

# Health complaints after a malodorous chemical explosion: a longitudinal study

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## Abstract

**Background:** Physical and psychological symptoms are prevalent in populations recently affected by industrial accidents. Follow-up studies of human health effects are scarce, and as most of them focus on residents, little is known about the long-term health effects among workers exposed to malodorous emissions following a chemical explosion.

**Aims:** To assess whether subjective health complaints (SHC) among workers declined over a four year period after an oil tank explosion that emitted malodorous sulphurous compounds.

**Methods:** A longitudinal survey from 2008 (18 months after the explosion) to 2012, performed using the Subjective Health Complaints Inventory. Questionnaire data were analyzed using a linear mixed effects model.

**Results:** There was a decrease in subjective health complaints among the exposed workers, but they still had significantly more subjective neurological symptoms ( $P < 0.01$ ) compared to controls, adjusted for gender, age, smoking habits, educational level and proximity to the explosion.

**Conclusions:** Although there was a downward trend in subjective health complaints among exposed workers in the follow-up period they reported more subjective neurological complaints than controls. Symptoms may be mediated by perceived pollution and health risk perception, and adaptation or anxiety may cause a chronic effect, manifested by a dysfunctional and persistent neuropsychological response.

**Keywords:** Subjective health complaints, epidemiological follow-up, oil tank explosion, environmental pollution, malodorous pollution, workers.

## Introduction

Industrial disasters involving environmental pollution or contamination are common in the industrialised parts of the world. They are caused by accidents, carelessness or incompetence and are responsible for much human suffering [1-4]. Both physical and psychological symptoms are prevalent in populations recently affected by industrial accidents [1-7], but less is known about the time course of subjective health complaints [8] and the long-term effects on subjective health [8] following such incidents.

In 2007, a chemical explosion occurred in an industrial harbour in the western part of Norway. An oil tank containing low-quality gasoline and sulphurous waste products exploded, causing a violent fire with environmental pollution by a mixture of malodorous sulphurous compounds and various hydrocarbons [9-12]. Professional firefighters extinguished the fire during the afternoon of the blaze. Clean-up work that included removing foul-smelling contamination from the area started the following day, but took more than two years to complete. In the meantime, the odour was continuously present. Workers in the industrial area, as well as residents in the neighbourhood, experienced acute health effects such as sore and irritated eyes, sore throat, cough, headache, sleep problems and nausea [13, 14]. Low levels of sulphurous compounds were measured both a few weeks after the explosion and at the time of the first part of the study [10, 12, 15].

Previous studies of relevance include those describing long-term human health effects in the aftermath of chemical explosions and fires [8, 16, 17], health effects

related to long-term mercaptan exposure [18], and from exposure to foul odour from a petroleum refinery [19] and a biofuel facility [20]. Most of these studies include only residents rather than workers. To our knowledge, very few have studied long-term effects among workers who have experienced a malodorous chemical explosion at their workplace.

This study reports on follow-up of an initial study performed one and a half years after the disaster. The first study showed reduced tear film stability [13], more airway symptoms and reduced lung function among residents close to the industrial area [11]. Workers who were employed in the industrial area or participated in the clean-up operation also had more subjective health complaints compared to unexposed workers [12]. Predominant among these were headache, hot flushes, sleep problems, tiredness, dizziness and sadness/depression [12]. These findings indicated a host of non-specific physical and mental symptoms attributed to exposure, with odour as a potential cause [12].

In this study, we hypothesized that removing malodorous pollution from the area of the 2007 explosion would reduce subjective health complaints among exposed workers. The aim of the survey was to assess the degree to which subjective health complaints among workers were lower five and a half years after the oil tank explosion. All the foul-smelling contamination was removed during the study period. More information about the long-term health effects among workers who experience a malodorous chemical explosion is useful if future accidents occur.

## Methods

The present study is a part of a longitudinal study that was started in 2008, one and a half years after the disaster. All employees in the industrial area and all residents over the age of two living within six kilometres of the industrial area were invited to participate in the main study. A control group, matched by gender and age to the employees and the residents, and from the same geographical area, but living 20-30 kilometres from the site, was also invited. All participants who took part in the first survey and could be located were invited to participate in a 2012 survey, five and a half years after the incident. We included employees in the industrial area at the time of the explosion and those who participated in the clean-up operation; these workers were aged 18-67 at the time of the incident. Firefighters were not included, as they represent a group selected for repeated occupational exposure to similar events. For the control group, working inhabitants living 20-30 kilometres from the industrial area and aged 18-67 during the first survey were included. As in the first survey, the participants were invited to join the study by a personal letter sent by ordinary mail.

