

Health in the aftermath of a malodorous chemical explosion

Subjective health complaints and post-traumatic stress
symptoms among workers

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I dedicate this thesis to my dear father, Karl-Olav Tjalvin; who always encouraged me to attain my goals, and never failed to support me along the way.

Scientific environment

This research project was carried out at the Research Group for Occupational and Environmental Medicine, Department of Global Public Health and Primary Care, Faculty of Medicine, University of Bergen, Norway, and Haukeland University Hospital, Department of Occupational Medicine, Bergen, Norway. The study was funded by the Ministry of Health and Care Services, Norway, and Haukeland University Hospital, Bergen, Norway. My doctoral work was financed by a scholarship granted by University of Bergen.

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Abbreviations

ATD/GC/MS	Automated thermal desorption, gas chromatographic separation and mass spectrometric detection
DSM-IV	Diagnostic and Statistical Manual of Mental Disorders, 4th Edition
HCl	Hydrochloric acid
HPLC/UV	High performance liquid chromatography with UV-detection
H ₂ S	Hydrogen sulphide
IES-R	Impact of Event Scale-Revised
LOD	Limit of detection
NaOH	Sodium hydroxide, caustic soda
PET	Positron emission tomography
ppm	Parts per million
PTSD	Post-traumatic stress disorder
PTSS	Post-traumatic stress symptoms
TVOC	Total volatile organic compounds
SEM	Standard error of the mean
SHC	Subjective health complaints <u>or</u> the Subjective Health Complaints Inventory
SO ₂	Sulphur dioxide
VOC	Volatile organic compound

Abstract

Background

A chemical explosion in an oil tank took place in an industrial harbour area in Norway, in May 2007. Nobody was killed in the accident, but a malodorous environmental pollution was emitted, and spread in the vicinity. The foul-smelling pollution mainly comprised of mercaptans and other sulphurous compounds, which have very low odour thresholds compared to their hazardous thresholds. The clean-up operation started the following day, but was not completed until February 2010. Meanwhile the unpleasant smell was continuously present in the area.

Aims

The main aim of this thesis was to study long-term health effects among workers in the aftermath of a chemical explosion that emitted malodorous sulphurous compounds.

The first objective was to assess whether employees in the industrial area and clean-up workers had more subjective health complaints than controls one and a half years after the oil tank explosion. The second objective was to assess whether the subjective health complaints in this group declined over a four-year period following the explosion. The third objective was to investigate whether perceived smell related to the malodorous environmental pollution was a determinant of subjective health complaints and post-traumatic stress symptoms among employed adults, when the malodorous pollution was present at the explosion site, and after pollution clean-up.

Material and methods

One and a half years after the accident, all residents living within six km to the explosion site and the whole population working in the industrial harbor area or participating in the firefighting or clean-up operation were invited to participate in a health survey including a questionnaire and a clinical examination. Inhabitants, matched by gender and age to the working population and the residents, and living

20-30 km away from the explosion site, were invited as controls. Of the total 1016 persons who were invited, 734 persons decided to participate (response rate 72 %). This thesis is based on sub-populations from this study.

From the main cohort, the employees in the industrial area, the clean-up workers and controls were included in a cross sectional study using the Subjective Health Complaints Inventory (SHC) in 2008. Similar data were obtained in 2012, and were analysed by a linear mixed effects model in a longitudinal study.

Next, all employed adults from the main cohort were divided into high and low odour score groups based on an individual odour score that was computed as the percentage of months each participant had noticed the specific incident-related odour.

Questionnaire data from the Subjective Health Complaints Inventory (SHC) and the Impact of Event Scale-Revised (IES-R), both validated instruments, were analysed using a mixed effects model in a longitudinal study involving data from when the malodorous pollution was present until three years after pollution clean-up (2008, 2010 and 2012, respectively).

Results

Employees in the industrial area and clean-up workers reported significantly more subjective health complaints, particularly neurological symptoms, compared to controls in 2008. In the longitudinal study, subjective health complaints among employees in the industrial area and clean-up workers declined over a four-year period following the explosion, but these workers still had significantly more neurological symptoms compared with controls in 2012. For the controls there were no significant changes.

In the study based on perceived smell, employed adults in the high odour score group reported more subjective health complaints and post-traumatic stress symptoms than those in the low odour score group, even after the pollution was eliminated.

Conclusion

This study showed a higher prevalence of health complaints such as sadness/depression, headache, sleep problems and tiredness among employees in the industrial area and clean-up workers, compared to controls who lived more than 20 kilometres away from the explosion site. A reduction of these complaints during the study period could be attributable to reduced exposure to the foul-smelling pollutants, the course of time since the accident, or both.

Additional assessments concluded that perception of the incident-related odour was a determinant of subjective health complaints as well as post-traumatic stress symptoms. These associations persisted for three years after the malodorous environmental pollution was removed from the area. This might indicate that early clean-up is of importance in order to avoid lasting health effects following malodorous chemical spills.

The findings of this doctoral work indicate that health complaints might be related to malodorous environmental pollution even if exposure levels are considered as low compared to occupational exposure limits.

List of publications

Paper I

Tjalvin G, Hollund BE, Lygre SH, Moen BE, Bråtveit M:

Subjective Health Complaints among Workers in the Aftermath of an Oil Tank Explosion.

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Contents

SCIENTIFIC ENVIRONMENT	4
ACKNOWLEDGEMENTS	5
ABBREVIATIONS	7
ABSTRACT	8
LIST OF PUBLICATIONS	11
CONTENTS	12
1. INTRODUCTION	15
1.1 INDUSTRIAL DISASTERS INVOLVING ENVIRONMENTAL POLLUTION	15
1.2 THE SLOVÁG INCIDENT	15
1.3 ACUTE HEALTH COMPLAINTS AMONG THE POPULATION.....	16
1.4 COURSE OF EVENTS THAT LED TO THE ACCIDENT	17
1.5 THE CLEAN-UP OPERATION.....	20
1.6 EXPOSURE.....	22
1.6.1 <i>Tank contents before the explosion</i>	22
1.6.2 <i>Air measurements after the accident</i>	23
1.7 HEALTH EFFECTS FROM HYDROGEN SULPHIDE, MERCAPTANS AND SULPHUR DIOXIDE	26
1.8 HEALTH EFFECTS FROM VOLATILE ORGANIC COMPOUNDS	29
1.9 MEDIA COVERAGE AND LEGAL ACTIONS	29
1.10 PREVIOUS STUDIES.....	30
1.10.1 <i>Chemical explosions and fires, and major oil spills</i>	31
1.10.2 <i>Industries emitting malodorous pollution, and malodorous chemical spills</i>	33
1.10.3 <i>Studies investigating odour-related mechanisms, and case reports</i>	37

2	AIMS OF THE STUDIES.....	40
3	MATERIALS AND METHODS.....	41
3.1	STUDIES IN THE DOCTORAL THESIS	44
3.1.1	<i>Studies based on proximity to the explosion site.....</i>	<i>44</i>
3.1.2	<i>Study based on perceived smell.....</i>	<i>49</i>
3.2	ETHICS	55
4	SUMMARY OF RESULTS.....	56
4.1	STUDIES BASED ON PROXIMITY TO THE EXPLOSION SITE	56
4.2	STUDY BASED ON PERCEIVED SMELL.....	58
5	DISCUSSION.....	61
5.1	MAIN FINDINGS.....	61
5.1.1	<i>Studies based on proximity to the explosion site.....</i>	<i>61</i>
5.1.2	<i>Study based on perceived smell.....</i>	<i>61</i>
5.2	DISCUSSION OF RESULTS	61
5.2.1	<i>Comparison with previous studies including accidents</i>	<i>61</i>
5.2.2	<i>Comparison with previous studies including odour.....</i>	<i>62</i>
5.2.3	<i>Possible mechanisms for health complaints.....</i>	<i>64</i>
5.3	METHODOLOGICAL CONSIDERATIONS	70
5.3.1	<i>Study design</i>	<i>70</i>
5.3.2	<i>Internal validity.....</i>	<i>71</i>
5.3.3	<i>External validity.....</i>	<i>80</i>
6	CONCLUSIONS AND RECOMMENDATIONS.....	81
7	REFERENCES	84

PUBLISHED PAPERS

Paper I: Subjective Health Complaints among Workers in the Aftermath of an Oil Tank Explosion.

Paper II: Health complaints after a malodorous chemical explosion: a longitudinal study.

Paper III: Odour as a determinant of persistent symptoms after a chemical explosion, a longitudinal study.

LETTERS AND QUESTIONNAIRES

APPENDIX I: Invitation letter 2008

APPENDIX II: Informed consent form

APPENDIX III: Questionnaire 2008 survey

APPENDIX IV: Questionnaire 2012 survey

1. Introduction

1.1 Industrial disasters involving environmental pollution

Industrial disasters involving environmental pollution may cause a lot of human suffering, including loss of lives [4-7]. Populations affected by an industrial disaster commonly report acute accident-related physical as well as psychological symptoms [4-10], but less is known about the long-term effects [4-7, 11-13].

1.2 The Sløvåg incident



Figure 1: Photo taken from a helicopter approximately 45 minutes after the first explosion of the Sløvåg disaster. Photo: Lasse Fossedal, Norsk Luftambulanse [The Norwegian Air Ambulance].

