurotoxicity among the 89 chemicals recorded in the Sumer 2010 survey: formaldehyde, acrylamide, arsenic and arsenic compounds, lead and lead compounds, pesticides, styrene and polyesters resins, ketones, benzene, n-hexane, toluene, white-spirit, dichloromethane, perchloroethylene, and trichloroethylene (according to an update of the Grandjean and Landrigan review).<sup>14-16</sup>

### 2.3 | Socio-professional factors

Occupations were coded using the first level of the French national classification of occupations (PCS 2003 by INSEE) and four categories were studied: professionals/managers, associate professionals/technicians, clerks/service workers, and blue-collar workers. Industry sectors were coded using the first level of the French national classification of economic activities (NAF 2008 by INSEE) grouped into four categories: agriculture, fishing, and forestry; industry, construction, and services. The type of job's contract was assessed in four categories (apprenticeship, temporary, non-permanent, and permanent) and the number of employees at worksite in five categories (1-9, 10-49, 50-199, 200-499,  $\geq 500$ ).

## 2.4 | Statistical analyses

The prevalence of (co-)exposure to biomechanical factors and neurotoxic chemicals was estimated for the 24 990 male and 18 283 female employees who had worked at their current job for at least one year in their current job and was compared according to the socio-professional characteristics. All analyses were performed using weighted data to provide estimates that were nationally representative of the French working population based on socio-professional factors (ie, sex, age, occupational category, industry sector, type of contract, number of employees in the establishment, classification of working conditions in the agriculture) and to avoid any bias related to the volunteering and the characteristics of the investigating physician.<sup>12</sup> Statistical differences were assessed using the Rao-Scott chi-square test to account for design correction in survey data. Analyses were performed with STATA SE version 14 and svy prefix command (StataCorp LP).

## 3 | RESULTS

Among male employees, 25.7% were exposed to at least one biomechanical factor and 8.3% were exposed to multiple biomechanical factors. Among female employees, 17.4% were exposed to at least one biomechanical factor and 5.0% were exposed to multiple biomechanical factors. Men were mainly exposed to manual handling of loads and hand-arm transmitted vibrations (12.3% and 11.5%, respectively), whereas women were mostly exposed to repetitive movements (9.4%). Eleven percent of male employees were exposed to at least one neurotoxic chemical and 3.5% were exposed to multiple substances. The corresponding values for women were 3% and 0.6%, respectively. Men were mostly exposed to white-spirit, ketones, and pesticides (5.2%, 3.7%, and 1.6%, respectively) and women to ketones, formaldehyde, and pesticides (1.3%, 0.7%, and 0.5%, respectively). Co-exposure to biomechanical factors and neurotoxic chemicals was observed among 4.9% of male and 0.9% of female employees, corresponding to 517 080 male and 72 619 female employees (Table 1).

Men under 30 years old were more often co-exposed to biomechanical factors and neurotoxic chemicals (8.4% <30 years vs 4.4% ≥30 years,  $P < .001$ ), whereas women were similarly co-exposed regardless of their age ( $P = .965$ ). Male and female blue-collar workers were more frequently co-exposed to biomechanical factors and neurotoxic chemicals than other employees (9.8% vs ≤2.1% for the other occupational categories in men,  $P < .001$  and 4.3% vs ≤0.6% for the other occupational categories in women,  $P < .001$ ). Prevalence of co-exposure to biomechanical factors and neurotoxic chemicals was also higher for male employees in the

construction sector, followed by men working in the agriculture and in the industry sectors (12.7%, 7.6%, and 6.1%, respectively,  $P < .001$ ), whereas women working in the industry sector were the most co-exposed (3.4% vs ≤2.2% in the other sectors,  $P < .001$ ). Male employees with an apprenticeship contract and those with a small number of colleagues at the worksite (ie, <10 employees) were more frequently co-exposed to biomechanical and neurotoxic chemicals ( $P < .001$ ) (Table 2).

## 4 | DISCUSSION

This study presents the first prevalence figures of co-exposure to biomechanical factors and neurotoxic chemicals among a representative sample of the French working population.