Both surveys used the Subjective Health Complaints Inventory (SHC), a validated instrument that measures subjective health complaints experienced by the participant in the previous 30 days [21]. This consists of 29 common somatic and psychological health complaints, including symptoms with minimal or no clinical findings. The respondents were asked to grade the intensity of each item experienced during the previous 30 days by using a four-point scale from 0 (no complaints) to 3 (severe complaints). The maximum total sum score was 87. Based on previous factor analysis the 29 items were grouped into subscales [21]. Musculoskeletal complaints consist of eight items (headache, neck pain, upper back pain, low back pain, arm

pain, shoulder pain, migraine and pain in the feet) giving a maximum subscale score of 24. Subjective neurological complaints consist of seven items (extra heartbeats, hot flushes, sleep problems, tiredness, dizziness, anxiety and sadness/depression) with a maximum subscale score of 21. This subscale was originally termed “pseudo-neurological” complaints by the developers of the instrument. Gastrointestinal complaints comprise seven items (heartburn, stomach discomfort, ulcer/non-ulcer dyspepsia, stomach pain, gas discomfort, diarrhoea and constipation), also with a maximum subscale score of 21. Allergy consists of five items (asthma, breathing difficulties, eczema, allergies and chest pain), (maximum subscale score 15) and flu, which comprises two items (cold/flu and coughing), with a maximum subscale score of six.

In this study, questionnaire data from both surveys are reported. The questionnaire for the present study sought data on gender, age, smoking, number of years of education after elementary school, employment (yes/no), employment in the industrial area (yes/no), distance from the accident site at the time of the explosion (in kilometres) and involvement in the clean-up operation (yes/no). In the 2008 survey participants were asked whether they were aware of a specific foul odour from the industrial area three months before the start of the survey, while in the 2012 survey they were asked if they had noted a specific foul odour from the industrial area during the month prior to the survey.

Some participants did not answer all questions in the SHC inventory. If fewer than half of the items within a subscale were missing, a missing score for an item was imputed by the mean score of the valid items within the respective subscale for that

individual [22]. Otherwise, the entire subscale was regarded as missing [22]. Mean subscale and total SHC scores were calculated and used in further analyses. The internal consistency of the five subscales in our study were analysed by using Cronbach's alpha.

To account for repeated responses from individual workers, linear mixed effects models were used to analyse possible differences in total SHC score and in subscale scores from the first to the second survey for exposed and control groups. In these analyses, the individual worker was entered as a random effect and time in question (2008 or 2012) was entered as fixed effect. The model included an interaction term between the time variable and the group variable. Linear mixed effects models were also used to analyse possible differences in mean scores of single items in subscales that were significantly different between exposed and control groups in 2012.

Estimated mean differences in scores were adjusted for possible confounding from smoking (non-smoker/daily smoker), education level (0, 1-3 or 4 or more years after elementary school), gender, and age (18-36, 37-44, 45-51 or 52-67 years). Proximity to the explosion of 1 kilometre or less was used to classify the participants as present in the industrial area during the explosion or not.

Among the exposed workers, possible differences in crude subjective neurological subscale scores by gender and smoking habits were analysed by the Student t-test. SPSS version 22 was used for the analysis, and the level of significance was set to 0.05 for all analyses.

Informed consent was obtained from each participant, and the study was completed in accordance with the Helsinki Declaration. The Regional Committee for Medical



Ethics of Western Norway and Norwegian Social Science Data Services approved the study.

## Results

In total, 1016 individuals were invited to participate in the first study in 2008. 734 (72%) gave their consent to participate. A total of 506 people (69% of the 2008 survey) were enrolled in the second survey. Men accounted for 80% of the exposed workers in both surveys. The total number of exposed workers in the 2012 survey was 106, or 72% of those participating in 2008. They included 85 men and 21 women. In the control group, there were 55% and 53% men in the 2008 and the 2012 survey respectively. In 2012, 97 controls participated (71% of those in 2008), numbering 51 men and 46 women (Fig. 1). Exposed workers were slightly younger and included more daily smokers compared to the control group (Table 1).