On 24 May 2007, at about 10 am, an oil tank in an industrial area on the western coast of Norway (Figures 1 and 2) exploded and started an extensive fire. A second and a third tank exploded shortly after. Big metal pieces were hurled through the air; some pieces landing several hundred meters away, and the burning petroleum products caused an extensive fire that emitted black smoke and a sulphurous, malodorous pollution. Despite the fact that some workers were very close to the exploding tanks, they suffered only minor physical injuries, and there were no casualties.



Figure 2: Sløvåg, indicated by the red marker, is a small community on the western coast of Norway.

1.3 Acute health complaints among the population

Shortly after the explosion, workers in the industrial area and residents living close by experienced different health complaints, which they reported to their local health care services. In June-July 2007, two local general physicians conducted a health survey based on unvalidated questionnaires, and found that about 60 % of the general adult population, and nearly 80 % of the employees in the industrial area, had health complaints after the accident. Cough, headache, sleep problems, sore throat, irritated

or sore eyes, and nausea were the most prevalent symptoms reported among both workers and residents [14]. A follow-up was conducted about 9 months later, in March 2008. At that time, about 70 % of the employees in the industrial area, and dependent on distance of residency from the industrial site, 10-40 % of the general population still reported health complaints [14].

The high prevalence of health complaints gave rise to concern, and as a consequence, the Norwegian Directorate of Health and the Ministry of the Environment decided to implement a health examination to assess possible long-term health effects among the affected population. In July 2008, Department of Occupational Medicine, Haukeland University Hospital in Bergen, Norway, was given a mandate to plan and conduct the health survey in co-operation with the University of Bergen [15]. The study was funded by the Norwegian Ministry of Health and Care Services, and Haukeland University Hospital.

The present doctoral thesis is based upon results from this study.

1.4 Course of events that led to the accident

The normal activity of the oil tank company in Sløvåg industrial area was to treat oil containing wash water and slop water from the shipping and offshore industry. Slop water is a variable mixture of water containing oil- or water-based drilling mud, soap and pipe dope from cleaning of drill pipes, and hydraulic oil from leakages and different residual chemicals from the mud room on offshore drilling installations. Wash water from cleaning of tanks from tankers carrying different petroleum products is also called slop water. After treatment, the water was released to the sea according to a discharge permit from the Norwegian Pollution Control Authorities [16-18].

Approximately eight months before the accident, the tank company received 6-7 tank loads of coker gasoline for treatment, in total, approximately 192 000 m³ [16]. The

company had not reported this part of their activity to the Norwegian Pollution Control Authorities [18].

Coker gasoline is produced by distillation of the residual product after the initial distillation of crude oil. The coker gasoline that was shipped to Sløvåg was based on Mexican crude oil, which is known to be one of the world's most sulphurous oils [19]. Hence, the coker gasoline that was shipped to Sløvåg for further treatment, had a very high sulphur content [16, 19].

Coker gasoline was pumped onshore from the tank ships. In the onshore tanks, coker gasoline was mixed with an alkaline aqueous solution of caustic soda (30 % NaOH). In the refining process, polar sulphurous compounds like mercaptans dissolved more readily in the aqueous NaOH solution than in the less polar solution of coker gasoline. After initial mixing, the two phases were left to separate into the denser NaOH solution containing dissolved mercaptans and precipitated sludge in the bottom layer with the treated coker gasoline layer on top. This process, called "sweetening", took about 5-7 days to complete, and the coker gasoline, now with considerably lower sulphur content, was pumped back on board the tank ships for export (Figure 3).

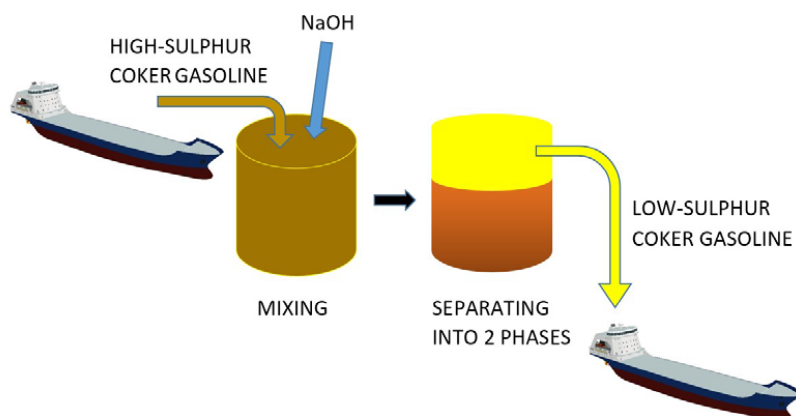


Figure 3: The sweetening procedure of high-sulphur coker gasoline into low-sulphur gasoline.

Eventually the accumulated solid sulphurous waste piled up in the onshore tanks, theoretically, to a total of 210 metric tons [16]. The company had to come up with a solution on how to get rid of the waste in order to continue the treatment of new tank loads of coker gasoline. A small-scale pilot project, in which the solid waste was dissolved by hydrochloric acid and water, was conducted. Despite gas generation and formation of a thin layer of an oily liquid on the surface of the solution, the pilot project was considered successful, and the same procedure was performed in large-scale, starting about 18 hours prior to the explosion [16].



Figure 4: The accident caused severe damage in the industrial area, and the tank truck that delivered the hydrochloric acid was completely destroyed in the subsequent fire. Photo taken approximately six hours after the first explosion. Photo: Karl Otto Nesdal, Bergen brannvesen [Bergen Fire Department].

Investigations after the accident have revealed that the accident probably was caused by self-ignition of a flammable mixture of gases or vapors that were released from the solution during the dissolving process. The mixture of vapors and gases gradually filled the free space in the tank, and eventually reached the activated carbon filter at the tank top. Adsorption of mercaptans and other hydrocarbons by the activated carbon granules resulted in self-ignition of the flammable mixture, and led to the first explosion (T3, Figure 7). Two tanks (T4 and C1, Figure 7) exploded shortly after,

and in the subsequent fire two more tanks, an office building and three tank trucks were destroyed [16] (Figures 4 and 5).

1.5 The clean-up operation

Trained fire fighters extinguished the fire during the afternoon of the accident. The fire fighters, including smoke and chemical divers wore proper personal protective equipment during their operation. Employees from different companies in the industrial area and professional clean-up workers from specialized external companies participated in the clean-up operation, which started the day after the accident. The employees of the tank company wore personal protective equipment during the initial phase of clean-up, but some of the other participants did not [20].



Figure 5: The land around the explosion site was partly covered with the sulphurous waste from the destroyed tanks. Photo taken before start of the clean-up operation. Photo: Glenn Rogers, M/T Karen Knutsen, Knutsen OAS Shipping.

Polluted soil was removed from the area during clean-up (Figure 5). The digging was done by hand, by excavators and mechanical shovels. The work was tedious, as some

of the polluted soil was found in small areas, up to a few kilometres from the explosion site. The solid waste was kept in containers and big bags (Figure 6).

The liquid waste and water from the fire extinction were mainly sucked into big mobile suction units, but about 300 million liters of fire water from the fire extinction was drained, without rinsing, to the sea [17]. Following collection, the liquid waste was partly pumped onboard tankers for export from the industrial quay or transported by the suction trucks to Norwegian disposal sites for hazardous waste. The last remnants, consisting of 5 300 m³ of liquid waste, were pumped onboard a tanker and exported for destruction by a specialized German company in February 2010 [21].

The clean-up operation also included transportation of solid waste and equipment used during fire extinction and clean-up, and even cleaning of vehicles and different equipment used in the clean-up operation.



Figure 6: Large amounts of malodorous solid waste were stored in big bags in the harbor area for a long time. Photo: Bent Are Iversen, Firda.

Until permissions were given for the waste to be exported abroad for destruction, large amounts of malodorous waste were stored big bags (Figure 6) and in tanks (Figure 7, tanks A and B) in the industrial harbour area for more than two years. Meanwhile the intensity of the foul odour fluctuated due to meteorological conditions such as wind direction and velocity, and temperature [15, 17, 20].

1.6 Exposure

1.6.1 Tank contents before the explosion



Figure 7: Manipulated satellite photo of the tank area. The three tanks that exploded in the accident, tanks T3, T4 and C1, are indicated. Sampling points for air measurements in 2007 (red arrows) and in 2008 (A and B) are also indicated. Satellite photo: Google Maps.

Three tanks exploded in the accident; T3, T4 and C1 (Figure 7).

T3 contained approximately 50 m³ solid sulphurous waste from the sweetening process of coker gasoline, 205 m³ water and 14-15 m³ hydrochloric acid [16].

T4 contained approximately 350 m³ sodium hydroxide solution containing dissolved mercaptans and precipitated sludge from the bottom layer in the sweetening process, including a combustible fraction [16].

C1 contained approximately 60 m³ liquid waste from the treatment of coker gasoline [16].

1.6.2 Air measurements after the accident

After the explosion, the Norwegian Pollution Control Authority requested chemical analyses of waste/sludge from the tank yard where the explosion took place. These samples contained a number of organic sulphur compounds, such as mercaptans and disulphides, but also phenols and different hydrocarbons. The smell from the samples was characterised as “sulphurous” [17]. During the investigation, a small scale reconstruction test of the chemical process before the explosion was performed, and extreme concentrations of mercaptans were measured following the mixture of hydrochloric acid and the bottom layer in the sweetening process (Figure 3) [15].