Five percent of French male and 1% of female employees were co-exposed to biomechanical factors and neurotoxic chemicals. Co-exposure to biomechanical factors and neurotoxic chemicals was particularly common among male blue-collar workers (circa 10%) and among men working in the construction (13%) and agriculture (8%) sectors. Male employees of the industry sector were also co-exposed to biomechanical factors and neurotoxic chemicals to a lesser extent, as previously suggested by Petit et al<sup>6</sup> Similarly, female employees in the manufacturing industry were the most co-exposed to biomechanical factors and neurotoxic chemicals. Prevalence of co-exposure to biomechanical factors and neurotoxic chemicals was also higher among young male employees (<30 years old), those in apprenticeships, and those working in small companies: socio-professional characteristics that have also been associated with the highest prevalence of multiple occupational exposures (including chemical and biomechanical exposures) among employees in France and in Australia.<sup>9,17</sup>

Biomechanical exposures (eg, repetitive gestures, vibration) have long been associated with entrapment neuropathies, such as CTS.<sup>2</sup> Previous studies have also suggested that occupational exposure to neurotoxic chemicals may induce both subclinical change of the central and the peripheral nervous system that could increase the effect of mechanical stress on the nerve in cases of co-exposure with biomechanical factors.<sup>7,10</sup> Moreover, heavy physical work results in increased heart rate, respiratory function, and sweating, thereby facilitating the absorption of chemicals (including neurotoxic compounds) through the respiratory or dermal system,<sup>18</sup> thus raising concerns about potential adverse synergistic effects of biomechanical factors and neurotoxic chemicals on the median nerve at the wrist.<sup>6</sup>

Strengths of the study include the large national and representative sample of the French employees and the high response rate. Information on occupational exposure was collected during face-to-face interviews carried out by

**TABLE 1** Weighted prevalence of exposure and co-exposure to biomechanical factors and neurotoxic chemicals among the French working population<sup>a</sup>, by sex (SUMER 2010, France)

|  | Men (n = 24 990) |             |                | Women (n = 18 293) |             |                |
|--|------------------|-------------|----------------|--------------------|-------------|----------------|
|  | N <sup>a</sup>   | n           | % <sup>b</sup> | N <sup>a</sup>     | n           | % <sup>b</sup> |
| Exposure to biomechanical factors  |                  |             |                |                    |             |                |
| Manual handling loads $\geq 10$ h/wk   | 24 471           | 2899        | 12.3           | 17 974             | 1382        | 7.7            |
| Forceful joints exertion $\geq 10$ h/wk  | 24 809           | 1578        | 6.2            | 18 170             | 1168        | 6.0            |
| Repetitive movements $\geq 20$ h/wk  | 24 745           | 1790        | 7.2            | 18 074             | 1887        | 9.4            |
| Hand-arm transmitted vibrations $\geq 2$ h/wk  | 24 884           | 2637        | 11.5           | 18 278             | 135         | 0.7            |
| <b><i>At least one biomechanical exposure</i></b>  | <b>24 970</b>    | <b>6243</b> | <b>25.7</b>    | <b>18 293</b>      | <b>3389</b> | <b>17.4</b>    |
| <b><i>Multiple biomechanical exposures</i></b>   | <b>24 970</b>    | <b>2021</b> | <b>8.3</b>     | <b>18 293</b>      | <b>979</b>  | <b>5.0</b>     |
| Exposure to neurotoxic chemicals   |                  |             |                |                    |             |                |
| Formaldehyde   | 24 990           | 177         | 0.6            | 18 293             | 146         | 0.7            |
| Acrylamide   | 24 990           | 61          | 0.2            | 18 293             | 19          | 0.1            |
| Arsenic and arsenic compounds  | 24 990           | 24          | 0.1            | 18 293             | 5           | 0.0            |
| Lead and lead compounds  | 24 990           | 208         | 0.9            | 18 293             | 32          | 0.1            |
| Pesticides <sup>c</sup>  | 24 990           | 453         | 1.6            | 18 293             | 88          | 0.5            |
| Styrene <sup>d</sup>   | 24 990           | 176         | 0.8            | 18 293             | 15          | 0.0            |
| Ketones  | 24 990           | 977         | 3.7            | 18 293             | 273         | 1.3            |
| Benzene  | 24 990           | 94          | 0.3            | 18 293             | 14          | 0.1            |
| n-Hexane   | 24 990           | 118         | 0.4            | 18 293             | 28          | 0.1            |
| Toluene  | 24 990           | 429         | 1.6            | 18 293             | 68          | 0.3            |
| White-spirit   | 24 990           | 1301        | 5.2            | 18 293             | 95          | 0.4            |
| Dichloromethane  | 24 990           | 149         | 0.5            | 18 293             | 31          | 0.1            |
| Perchloroethylene  | 24 990           | 41          | 0.2            | 18 293             | 28          | 0.1            |
| Trichloroethylene  | 24 990           | 98          | 0.5            | 18 293             | 15          | 0.1            |
| <b><i>At least one neurotoxic chemical exposure</i></b>  | <b>24 990</b>    | <b>2907</b> | <b>11.2</b>    | <b>18 293</b>      | <b>632</b>  | <b>3.0</b>     |
| <b><i>Multiple neurotoxic chemical exposures</i></b>   | <b>24 990</b>    | <b>895</b>  | <b>3.5</b>     | <b>18 293</b>      | <b>143</b>  | <b>0.6</b>     |
| <b>Co-exposure to at least one biomechanical factors and at least one neurotoxic chemicals</b> | <b>24 970</b>    | <b>1216</b> | <b>4.9</b>     | <b>18 293</b>      | <b>179</b>  | <b>0.9</b>     |