Validity of the survey scales was good to excellent. Cronbach's alpha values for musculoskeletal complaints were 0.80 and 0.78 in the 2008 and 2012 surveys respectively. Equivalent values for subjective neurological symptoms were 0.73 and 0.69, for gastrointestinal complaints 0.66 and 0.69, for flu 0.73 and 0.70 and for the allergy subscale 0.47 and 0.54. For the total score of all 29 items, Cronbach's alpha was 0.86 in both surveys.

From 2008 to 2012 there were significant reductions in both the total SHC score ( $p < 0.01$ ) and in the subjective neurological ( $p < 0.001$ ) and the gastrointestinal subscale scores ( $p < 0.01$ ) among the exposed workers, but no significant changes in the controls, adjusted for gender, age, smoking habits, education level and proximity

to the explosion (Table 2). For the subjective neurological subscale there was a significant interaction between exposure group and time, indicating that the changes in scores from 2008 to 2012 were different between exposed and controls ( $p < 0.05$ ). No significant interaction between exposure group and time were found for the total SHC score and the gastro-intestinal subscale score (Table 2). Despite the significant reduction in subjective neurological subscale score among the exposed workers from 2008 to 2012, a significantly higher subscale score was seen in 2012 compared to controls (2.54 vs 1.62,  $p < 0.01$ ), adjusted for gender, age, smoking habits, education level and proximity to the explosion. For the total SHC score and the other subscale scores there were no significant differences between the exposed workers and the controls in 2012 (Table 2). Proximity to the explosion was not associated with the symptom scores among the exposed workers. Compared to controls, the exposed workers had significantly higher scores for the single items describing sleep problems and tiredness within the subjective neurological subscale ( $p < 0.05$  and  $p < 0.05$ , respectively) in 2012 (Fig. 2). Among the exposed workers, there were no significant differences in the crude subjective neurological subscale scores between men and women or between smokers and non-smokers in 2008. This was also seen in 2012 for gender, but smokers had significantly higher scores than non-smokers in this latter survey. Of the exposed workers, 6% reported that they had noticed a foul odour from the industrial area in 2012, compared to 56% in 2008.

## Discussion

Our study showed an overall decrease of complaints among the exposed workers over the follow-up period, a time period that included removal of the malodorous pollution from the area. No significant differences across the two periods were found

among controls. The exposed workers still reported significantly more subjective neurological symptoms than the controls. By use of a longitudinal design, we were able to follow the participants from before to after the removal of the malodorous pollution. Following the chemical explosion the exposed workers were exposed to sulphurous compounds, which produce a bad smell at very low concentrations [23-26]. Previous studies after an accidental leakage from a mercaptan storage facility showed an increased prevalence of both physical and psychological health complaints among a population who experienced long-term exposure to this spill [18]. These results are similar to the results of our study. Toxic effects of the pollutants were unlikely in this study, since such effects arise at significantly higher exposure levels [23-26] than the measurements performed in the area indicated [9-12, 15]. In the present study, the foul-smelling contamination was not removed from the area until two years after the accident. Five and a half years after the incident, 6% of the exposed workers still reported a foul odour from the industrial area.

The higher prevalence of subjective neurological complaints among the exposed workers is comparable to the results of a longitudinal study performed among residents in a community close to a petroleum refinery that implemented an odour-reduction plan during the study period [19]. The participants continued to report the same degree of symptoms caused both by stress-mediated mechanisms related to odour annoyance and by irritant mechanisms due to the chemical properties of the emissions, despite a substantial reduction of odorous emissions from the refinery [19]. The decline of complaints among exposed workers in our study is similar to results from population studies that examined prevalence and time course of subjective health complaints in survivors after an explosion in a firework depot in a

residential area in the Netherlands [8]. A gradual decrease of symptoms was found among the residents in the firework study [8]. No significant exposure to toxic substances was detected in the aftermath of the firework explosion, but even so the survivors reported significantly more symptoms than controls, both one and a half years and four years after the disaster [8].

Other strengths of this study include the high response rates, a control group from the same geographical area suggesting fewer cultural differences between the groups and a validated instrument to assess the subjective health complaints. By surveying complaints instead of diagnoses, we included possible health effects without clinical findings, which is of importance among participants expected to be relatively healthy. Moreover, by asking about symptoms experienced in the last 30 days, regardless of the accident, we attempted to reduce the possibility of introducing both a recall bias and a common-instrument bias. However, such biases could not be totally ruled out.