Figure 8: Map showing the industrial area with the explosion site (yellow star) and the residential area where samples were taken (red circle) 2-3 weeks after the accident. The wind direction during sampling is indicated by a white arrow. Satellite photo: Google Maps.

Shortly after the explosion, no efforts were made to analyse the air pollution. Three weeks after the explosion, mercaptans at low levels, but well above the odour thresholds, were measured in air samples taken from different locations at the explosion site (Figure 7 and Table 1) [22]. Low levels of volatile organic compounds (VOCs) were also detected 2-3 weeks after the explosion (TVOC: 0.7-3.2 mg/m³)

[22]. Likewise, air measurements were performed in a residential area, 2.8 kilometre from the explosion site, where the residents had complained about extremely foul odour (Figure 8). Both mercaptans and VOCs were below the detection limits for the respective laboratory methods (HPLC/UV and ATD/GC/MS) in these samples, but during sampling the wind direction was not towards this residential area. It should even be noted that the odour detection threshold for the different mercaptans are much lower than their respective detection limits.

Samples to be analysed for hydrogen sulphide were collected three weeks after the explosion, but due to an incorrect procedure at the laboratory, these samples could not be analysed (Table 1) [22].

Eighteen months after the incident, air samples were collected on the top of two tanks (Tank A and B, respectively) at the explosion site (Figure 7). Tank A contained a mixture of waste oil and a smaller volume of waste water from the “sweetening” process of coker gasoline (less than 60 m³) [16]. This waste water was assumed to have a high content of mercaptans because mercaptans are relatively polar compounds, and hence readily soluble in water. Tank B contained slop water from offshore oil producing rigs or oil tankers and water from the fire extinction [16, 23]. The fire water was assumed to contain a mixture of waste from the exploded tanks.

The rationale to take samples immediately above these two tanks was to measure pollutants in air, in a setting comparable to conditions on the site after the explosion when tank contents were spread in the area. Hydrogen sulphide as well as mercaptans and sulphur dioxide were detected in the samples (Table 1) [23]. For hydrogen sulphide, the filters above Tank A were overloaded. Different kinds of mercaptans, well above their respective odour thresholds (Table 2), were measured above both tanks. Accordingly, it is reasonable that the population in the vicinity of the industrial area could smell the malodorous pollution of sulphurous compounds in the aftermath of the accident.

Table 1: Mean values of sulphur dioxide (SO₂), hydrogen sulphide (H₂S) and mercaptans measured in air 3 weeks and 18 months after the explosion.

Time after explosion	Sample location ^a	SO ₂ ^b (ppm)	H ₂ S ^c (ppm)	Methyl mercaptan ^d (ppm)	Ethyl mercaptan ^d (ppm)	Propyl mercaptan ^d (ppm)	Butyl mercaptan ^d (ppm)
3 weeks (n ^e =2)	At explosion site	Not sampled	Analysis error	0.0056	0.055	0.0084	<LOD
3 weeks (n ^e =1)	2.8 km away from explosion site	Not sampled	Analysis error	<LOD	<LOD	<LOD	<LOD
18 months (n ^e =6)	At top of tank A ^f (at explosion site)	0.025	Filter overload	<LOD	0.77	0.083	0.013
18 months (n ^e =6)	At top of tank B ^g (at explosion site)	<LOD	0.035	0.31	1.11	0.032	<LOD

^aSampling points are indicated on Figures 7 and 8.

^bSO₂ was collected on filters pre-coated with potassium hydroxide/glycerol and analyzed by ionic chromatographic separation.

^cH₂S was collected on filters pre-coated with cadmium acetate and analyzed by spectrophotometry.

^dMercaptans were collected on bottles containing 5,5 dithio-bis-(2-nitro)-benzoic acid and analyzed by high performance liquid chromatography with UV-detection (HPLC/UV). Estimated mean values presented according to previous recommendation [24].

^eNumber of samples.

^fTank A contained a mixture of waste oil and waste water from the “sweetening” process of coker gasoline.

^gTank B contained slop water from offshore oil producing rigs and oil tankers, and water after the fire extinction.

LOD: Limit of detection.

1.7 Health effects from hydrogen sulphide, mercaptans and sulphur dioxide

Perception of odours is of vital importance for our ability to detect malodorous pollutants that can be potentially hazardous [25]. The perception of chemical exposure by the nose is mediated by both the olfactory nerve (first cranial nerve) and the trigeminal nerve (fifth cranial nerve). The olfactory nerve mediates the sensation of odours, such as, for instance, fruity, floral, faecal or rotten smell, whereas the trigeminal nerve mediates burning, stinging, tingling and painful sensations. Different chemicals have different odorant and irritant potencies [25, 26], but the way a chemical exposure is perceived, is also dependent upon how the stimulus is processed by the brain [27].

The sulphurous compounds hydrogen sulphide and mercaptans, are very potent odorants, but weak irritants. Therefore, an offensive smell is the first sensation of such sulphurous compounds at low exposure levels. Typically their irritation thresholds are 1000 – 10 000 times higher than the corresponding odour thresholds (Table 2), and hence irritant symptoms are initiated at much higher exposure levels [28]. In general, perceived exposure to malodorous sulphurous compounds has been associated with both physical and psychological health complaints [29, 30].

Table 2: Reported smell and odour thresholds for some sulphurous compounds.

Sulphurous compound	Smell	Odour threshold (ppm)
Hydrogen sulphide	Rotten eggs	0.0002-0.3
Methyl mercaptan	Rotten cabbage	0.00001-0.0004
Ethyl mercaptan	Offensive garlic or leek-like	0.0001
Propyl mercaptan	Cabbage-like	0.00075-0.0016
Butyl mercaptan	Garlic, skunk secretion	0.0001-0.001
Sulphur dioxide	Pungent	0.5-5

Hydrogen sulphide

Hydrogen sulphide (H₂S) is a highly flammable, explosive and colourless gas that smells like rotten eggs. The gas results from bacterial decay of organic matter, and

occurs naturally in crude oil, petroleum products and natural gas. The odour threshold ranges from 0.0002 to 0.3 ppm [31]. At higher exposure levels, in particular following peak exposures, hydrogen sulphide is extremely toxic (Table 3), and is the second most common cause of fatal occupational accidents due to gas inhalation [32]. To avoid odour annoyance, the World Health Organization (WHO) has proposed that hydrogen sulphide concentrations in ambient air should not exceed 0.005 ppm [33].

Table 3: Health effects of hydrogen sulphide at different exposure levels.

Exposure level	Acute symptoms/health effects
0.0002-0.3 ppm	Odour threshold.
1-5 ppm	Malodorous smell of rotten eggs. Nausea. Headaches. Tearing of the eyes. Sleep problems (if prolonged exposure). Bronchial constriction in some asthma patients.
20-50 ppm	Fatigue. Loss of appetite. Irritability. Poor memory. Dizziness. Eye and lung irritation. Cough.
150-200 ppm	Odour disappears due to olfactory fatigue or paralysis.
250-500 ppm	Pulmonary oedema.
500-2000 ppm	Sudden unconsciousness. "Knockdown". Post-exposure amnesia. Respiratory paralysis. Anoxia. Death.

Mercaptans

Mercaptans are organic sulphur compounds composed of an alkyl or aryl group and a thiol group [34].

Generally, human health effects due to mercaptan exposure are not very well studied. Most studies are case reports based on very few observations in the aftermath of accidental exposure, published in the 1960ies -1980ies, and in most cases the exposure levels were unknown [35-38].

The following mercaptans were detected at low levels in air samples 3 weeks and 18 months after the explosion: methyl, ethyl, propyl and butyl mercaptan, respectively (Table 1).

Methyl mercaptan (CH₄S) is a colourless, flammable gas with a strong odour of rotten cabbage (Table 2) [34, 35, 38]. Exposure to methyl mercaptan has been associated with eye and mucous membrane irritation, dizziness, nausea, vomiting,

and central nervous system depression [34, 38], but due to the offensive odour at very low exposure levels, humans are seldom exposed to hazardous levels [35].

Ethyl mercaptan (C_2H_6S) is a colourless, flammable liquid with one of the most penetrating foul odours known. It has a persistent offensive garlic or leek-like smell (Table 2) [37]. Exposure to ethyl mercaptan at levels of about 4 ppm has been associated with nausea, irritation of mucous membranes and fatigue, but no signs or symptoms were reported at 0.4 ppm [34, 37]. The central nervous system is affected at exposure levels above 100 ppm [34].

Propyl mercaptan (C_3H_8S) is a colourless, flammable liquid with an offensive, cabbage or onion-like smell (Table 2). No human health effects have been reported at exposure levels of 0.5 ppm [39].

Butyl mercaptan ($C_4H_{10}S$) is a colourless, flammable liquid with a strong, obnoxious smell of garlic (Table 2). The compound has a potential for mucous membrane irritation. Exposures to relatively high levels (50-500 ppm) has been associated with acute symptoms from the central nervous system, such as muscular weakness, malaise and headache, sweating, nausea and vomiting [36].