Note: N, total number of workers (unweighted); n, number of exposed workers (unweighted).

<sup>a</sup>Total numbers differ because of missing values for some variables.

<sup>b</sup>% based on weighted data.

<sup>c</sup>Including herbicides, fungicides, insecticides, and other pesticides.

<sup>d</sup>Including polyester resins.

Values in bold/italic include biomechanical or neurotoxic chemical exposures, including the other biomechanical and neurotoxic chemicals mentioned above.

occupational physicians based on workers' descriptions of their jobs and occupational physicians' knowledge of the employees' working environment. Furthermore, levels of exposure to biomechanical factors were defined based on a European consensus.<sup>13</sup> This study has, however, some limitations. First, occupational exposures were estimated using

indirect approaches: both biomechanical and neurotoxic exposures were assessed based on a combination of workers' self-reports and expert judgments by the occupational physicians potentially leading to less accurate estimations than direct approaches (ie, personal monitoring). Furthermore, intensity and duration levels were not used in the estimation of

**TABLE 2** Weighted prevalence of employees co-exposed to at least one biomechanical factors and at least one neurotoxic chemicals according to their socio-professional characteristics, by sex (SUMER 2010, France)

|  | Men (n = 24 970) |      |                |               |                      | Women (n = 18 293) |     |                |                    |                      |
|--|------------------|------|----------------|---------------|----------------------|--------------------|-----|----------------|--------------------|----------------------|
|  | N                | n    | % <sup>a</sup> | [95% CI]      | P-value <sup>b</sup> | N                  | n   | % <sup>a</sup> | [95% CI]           | P-value <sup>b</sup> |
| Age  |                  |      |                |               | <.001                |                    |     |                |                    | .965                 |
| <30 y                                      | 4152             | 322  | 8.42           | [6.59-10.25]  |                      | 2811               | 29  | 0.81           | [0.46-1.15]        |                      |
| 30-39 y                                    | 7050             | 318  | 4.11           | [3.46-4.76]   |                      | 4891               | 51  | 0.92           | [0.57-1.27]        |                      |
| 40-49 y                                    | 7582             | 345  | 4.41           | [3.74-5.08]   |                      | 5616               | 61  | 0.85           | [0.56-1.14]        |                      |
| ≥50 y                                      | 6186             | 231  | 3.73           | [3.07-4.38]   |                      | 4975               | 38  | 0.81           | [0.42-1.20]        |                      |
| Industry sector                            |                  |      |                |               | <.001                |                    |     |                |                    | <.001                |
| Agriculture, fish-<br>ing, and forestry    | 665              | 50   | 7.57           | [3.27-11.87]  |                      | 203                | 5   | 1.29           | [0.00-2.73]        |                      |
| Industry                                   | 7484             | 401  | 6.15           | [5.29-7.01]   |                      | 2496               | 79  | 3.36           | [2.37-4.35]        |                      |
| Construction                               | 1895             | 243  | 12.72          | [10.02-15.42] |                      | 273                | 5   | 2.15           | [0.19-4.11]        |                      |
| Services                                   | 14 926           | 522  | 3              | [2.57-3.44]   |                      | 15 321             | 90  | 0.54           | [0.38-0.70]        |                      |
| Occupational<br>category                   |                  |      |                |               | <.001                |                    |     |                |                    | <.001                |
| Professionals/<br>managers                 | 4842             | 9    | 0.17           | [0.04-0.30]   |                      | 2656               | 5   | 0.12           | [0.00-0.24]        |                      |