More health complaints among the exposed workers in this study might be related to the malodorous pollution or a perceived health risk. Previous epidemiological studies of physical health complaints after major disasters involving environmental exposures found that affected populations often relate their symptoms to the chemical exposure, even if such causal associations are unlikely [27]. A previous study among residents exposed to malodorous, non-toxic levels of emissions from a biofuel facility suggested that both symptoms and annoyance were mediated by perceived pollution and health risk perception; not by the pollution itself [20]. The term *bottom-up processing* of a stimulus is used to describe how the flow of information from the

environment to the brain is processed [28]. Its counterpart, *top-down processing*, which includes interpretation based on previous knowledge, expectations or beliefs [28] is particularly important in connection with odorous exposure [20].

In our regression models, proximity to the explosion of 1 km or less did not have any significant effect on subjective health complaints. Exposure to foul odour was apparently of more importance than being close to the accident for the degree of complaints in this study. This is comparable to results of studies after a fireworks disaster [16, 17]. In these studies disaster-related experiences such as injury or losing a home or a loved one were not found to be very strong risk factors for physical symptoms among survivors four years after the firework explosion [17]. However, among other factors sleeping problems were found to maintain physical complaints and mediated the relationship between traumatic stress and these complaints [17]. Within the first years after the firework disaster, residents who had been exposed to the most extreme disaster exposures, like losing their homes or a loved one, had an increased responsiveness to subsequent stressful events, compared to participants who reported less extreme disaster exposure [16]. Four years after the accident, however, there were no differences in stress responsiveness [16].

Five and a half years after an oil tank explosion involving a mixture of malodorous sulphurous compounds affected workers reported fewer subjective health complaints compared to one and a half years after the incident. As there were no other apparent changes than the removal of the foul-smelling contamination in their work environment, it is likely that the reduction of symptoms was due to the decreased

exposure to odorous pollutants or to time passed since the explosion. However, exposed workers still had more subjective neurological complaints, particularly tiredness and sleep problems, compared with the controls. We do not know why exposed workers still reported more such complaints than controls, but previous studies involving malodorous exposure at non-toxic exposure levels indicated that symptoms were mediated by perceived pollution and risk to health, not by the pollution itself [20]. In this study, population adaptation and anxiety might have resulted in a chronic effect manifested by a dysfunctional and persistent neuropsychological response. This should be considered in future studies.

### Key points:

- Subjective health complaints among workers exposed to a malodorous chemical explosion showed a downward trend during follow-up, but exposed workers still had more subjective neurological symptoms than controls after five years.
- The symptoms might be mediated by perceptions of pollution exposure and resulting health risk.
- Health personnel should be aware of the likely development of subjective health complaints after malodorous chemical incidents.

**Conflicts of interest:** None declared.

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**Table 1.** Descriptive data among workers studied one and a half and five and a half years after a malodorous chemical explosion

|   | 2008                                     |                                   | 2012                                     |                                  |
|---|--|-----------------------------------|--|----------------------------------|
|   | Exposed workers <sup>a</sup><br>n (=147) | Controls <sup>b</sup><br>n (=137) | Exposed workers <sup>a</sup><br>n (=106) | Controls <sup>b</sup><br>n (=97) |
| Gender                                  |  |                                   |  |                                  |
| Male n(%)                               | 117 (80)                                 | 75 (55)                           | 85 (80)                                  | 51 (53)                          |
| Female n(%)                             | 30 (20)                                  | 62 (45)                           | 21 (20)                                  | 46 (47)                          |
| Mean age (SD)                           | 43 (11)                                  | 46 (11)                           | 48 (10)                                  | 50 (11)                          |
| Daily smokers n(%)                      | 59 (40)                                  | 29 (21)                           | 35 (33)                                  | 17 (18)                          |
| Education level n(%)                    |  |                                   |  |                                  |
| 0 year after elementary school          | 15 (10)                                  | 9 (7)                             | 12 (11)                                  | 3 (3)                            |
| 1 to 3 years after elementary school    | 88 (60)                                  | 64 (47)                           | 65 (62)                                  | 48 (51)                          |
| 4 years or more after elementary school | 43 (29)                                  | 60 (44)                           | 28 (27)                                  | 44 (46)                          |
| Proximity to the explosion n(%)         |  |                                   |  |                                  |
| 1 km or closer to the explosion         | 73 (50)                                  | 1 (1)                             | 60 (57)                                  | 0 (0)                            |
| More than 1 km from the explosion       | 74 (50)                                  | 136 (99)                          | 46 (43)                                  | 97 (100)                         |

<sup>a</sup>Exposed workers defined as employees in the industrial area at the time of the explosion and/or clean-up workers (aged 18-67 in 2008).