Sulphur dioxide

Sulphur dioxide (SO_2) is a colourless, non-flammable gas or liquid with a pungent, penetrating smell. The odour threshold is reported to be in the range 0.5-5 ppm, whereas the irritation threshold is 2 ppm [40] (Table 2). The irritating effect results from sulphuric acid, which is formed when sulphur dioxide dissolves on the mucous membranes. Exposure to sulphur dioxide is associated with cough, sore throat, tearing of the eyes, burning nose, eyes and throat, substernal pain and dyspnoea, with asthmatics being more likely to develop broncho-constriction than those without asthma [40].

1.8 Health effects from volatile organic compounds

Volatile organic compounds

A volatile organic compound (VOC) can be defined as any organic compound with a boiling point in the range from approximately 50°C to 250 °C, measured at a standard atmospheric pressure of 101.3 kPa [41]. N-octane, n-nonane and diethyl disulphide were among VOCs that were detected at low levels in air samples 2-3 weeks after the explosion [22].

Due to their relatively low boiling points VOCs have high vapour pressures at room temperature. As a consequence these compounds easily evaporate from their liquid to their gaseous forms, and can cause health effects when inhaled by exposed individuals.

Dependent on the level, acute exposure to different VOCs is associated with mucous membrane irritation, including irritation of eyes, nose and throat, and dizziness. Chronic exposure is associated with vomiting, diarrhoea, insomnia, headache, dizziness, muscle and different neurological symptoms [42, 43].

1.9 Media coverage and legal actions

The accident was initially extensively covered in Norwegian media, including news reports on national television and radio, in local and national newspapers, and on the internet. Even later on, when the population started to report different health complaints, as well as when it became evident that the accident was caused by illegal activity performed by the tank company, the incident received considerable media coverage [44-46] (Figure 9). The extensive and lengthy media coverage emphasizing the possibility of hazardous health effects from the pollution might be a reason that it took so long before permissions were given for the waste to be exported abroad for destruction.



Figure 9: Facsimiles from Norwegian newspapers.

In 2009, the manager of the tank company and the chairman of the board were prosecuted under the Pollution Control Act [47], the Working Environment Act [48], and the Act relating to the prevention of fire, explosion and accidents involving hazardous substances and the fire services [49]. In 2013, they were both found guilty as charged, and convicted by the Norwegian Supreme Court to prison for two years and two years and five months, respectively, the maximum sentence for environmental crime in Norway [50, 51]. The chemical engineer (consultant) was charged under the Pollution Control Act [47], found guilty and sentenced to three months' imprisonment [50, 52]. The law suit and the convictions were also reported in the media [53].

1.10 Previous studies

Previous studies of relevance for this doctoral thesis are studies of human health effects in the aftermath of major accidents including chemical explosions and fires,

oil spills and malodorous chemical emissions. Studies of possible mechanisms for odour-related health complaints among humans, who are exposed to malodorous emissions at non-toxic levels, are also of relevance (Tables 4, 5 and 6).

1.10.1 Chemical explosions and fires, and major oil spills

Studies in the aftermath of chemical explosions and fires have shown high prevalence of physical and psychological health complaints shortly after the accident [8-13, 54], mostly diminishing with time [12, 13], but in some cases lasting symptoms are found [11-13] (Table 4).

Few have studied human health effects in the aftermath of major oil spills. Most studies were cross sectional, making assessment over time impossible. Relevant studies indicated high levels of event-related psychological stress and acute physical symptoms [4, 55, 56] that decreased with time [4, 56], and were mainly reversible [4] (Table 4).

Table 4: An overview of relevant previous studies; chemical explosions and fires, and major oil spills.

Accident (year)	Aim	Design/participants	Results/conclusion	Ref. (year)
Fire in agrochemical storehouse. Switzerland (1986). Foul smelling cloud. Health authorities assured about no health hazard.	To assess the impact of fire on health.	Cross sectional, 0-6 weeks after accident. Families already in respiratory study (n=843), general adult population (n=400).	Those who smelled the fire experienced more symptoms compared to those who did not.	[8] (1992)
Explosion in fireworks factory. Denmark (2004). 1 killed. Few injured.	To examine psychological consequences of the accident.	Cross sectional, 3 months after explosion. Residents (n _{exp} =516, n _{contr} =119).	High levels of post-traumatic stress among residents affected by the explosion.	[54] (2007)
Explosion in fireworks factory. Denmark (2004). 1 killed. 6 injured.	To investigate the predictive effect of potential risk factors for somatization in trauma survivors.	Longitudinal, 3 months and 1 year later.	Somatization was predicted by negative affectivity and feelings of incompetence.	[57] (2009)

Table 4, continued: An overview of relevant previous studies; chemical explosions and fires, and major oil spills.

Accident (year)	Aim	Design/participants	Results/conclusion	Ref. (year)
Explosion in fireworks storage. The Netherlands (2000). 23 killed, >900 injured.	To examine psychological, musculoskeletal and respiratory symptoms and sickness absence before and after the explosion.	Longitudinal, 6 months pre disaster until 2 years post disaster. Rescue workers, municipal personnel, clean-up workers. (n _{tot} =1036).	Lasting high prevalence of psychological, musculoskeletal and respiratory symptoms post disaster. Increased number of sick days post disaster.	[11] (2004)
Explosion in fireworks storage. The Netherlands (2000). 23 killed, >900 injured. No toxic exposures assumed.	To assess self-reported physical and psychological health among the affected population.	Cross sectional, 2-3 weeks after accident. Residents, rescue workers and by-passers. (n _{tot} =3792).	High prevalence of physical and psychological health complaints 2-3 weeks after the accident; highest among residents and by-passers.	[10] (2005)
Explosion in fireworks storage. The Netherlands (2000). 23 killed, >900 injured.	To assess prevalence and course of physical complaints among survivors post disaster.	Longitudinal, 3 weeks, 18 months, 4 years post disaster. Survivors (n _{surv} =815, n _{contr} =821).	Gradual decrease of physical complaints among survivors, but still more symptoms up to 4 years post disaster.	[13] (2005)
Explosion in fireworks storage. The Netherlands (2000). 23 killed, >900 injured.	To investigate the health status among the affected population 18 months post disaster and possible change from 2-3 weeks post disaster.	Longitudinal, 2-3 weeks and 18 months post disaster. Residents (n _{exp} =891, n _{contr} =700).	Physical and mental health complaints decreased, but affected residents still reported 2-3 times more health complaints compared to controls.	[12] (2007)
Explosion in fireworks storage. The Netherlands (2000). 23 killed, >900 injured.	To examine if degree of disaster exposure was a risk factor for PTSS.	Longitudinal, 3 weeks, 18 months, 4 and 10 years post disaster. Residents (n _{tot} =1567).	Disaster exposure was a risk factor for PTSS 4 years, but not 10 years post disaster. Previous psychological problems were strong predictors of PTSS.	[58] (2012)
Explosion and fire in fuel depot. UK (2005). No fatalities, few injuries.	To assess health complaints among workers occupationally deployed to the fire.	Cross sectional, 2 months after accident. Fire fighters, rescue personnel, police, clean-up workers. (n _{exp} =815, n _{contr} =413).	More acute symptoms among deployed in the burn phase. Symptoms prevalence similar to general population in post-burn phase.	[9] (2008)

Table 4, continued: An overview of relevant previous studies; chemical explosions and fires, and major oil spills.

Accident (year)	Aim	Design/participants	Results/conclusion	Ref. (year)
Major oil spill from the super tanker <i>Exxon Valdez</i> , Alaska (1989).	To investigate how technological disasters affect community stress levels.	Longitudinal, 5 months, and up to 4 years after disaster. 3 indicators of community stress. ($n_{\text{exp-89}}=118, n_{\text{contr-89}}=73$).	Initially, high levels of community stress, diminishing as time passed.	[56] (1998)
Major oil spill from the oil tanker <i>Prestige</i> , Spain (2002).	To examine associations between oil spill exposure and health-related quality of life, and mental health.	Cross sectional, 16 months after accident. Residents divided by geographical zone and individual exposure (personal affectation). ($n_{\text{tot}}=2700$).	No associations between health-related quality of life or mental health status and oil spill exposure 16 months after the accident.	[59] (2007)
Major oil spill from the oil tanker <i>Prestige</i> , Spain, (2002).	To assess impact on mental health and health-related quality of life from accidental oil spill.	Cross sectional, 1 year after accident. Residents divided by geographical zone and exposure status. ($n_{\text{tot}}=926$).	More mental symptoms and lower perception of physical health among those most affected by the spill.	[55] (2010)
Accidental oil spills from supertankers. UK, Spain, Alaska, Pakistan, France, Japan (1989-2003).	To review studies of accidental oil spills and human health effects.	Review. 7 different supertanker accidents.	Oil spill accidents resulted in high levels of event-related psychological stress and acute physical symptoms, decreasing with time, and mainly reversible.	[4] (2010)

1.10.2 Industries emitting malodorous pollution, and malodorous chemical spills

Exposure to malodorous environmental pollution such as sulphurous emissions from pulp mills, petroleum refineries and petrochemical industries has previously been associated with both physical and mental health complaints [29, 30, 60-62].