| Associate<br>professionals/<br>technicians | 6070             | 105  | 1.56           | [1.05-2.08]   |                      | 5262               | 26  | 0.33           | [0.17-0.49]        |                      |
| Clerks/service<br>workers                  | 3195             | 54   | 2.11           | [1.42-2.80]   |                      | 8323               | 43  | 0.59           | [0.34-0.84]        |                      |
| Blue-collar<br>workers                     | 10 863           | 1048 | 9.82           | [8.82-10.82]  |                      | 2052               | 105 | 4.29           | [3.25-5.33]        |                      |
| Type of contract                           |                  |      |                |               | <.001                |                    |     |                |                    |                      |
| Apprenticeship                             | 296              | 33   | 19.24          | [7.17-31.31]  |                      | 135                | 3   | —              | —                  |                      |
| Temporary                                  | 293              | 15   | 5.3            | [2.12-8.48]   |                      | 107                | 0   | —              | —                  |                      |
| Non-permanent                              | 701              | 37   | 3.29           | [1.68-4.90]   |                      | 716                | 8   | 1.22           | [-0.06 to<br>2.51] |                      |
| Permanent                                  | 23 656           | 1130 | 4.7            | [4.28-5.11]   |                      | 17 318             | 168 | 0.83           | [0.66-1.00]        |                      |
| Number of employ-<br>ees in the company    |                  |      |                |               | <.001                |                    |     |                |                    | .013                 |
| 1-9  | 3851             | 347  | 9.07           | [7.71-10.42]  |                      | 3333               | 44  | 1.22           | [0.75-1.68]        |                      |
| 10-99                                      | 5909             | 385  | 5.48           | [4.72-6.23]   |                      | 4315               | 32  | 0.58           | [0.33-0.83]        |                      |
| 50-199                                     | 4823             | 193  | 4.54           | [3.24-5.83]   |                      | 3436               | 37  | 1.08           | [0.56-1.60]        |                      |
| 200-499                                    | 3332             | 107  | 3.78           | [2.24-5.33]   |                      | 2113               | 30  | 1.11           | [0.59-1.62]        |                      |
| 500  | 7055             | 184  | 2.1            | [1.61-2.58]   |                      | 5096               | 36  | 0.5            | [0.27-0.73]        |                      |

Note: N, total number of workers (unweighted); n, number of exposed workers (unweighted).

<sup>a</sup>% based on weighted data.

<sup>b</sup>Statistical comparisons of co-exposed employees according to socio-professional characteristics were performed using the Rao-Scott chi-square test.

neurotoxic exposures due to many missing data, neither the use of individual or collective protective equipment because it was not possible to determine whether protections were efficient and adapted against neurotoxic chemicals. Exposure to pesticides was also globally assessed without distinguishing the pesticides' chemical properties. Second, by excluding

employees that had worked at their current job for less than one year to ensure the representativeness of occupational exposures measured during the seven days before the interview, we may have overlooked information on seasonal or temporary workers and thus underestimated occupational exposures occurring beyond the assessment period.



The common co-exposure to biomechanical factors and neurotoxic chemicals, especially among male blue-collar workers and male employees in the agriculture, construction, and manufacturing industry sectors, suggests that studies are required to further investigate its association with peripheral neuropathies.

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## DISCLOSURE

*Approval of the research protocol:* N/A. *Informed consent:* N/A. *Registry and the registration no. of the study/trial:* N/A. *Animal studies:* N/A.

## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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