<sup>b</sup>Controls defined as working inhabitants (aged 18-67 in 2008) living 20-30 km away from the explosion site, and who were neither employees in the industrial area nor clean-up workers.

**Table 2** Mean scores and adjusted differences in mean scores from the Subjective Health Complaints Inventory in exposed workers<sup>a</sup> and controls<sup>b</sup>

|   | 2008           | 2012           | Mean Difference :Time <sup>c</sup> | 95 % CI for mean difference | p-value | p-value for Group*Time interaction |
|---|----------------|----------------|------------------------------------|-----------------------------|---------|------------------------------------|
| <b>Total SHC Score</b>                    |                |                |                                    |                             |         |                                    |
| Exposed workers                           | 14.01          | 11.89          | -2.07                              | (-3.63, -0.52)              | <0.01   | NS                                 |
| Controls                                  | 9.88           | 8.85           | -0.61                              | (-2.23, 1.02)               | NS      |                                    |
| Mean Difference: Group (MDG) <sup>d</sup> | -4.07          | -2.60          |                                    |                             |         |                                    |
| 95% CI                                    | (-6.80, -1.34) | (-5.50, 0.30)  |                                    |                             |         |                                    |
| p-value                                   | <0.01          | NS             |                                    |                             |         |                                    |
| <b>Subjective neurological complaints</b> |                |                |                                    |                             |         |                                    |
| Exposed workers                           | 3.60           | 2.54           | -0.80                              | (-1.25, -0.36)              | <0.001  | <0.05                              |
| Controls                                  | 1.76           | 1.62           | -0.13                              | (-0.59, 0.33)               | NS      |                                    |
| MDG                                       | -1.86          | -1.19          |                                    |                             |         |                                    |
| 95% CI                                    | (-2.69,-1.04)  | (-2.03, -0.35) |                                    |                             |         |                                    |
| p-value                                   | <0.001         | <0.01          |                                    |                             |         |                                    |
| <b>Flu</b>                                |                |                |                                    |                             |         |                                    |
| Exposed workers                           | 1.53           | 1.42           | -0.16                              | (-0.50, 0.18)               | NS      | NS                                 |
| Controls                                  | 1.28           | 1.07           | -0.18                              | (-0.54, 0.18)               | NS      |                                    |
| MDG                                       | -0.06          | -0.04          |                                    |                             |         |                                    |
| 95% CI                                    | (-0.51, 0.40)  | (-0.54, 0.46)  |                                    |                             |         |                                    |
| p-value                                   | NS             | NS             |                                    |                             |         |                                    |
| <b>Musculo-skeletal complaints</b>        |                |                |                                    |                             |         |                                    |
| Exposed workers                           | 5.05           | 5.25           | 0.04                               | (-0.77, 0.84)               | NS      | NS                                 |
| Controls                                  | 4.01           | 4.22           | 0.38                               | (-0.46, 1.22)               | NS      |                                    |
| MDG                                       | -1.29          | -0.94          |                                    |                             |         |                                    |
| 95% CI                                    | (-2.51, -0.06) | (-2.32, 0.44)  |                                    |                             |         |                                    |
| p-value                                   | <0.05          | NS             |                                    |                             |         |                                    |

**Gastro-intestinal complaints**

|                 |               |               |       |                |       |    |
|-----------------|---------------|---------------|-------|----------------|-------|----|
| Exposed workers | 2.49          | 1.82          | -0.68 | (-1.18, -0.18) | <0.01 | NS |
| Controls        | 1.97          | 1.85          | -0.08 | (-0.60, 0.44)  | NS    |    |
| MDG             | -0.47         | 0.13          |       |                |       |    |
| 95% CI          | (-1.22, 0.28) | (-0.72, 0.99) |       |                |       |    |
| p-value         | NS            | NS            |       |                |       |    |