Sulphurous compounds have been shown to cause adverse health effects even at very low exposure levels [30, 62]. A qualitative study reported flashbacks in a war veteran suffering from PTSD due to odours reminiscent of the odour of burning waste in a war zone [63]. Most studies were cross sectional, making assessment over time impossible. Characterization of odour exposure varied in different studies. Most

studies used distance to odorous source [29, 60, 64-68] as a proxy for exposure, whereas some studies used calibrated human observers [68, 69] (Table 5).

Previous studies of odour-related health complaints among humans who are exposed to malodorous emissions at non-toxic levels have suggested that odour perception and odour annoyance are of importance for the development of such complaints [60, 64, 66-69]. Even worries about a possible health risk have been associated with more health complaints among residents who lives close to a hazardous waste site [61]. A study among residents exposed to malodorous emissions from a biofuel facility suggested that neither annoyance nor health complaints were mediated by the malodorous pollution itself, but rather by perceived air pollution and health risk perception [66] (Table 5).

Table 5: An overview of relevant previous studies; industries emitting malodorous air pollution and other malodorous chemical spills.

Industry	Aim	Design/participants	Results/conclusion	Ref. (year)
Three different hazardous waste sites.	To investigate odour perception and environmental worry as determinants for physical symptoms.	Cross sectional. Residents ($n_{\text{tot}}=2040$). Exposure: frequency of odour perception.	Significant positive associations between physical symptoms and perceived odour and degree of worry, but stronger associations for worry.	[61] (1991)
Sulphate pulp mill. Very low levels of sulphurous compounds in ambient air.	To evaluate acute health effects of sulphurous emissions from pulp mill.	Longitudinal. 2 days higher exposure. 4 months later; 2 days low exposure. Residents ($n=60$).	Irritative effect on mucous membranes and eyes, and significantly more breathlessness, on days with highest exposure.	[62] (1992)
Sulphate pulp mill. Very low levels of sulphurous compounds in ambient air.	To assess the effect of exposure to very low levels of sulphur compounds on eye, respiratory, and central nervous system symptoms, respectively.	Cross sectional. Residents near pulp mill vs non-polluted area ($n_{\text{exp}}=336$, $n_{\text{contr}}=380$). Measured annual mean concentrations of sulphur compounds.	Significantly more headache and cough among exposed. Adverse health effects occur at lower exposure levels than previously reported.	[30] (1996)

Table 5, continued: An overview of relevant previous studies; industries emitting malodorous air pollution and other malodorous chemical spills.

Industry	Aim	Design/participants	Results/conclusion	Ref. (year)
1: Fertilizer plant. 2: Pig rearing facility.	To investigate the association between odorous exposure, annoyance and physical symptoms.	2 cross sectional field studies. Residents ($n_{\text{fert}}=250$, $n_{\text{pig}}=322$). Exposure _{fert} : distance. Exposure _{pig} : frequency (trained human observers).	Direct associations between high odour exposure and physical symptoms, indirect link via annoyance. At moderate odour exposure, symptoms were mediated by annoyance.	[68] (1999)
Biofuel facility that emitted malodorous air pollution at non-toxic exposure levels.	To test a model that describes interrelations between malodorous emissions, perceived pollution, health risk perception, annoyance and health complaints.	Cross sectional. Path analysis. Residents ($n_{\text{tot}}=722$). Exposure: 3 zones.	Annoyance and health complaints were not directly influenced by malodorous emissions, but were mediated by perceived air pollution and health risk perception.	[66] (2013)
Petroleum refinery that emitted sulphurous air pollution. Significant odour reduction during study period.	To examine changes in odour perception, annoyance and health complaints following reduction of odorous emissions.	Two cross sectional surveys, 1992 and 1997. Residents ($n_{1992}=391$, $n_{1997}=427$) in 3 zones.	Odour perception and annoyance decreased while health complaints remained unchanged.	[60] (2000)
Petroleum refinery that emitted sulphurous air pollution. Significant odour reduction during study period.	To study the mediating role of odour perception and annoyance on health complaints due to odorous emissions.	Two cross sectional surveys, 1992 and 1997. Testing direction of relationships. Residents ($n_{1992}=391$, $n_{1997}=427$).	Odour perception and annoyance had a strong mediating effect on health complaints.	[67] (2002)

Table 5, continued: An overview of relevant previous studies; industries emitting malodorous air pollution and other malodorous chemical spills.

Industry	Aim	Design/participants	Results/conclusion	Ref. (year)
1: Industrial odours. 2: Agricultural odours.	To study the effect of hedonic tone and odour intensity on the association between odour exposure and somatic symptoms.	Cross sectional. Residents ($n_{ind}=1456$, $n_{agri}=1053$). Exposure: External observers.	Symptoms associated with odours were highly influenced by hedonic tone. Somatic symptoms were exclusively mediated by annoyance.	[69] (2009)
Petrochemical industry emitting malodorous air pollution.	To estimate long-term prevalence and change over time of annoyance caused by malodorous pollution, and worries about adverse health effects, and to identify risk factors.	Cross sectional. 3 samples, 1992, 1998 and 2006. Residents from 4 areas close to industrial site vs control areas ($n_{exp}=600-800$, $n_{contr}=200-1000$).	Odour annoyance was reduced during the study period, but worries about negative health effects remained constant. Worries about adverse health effects increased the odour annoyance.	[64] (2013)
Chronic exposure to low-moderate levels of air pollutants from biodegradable wastes in non-urban areas.	To investigate direct and indirect associations between exposures to a marker (NH_3) from biodegradable waste, odour annoyance and non-specific symptoms.	Cross sectional. Residents ($n_{tot}=454$). Individual-level exposure to a proxy indicator (NH_3).	Strong dose-response associations between level of NH_3 exposures and annoyance, and between annoyance and non-specific symptoms. Indirect, annoyance-mediated, associations between exposure levels and symptoms.	[65] (2015)
Mercaptan spill following a lightning strike. USA (2008). Long-lasting foul odour.	To assess self-reported health effects.	Cross sectional. Residents ($n_{tot}=204$) living in 2 circular zones based on distance from odorous source.	Significant association between residential zone and self-reported odours. Long-term perceived foul odour was associated with physical and psychological health complaints.	[29] (2013)

Table 5, continued: An overview of relevant previous studies; industries emitting malodorous air pollution and other malodorous chemical spills.

Industry	Aim	Design/participants	Results/conclusion	Ref. (year)
Treated sewage sludge used as soil amendment.	To assess health and quality of life.	Qualitative study. Semi-structured interview. Residents within 1 mile (=1.6 km) of soil amendment application sites (n=34).	Physical reactions as well as adverse impacts on mental and social well-being were reported. One report of exacerbation of PTSD.	[63] (2014)

1.10.3 Studies investigating odour-related mechanisms, and case reports

Odour related mechanisms for the development of health complaints are complex, and comprise of both psychological and physiological responses [70-77].

Furthermore, olfaction has a complex role in threat recognition [77] (Table 6).

Table 6: An overview of relevant previous studies; studies investigating odour-related mechanisms, including experimental studies and case reports.

Setting	Aim	Design/participants	Results/conclusion	Ref. (year)
Laboratory.	To test if aversive odours activate amygdala and other limbic and paralimbic regions.	Experimental study. Healthy women (n=12). Sulphurous odour stimulus. Regional cerebral blood flow measured with PET-scan.	Amygdala was highly activated by aversive odours. Amygdala participates in the emotional processing of odours.	[76] (1997)
Questionnaire based. Hypothesized that odors play a significant role in the pathophysiology of PTSD.	To investigate self-reported, odor-evoked distress in PTSD.	Cross sectional. Combat veterans with and without PTSD ($n_{PTSD}=30$, $n_{notPTSD}=22$) and healthy controls ($n_{contr}=21$). Questionnaire (hedonic tone of specified odours and their ability to elicit relaxation or distress).	Olfaction has a complex role in threat detection. Several theoretical models. Suggest an inability to extinguish the conditioned fear response in soldiers who develop PTSD.	[77] (2015)

Table 6 continued: An overview of relevant previous studies; studies investigating odour-related mechanisms, including experimental studies and case reports.

Setting	Aim	Design/participants	Results/conclusion	Ref. (year)
Laboratory.	To investigate relations between olfaction and processing of emotional information.	Designed for patients with a history of childhood maltreatment ($n_{CM}=31$, $n_{notCM}=28$), healthy controls ($n_{contr}=27$). Odour thresholds and identification. Chemosensory event-related potentials. Questionnaire to assess PTSD (IES-R).	Current PTSD leads to increased olfactory identification and to a faster response to unpleasant odours.	[71] (2010)
Case reports that illustrate the role of olfaction in PTSD.	To review olfaction as traumatic reminder.	3 cases: War veteran, paramedic in the fire department, rape victim.	Memory for trauma-related odours in PTSD is quite specific and long-lasting.	[75] (2003)
Laboratory.	To test the hypothesis that IEI (idiopathic environmental intolerances) symptoms result from learning via classical conditioning of odors to fear.	Experimental study. Healthy students ($n=53$). Unpleasant and pleasant conditioned stimuli. Electrical shock as unconditioned stimulus. Electro-dermal response as a measure of fear-induced arousal.	Successful fear conditioning irrespective of pleasant or unpleasant odour stimulus. Fear acquired during conditioning did not extinguish. Suggest that fear conditioned to odours extinguish slowly.	[72] (2001)
Experimental studies and studies of naturally formed autobiographical memories.	To review if odours are especially powerful reminders of autobiographical experience.	Review concerning the Proust phenomenon.	Preliminary evidence that olfactory cues trigger autobiographical memories more effectively than triggers from other senses.	[70] (2000)

Table 6 continued: An overview of relevant previous studies; studies investigating odour-related mechanisms, including experimental studies and case reports.

Setting	Aim	Design/participants	Results/conclusion	Ref. (year)
Laboratory.	To investigate if olfactory memories are more detailed and arousing than memories elicited by auditory or visual cues.	Experimental study. Healthy female students (n=80). Olfactory, auditory and visual stimuli. Rating of memory (intensity, valence, and arousal).	Odour-elicited memories of aversive events were more detailed, unpleasant and arousing than memories evoked by auditory, but not by visual, cues.	[74] (2012)
Laboratory.	To study the psychological and physiological responses accompanying odor-elicited autobiographic memories.	Experimental study. Healthy volunteers (n=23). Individual nostalgic odour vs control odour. Mood status, physiological, endocrine and immunological parameters.	Odor-elicited autobiographic memories induce physiological responses including autonomic nervous and immune responses.	[73] (2011)

2 Aims of the studies

The overall aim of this research project was to study long-term health effects among workers in the aftermath of a chemical explosion that emitted malodorous pollution in an industrial harbour area.

The specific objective of Paper I was to assess whether employees in the industrial area and clean-up workers had more subjective health complaints than controls one and a half years after the chemical explosion [1].

In Paper II, we hypothesized that elimination of the malodorous pollution from the area would reduce the prevalence of subjective health complaints among the exposed workers. The specific aim was to determine whether subjective health complaints among employees in the industrial area and clean-up workers declined over a four-year period after the chemical explosion [2].

In Paper III, our hypothesis was that perception of smell due to malodorous environmental pollution was of importance for persistent adverse health outcomes, including post-traumatic stress symptoms. The specific research question was whether perceived incident-related odour was a determinant of subjective health complaints and post-traumatic stress symptoms among employed adults, when the malodorous pollution was still present at the explosion site, as well as after pollution clean-up [3].

3 Materials and methods

This doctoral work is a part of a longitudinal study started one and a half years after the explosion with follow-ups three and a half and five and a half years after the accident, in order to investigate possible long-term health effects and to study the development of symptoms over time (Figure 10).

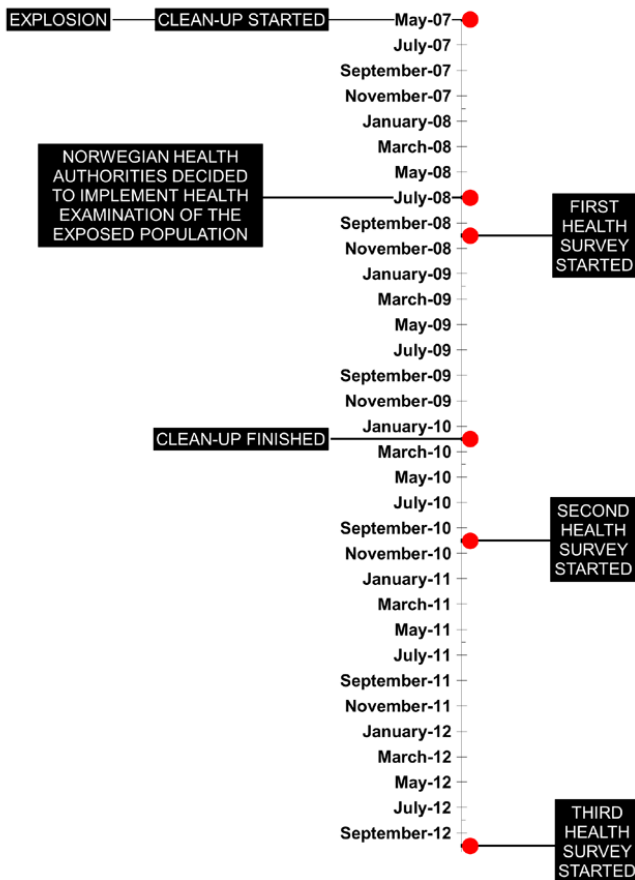


Figure 10: Timeline showing important milestones for the study.

In the main cohort study, all employees in the industrial area, clean-up workers, fire fighters, rescue personnel, and all inhabitants living within a distance of six kilometres (according to the Norwegian National Registry), and above the age of two,

were invited to participate in the study in 2008. These persons were considered as potentially affected by the accident and the malodorous pollution in the aftermath of the explosion.

Inhabitants living in two communities 20-30 kilometers from the accident site were invited as controls as they were considered as not directly affected by the incident, but still living in the same geographical area (Figure 11). The controls were matched by gender and age to the workers in the industrial area and the near-by residents. Persons living in the control areas, but working in the industrial area or participating in firefighting, rescue- or clean-up operations, were not included as controls.



Figure 11: Map of Norway and a close-up of the area affected by the accident. The red marker points at the industrial area where the explosion happened 24 May 2007. The red circle indicates the area where the near-by inhabitants lived. The black circles indicate the areas where the controls lived.

In total, 1016 persons were invited to participate in the main cohort study, 283 workers potentially affected by the accident, 335 near-by residents, and 398 inhabitants living more than 20 kilometres from the accident site. Altogether 734 persons participated in the study in 2008, giving a response rate of 72 % [15].

In 2010 and 2012, three and a half years and five and a half years after the incident, respectively, all 734 participants from the 2008 survey who could be located, were once more invited to participate in a survey. In total, 554 (76 % of the 2008 survey) and 506 (69 % of the 2008 survey) were enrolled in the 2010 and 2012 surveys, respectively [78, 79].

All the participants were invited to participate in the health examination by a personal letter (Appendix I). An informed consent form (Appendix II) and a questionnaire (Appendix III) were included in the postal consignment. The participants were asked to fill in these documents and bring them when they came for the clinical examination [15]. Participants under the age of 18 are not a part of this doctoral work, but have been described in a previous publication [80].

The questionnaire had questions about possible health effects in the aftermath of the explosion accident, and included validated instruments [81-87]. The same validated instruments were used in the questionnaires in 2008 (Appendix III), 2010 and 2012 (Appendix IV), respectively.

The participants were also asked about gender, age, smoking habits, previous chronic diseases, education, employment status, and occupation, participation in firefighting or clean-up, perception of the incident-related odour, and distance to explosion site at the time of the explosion.

Clinical examination included inspection of eyes, throat and skin, assessment of tear film stability, lung auscultation, spirometry including reversibility test, and analyses of blood and urine samples. Individual evaluations of results were performed, and in case of pathology, the participants were referred to his or her general physician and specialist health care for further investigations. All workers went through a semi-structured interview related to their occupation, concerning chemical exposure (agents and exposure levels), and their use of personal protective equipment.

3.1 Studies in the doctoral thesis

Results from the questionnaire based health surveys conducted by the general practitioners shortly after and 10 months after the accident, indicated a high degree of health complaints among those potentially affected by the accident and the malodorous pollution in the aftermath of the explosion [14].

Based on knowledge from previous research, we knew that experiencing an accident, living close to, or being present at a disaster site [4, 8-13, 54-59], as well as being exposed to malodorous environmental pollution [29, 30, 60-62, 64-69] could result in health complaints among the affected population. In this doctoral work we therefore decided to use two different exposure classifications to study health effects in the aftermath of the accident; 1) proximity to the explosion site (Papers I and II) [1, 2], and 2) perceived malodorous pollution following the accident (Paper III) [3]. We focused on physical and psychological symptoms among workers. Previous studies have examined respiratory health [88-90] and tear film stability [91] among workers and residents in the area.

3.1.1 Studies based on proximity to the explosion site

Study designs

The prevalence of health complaints among the study population was investigated by a cross sectional study based on data from the 2008 health survey. The clean-up operation was not completed until February 2010, and hence the malodorous pollution was still present in the area during the 2008 survey. Next, we conducted a longitudinal study including data from the surveys in 2008 and 2012. In this follow-up we studied the development of health complaints over time, from when the malodorous pollution was present, until after removal of the malodorous pollution (Figure 12).

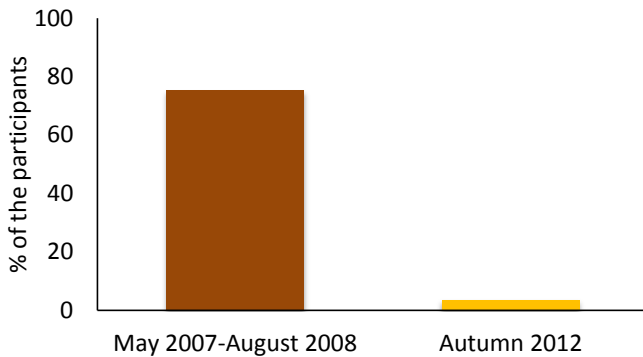


Figure 12: In the studies based on proximity to the explosion site, nearly 80 % of the participants reported perception of the incident-related foul odour during May 2007-August 2008 (brown bar), while only 4 % of the participants reported perception of the incident-related foul odour during the last month before the 2012 survey (yellow bar).