**Allergy**

|                 |                |               |       |               |    |    |
|-----------------|----------------|---------------|-------|---------------|----|----|
| Exposed workers | 1.36           | 1.21          | -0.09 | (-0.38, 0.20) | NS | NS |
| Controls        | 0.86           | 0.79          | -0.08 | (-0.38, 0.22) | NS |    |
| MDG             | -0.50          | -0.49         |       |               |    |    |
| 95% CI          | (-1.00, 0.007) | (-1.03, 0.05) |       |               |    |    |
| p-value         | NS             | NS            |       |               |    |    |

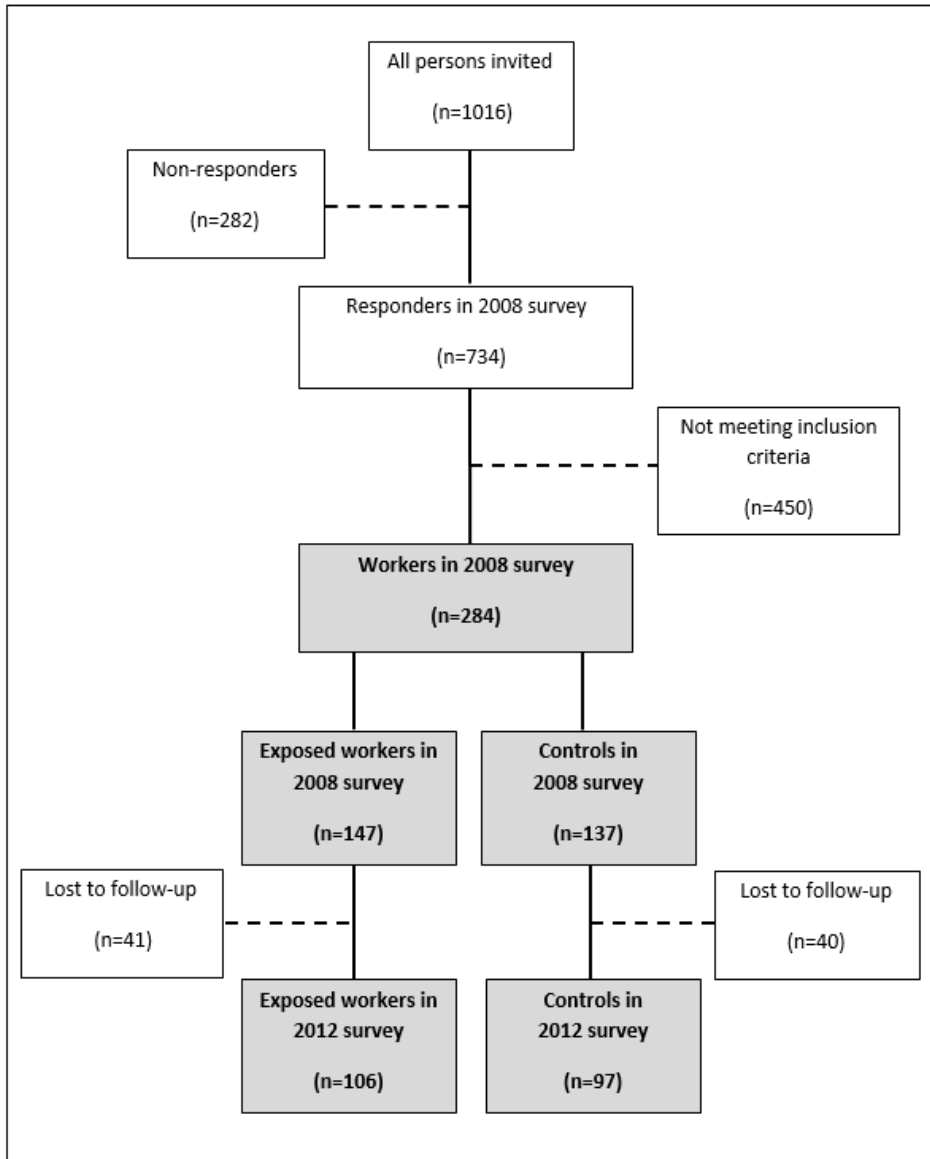
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<sup>a</sup>Exposed workers defined as employees in the industrial area at the time of the explosion and/or clean-up workers (aged 18-67 in 2008).

<sup>b</sup>Controls defined as working inhabitants (aged 18-67 in 2008) living 20-30 km from the explosion site, and who were neither employees in the industrial area nor clean-up workers.

<sup>c</sup>Mean difference in total SHC score and subscale scores within each exposure group from 2008 to 2012, adjusted for gender, age, smoking habits, education level and proximity to the explosion in a mixed effects model.