Study population

All employees in the industrial area at the time of the explosion and workers who participated in the clean-up operation were included as exposed workers (Table 7). These participants were considered as potentially affected by the accident and the malodorous pollution in the aftermath of the explosion. Residents living close to the explosion site were not included unless they were employed in the industrial area or participated in the clean-up operation. Fire fighters and rescue personnel were not included as exposed workers in these studies because handling traumatic incidents is part of their normal duty (Figure 13).

As controls, we included employed inhabitants who lived 20-30 kilometres away from the explosion site, and who were neither employed in the industrial area nor participating in the clean-up operation (Table 7). These workers were considered as not directly affected by the incident. Workers in both groups were restricted to the age range 18-67 at the time of the incident (Figure 13).

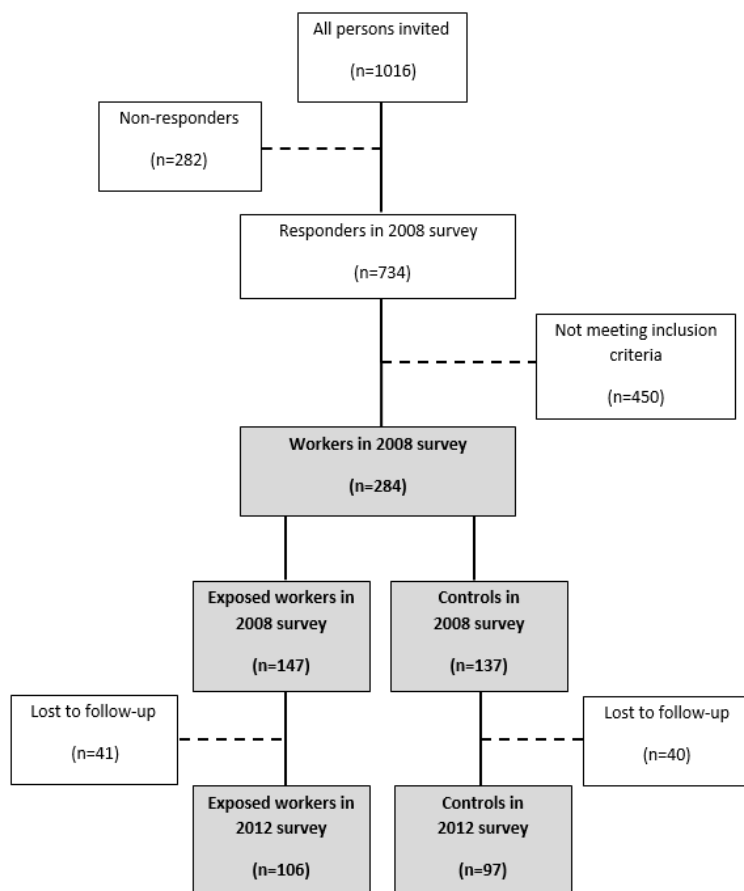


Figure 13: The main cohort and the population in the substudies based on proximity to the explosion site (shaded in grey), respectively.

Table 7: Participants in the studies based on proximity to the explosion site. Exposed workers grouped by employment in the industrial area and/or participation in the clean-up operation.

Participants	2008		2012	
	n		n	(% of those in 2008)
Exposed workers	147		106	(72)
Employees in the industrial area ^a		124		91 (73)
External clean-up workers		23		15 (65)
Controls	137		97	(71)
Total	284		203	(71)

^aIncluding internal clean-up workers, n=32 and n=23 in 2008 and 2012, respectively.

Instruments

Subjective health complaints

Subjective health complaints were surveyed by the Subjective Health Complaints Inventory (SHC), which previously has been validated [84]. Because this instrument asks about symptoms, not diagnoses, it is particularly suitable to measure self-perceived health in populations that are expected to be relatively healthy.

SHC comprises of 29 common physical and psychological health complaints, which the respondents were requested to grade according to perceived intensity the previous 30 days by using a four-point Likert scale (0-3). Maximum total sum score was 87. The 29 items have been grouped into subscales according to previous factor analysis [84]. Musculoskeletal complaints comprises of eight items (headache, neck pain, upper back pain, low back pain, arm pain, shoulder pain, migraine and leg pain) giving a maximum subscale score of 24. Gastrointestinal complaints consists of seven items (heartburn, stomach discomfort, ulcer/non-ulcer dyspepsia, stomach pain, gas discomfort, diarrhea and constipation) giving a maximum subscale score of 21. Subjective neurological complaints (originally named “pseudoneurology” by the developers of the instrument [84]) comprises of seven items (extra heartbeats, hot flushes, sleep problems, tiredness, dizziness, anxiety and sadness/depression) also giving a maximum subscale score of 21. Allergy contains five items (asthma, breathing difficulties, eczema, allergies and chest pain) giving a maximum subscale score of 15, and flu which has two items (cold/flu and coughing), giving a maximum subscale score of six [84].

Mean intensity for the complaints (SHC total and subscale scores) were computed and used in the analyses.

Missing items

A missing score for an item was substituted by the mean score of the valid items within the respective subscale for the respective participant. If more than half of the items within a subscale were missing, the entire subscale was regarded as missing [92].

Variables

We used information from the 2008 questionnaire about gender, age, number of years of education after nine years of elementary school, occupation, employment (yes/no), employment in the industrial area (yes/no), involvement in the clean-up operation (yes/no), and distance from the accident site at the time of the explosion (kilometres). To classify the participants as present in the industrial area during the explosion we used proximity to the explosion site of 1 kilometre or less. For smoking habits (non-smoker/daily smoker), we used data from the 2008 survey for the cross sectional study, and from 2008 as well as 2012, in the longitudinal study.

In 2008, we collected information about perceived accident-related odour (yes/no), and if “yes”, during which months (May 2007-August 2008). In the 2012 survey, we asked about perceived odour from the industrial area during the last month prior to the survey (yes/no).

Statistics

In the cross sectional study, multiple linear regression models with adjustment for possible confounding from age, gender, smoking habits (non-smoker/daily smoker) and education level (0 year after elementary school/1-3 years after elementary school/4 years or more after elementary school) were used to investigate a possible impact on SHC total score and subscale scores from exposure (employees in the industrial area and/or clean-up workers vs controls). The participants were grouped into four age categories (18-36 years/37-44 years/45-51 years/52-67 years) each comprising a similar number of individuals. SPSS version 21 was used for the analyses, and the level of significance was set to 0.05.

In the longitudinal study, linear mixed effects models with adjustments for possible confounding from the same factors as in the cross sectional study, as well as proximity to the explosion (1 kilometre or closer vs more than 1 kilometre) were used to analyze possible differences in total SHC score and in subscale scores from the 2008 survey to the 2012 survey for exposed workers and controls. The individual worker was entered as a random effect, and time in question (2008 or 2012) was

entered as fixed effect. To assess possible time-dependent differences between exposure groups, an interaction term between the time variable and the group variable was included in the model.

Corresponding models were used to analyze possible differences in mean scores of single items in subscales that were significantly different between exposed and control groups in 2012. SPSS version 22 was used for the analyses, and the level of significance was set to 0.05.

3.1.2 Study based on perceived smell

Study design

The prevalence and changes of health complaints among the study population were investigated by a longitudinal study including data from the 2008 survey and the 2010 and 2012 surveys; when the malodorous pollution was present and after removal of the pollution, respectively.

Study population

All employed adults (aged 18-67) from the main cohort in 2008 were included (n=486) (Figure 14), irrespective of employment or not in the industrial area at the time of the accident or possible participation in accident-related tasks (Table 8).

Table 8: Accident-related tasks among participants in the low and high odour score groups.

	Total participants n	Low odour score group n (%)	High odour score group n (%)
Participants	486	253 (52)	233 (48)
Employees in the industrial area at the time of the accident	115	13 (11)	102 (89)
Clean-up workers	52	17 (33)	35 (67)
Fire fighters	54	35 (65)	19 (35)

Adults who were not in employment in the 2008 survey included participants who received sickness or disability benefits. To avoid possible biases introduced by

persons who were out of employment due to disorders diagnosed before the accident, we excluded all adults who were out of employment (n=41).