<sup>d</sup>Mean difference in total SHC score and subscale scores between exposed workers and controls in 2008 and 2012, adjusted for gender, age, smoking habits, education level and proximity to the explosion in a mixed effects model.



*Figure 1: The main study population and participants included in this study (shaded grey). Inclusion criteria: Employees in the industrial area at the time of the explosion and/or clean-up workers (aged 18-67 in 2008), defined as exposed workers. Controls defined as working inhabitants (aged 18-67 in 2008) living 20-30 km away from the explosion site and who were neither employees in the industrial area nor clean-up workers.*

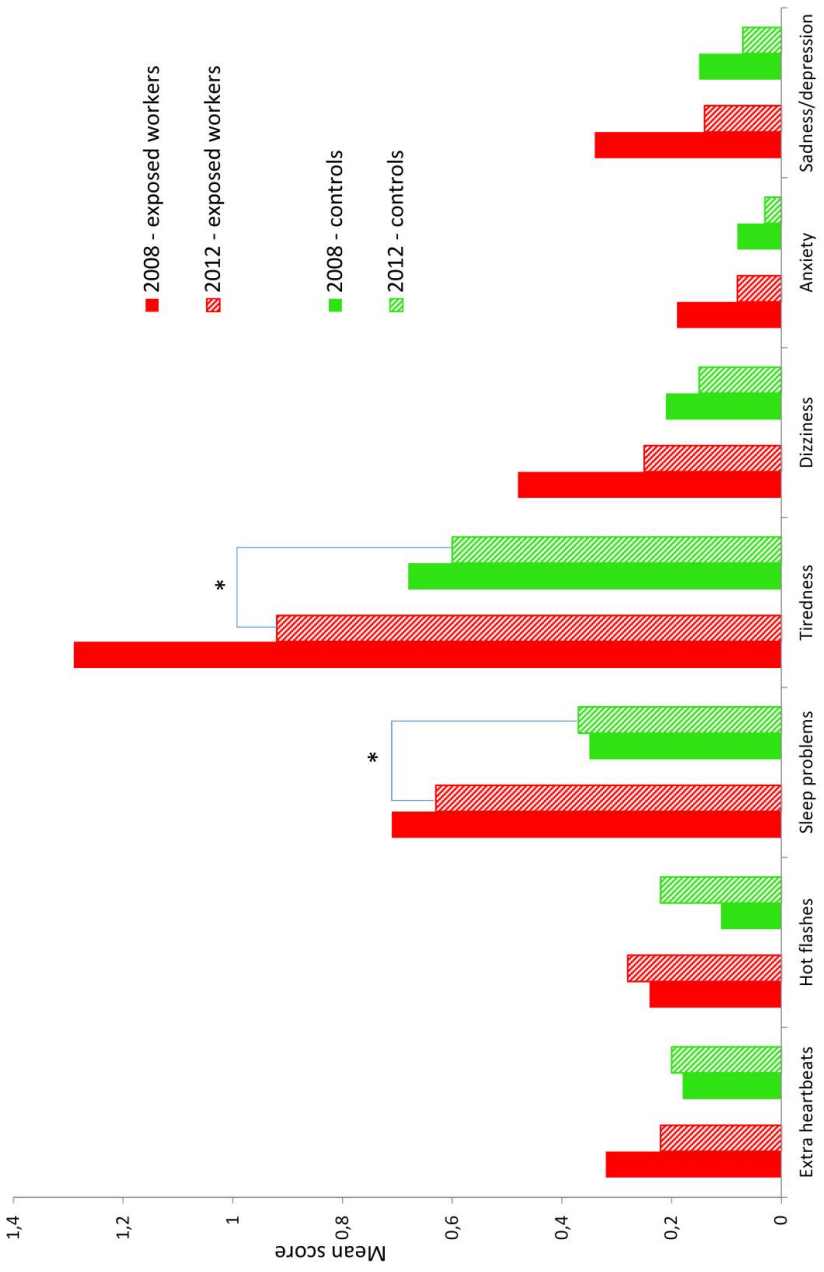


Figure 2: Mean scores for the single items within the subjective neurological subscale among exposed workers and controls in 2008 and 2012. Asterisk indicates a significant difference in score between exposed workers and controls in 2012 ( $P < 0.05$ ), adjusted for gender, age, smoking habits, proximity to the explosion and education level in a mixed effects model.