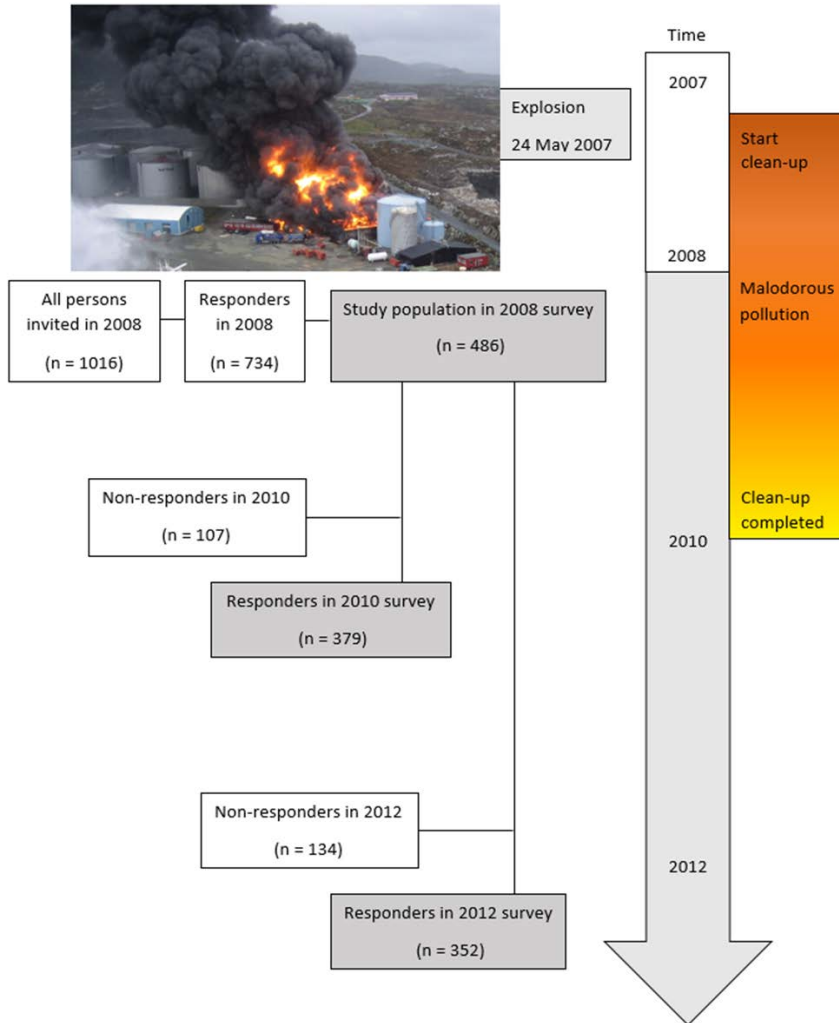


Figure 14: The study population in the study based on perceived smell (shaded grey), comprised of all employed adults (aged 18 -67) from the main cohort in 2008. Surveys were performed when the malodorous pollution was present in the area (in 2008), as well as after clean-up (in 2010 and 2012, respectively). Photo: Lasse Fossedal.

Odour score

No standardized method for objective measurement of malodorous pollution exists [65, 93]. Analytical methods ranging from simple gas detection to analysis by gas chromatography-mass spectrometry (GC/MS) can be used to measure constituents of odorants and their concentrations, but they cannot be used to measure odour [93], which is a subjective sensation that includes hedonic tone (pleasant/neutral/unpleasant) and intensity (not perceptible - extremely strong). In many previous studies, distance between residency and the odorous source has been used to characterize the participants' odour exposure [29, 60, 64-68]. This way to characterize odour exposure has been shown to be prone to exposure misclassification [65]. To reduce the possibility of this kind of misclassification some studies have used trained and calibrated human observers to characterize odour exposure [68, 69, 93]. In the present study, however, we designed an individual odour score as a proxy for perceived odour related to the explosion accident to diminish the chance for exposure misclassification.

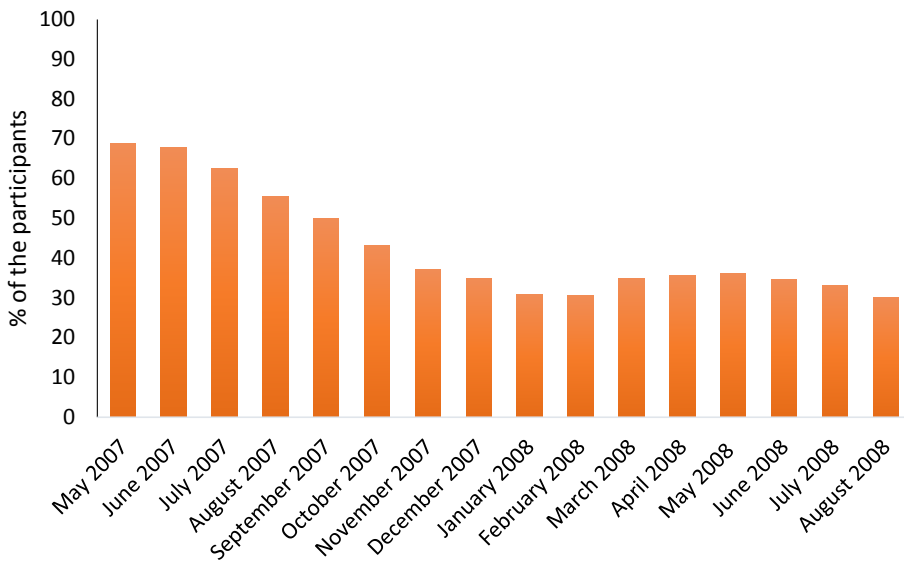


Figure 15: Percentage of participants (n=486) who perceived the accident-related odour each month in the period May 2007-August 2008.

In the 2008 survey, the participants (n=486) were asked if they had been aware of the characteristic accident-related odour (yes/no). If yes, they were requested to indicate which months they had noticed the smell (May 2007-August 2008, a total of 16 months) (Figure 15).

The odour score was computed as the percentage of months each participant had reported the characteristic accident-related odour, giving a maximum score of 100. The study population were dichotomized into the high or the low odour score group by the odour score median (31.25). In the high and the low odour score groups, the odour score median was 81.25 and 6.25, respectively (Figure 16).

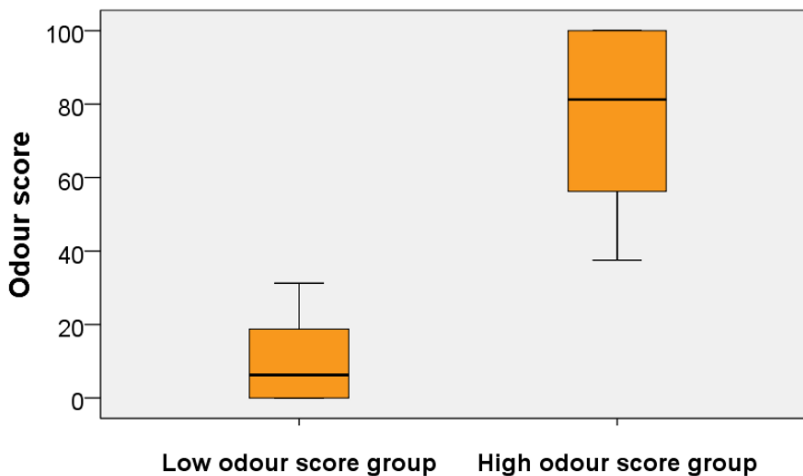


Figure 16: Box plot which shows the odour score distribution within the two odour score groups. The black line inside each box represents the odour score median for the low odour score (6.25) and high odour score (81.25) groups, respectively.

Instruments

Subjective health complaints

As in the studies based on proximity to the explosion site, the Subjective Health Complaints Inventory (SHC) was used to survey subjective health complaints among the participants [84].

Post-traumatic stress symptoms

In the studies based on proximity to the explosion site, the exposed workers reported significantly more sleep problems, tiredness, and sadness or depression than controls [1, 2]. Therefore, we also wanted to investigate a possible association between perceived incident-related odour and psychological agony in response to the accident. To accomplish this, we decided to use the Impact of Event Scale-Revised (IES-R), a validated instrument that measures current (previous seven days) subjective distress in response to a specific upsetting experience [86]. This instrument correlates well with the diagnostic criteria for post-traumatic stress disorder (PTSD) given in the fourth edition of Diagnostic and Statistical Manual of Mental Disorders (DSM-IV) [94]. IES-R is a screening tool that can be used repetitively to measure progress and regress of post-traumatic stress symptoms, but it cannot be used alone to diagnose PTSD in an individual.

The participants were requested to specify how much they were distressed or bothered during the previous seven days with respect to the explosion accident. Twenty-two difficulties were listed and the participants responded by using a five point Likert scale (0-4). A higher degree of distress was associated with a higher score. Maximal total sum score was 88.

Previously the 22 difficulties have been assembled into three response sets, or subscales; intrusion, avoidance and hyperarousal. Intrusion comprises of eight items including intrusive thoughts, nightmares, intrusive feelings and imagery associated with the traumatic incident, giving a maximum subscale score of 32. Avoidance also contains eight items describing avoidance of feelings and situations, and numbing of responsiveness, giving a maximum subscale score of 32. Hyperarousal have six items concerning anger and irritability, hypervigilance, difficulty concentrating, and heightened startle, giving a maximum subscale score of 24.

Mean total scores and mean subscale scores were calculated from the scores of each item in the IES-R instrument.

Missing items

A missing score for an item within the SHC or IES-R instruments was substituted by the mean score of the valid items within the respective subscale for the individual participant. The subscale score was regarded as missing for a participant if more than half of the items within a SHC subscale were missing [92], and if more than two items within a IES-R subscale were missing.

Variables

From the 2008 questionnaire, we collected information about gender, age, educational level (0, 1-3 or 4 or more years after nine years of elementary school), and how far the participants were from the explosion during the accident (1 km or less was used to classify the participants as present in the industrial area). We also used data about employment status (employed/have a job or not) in 2008, and distance from explosion site to residency (kilometres). For smoking habits (non-smoker/daily smoker), data from all three surveys (2008, 2010 and 2012) were used. Individual odour scores were calculated from data on perceived odour from the 2008 survey, and each participant's odour score group assignment was maintained throughout the follow-ups.

Statistics

Mixed effects models to account for correlated data, were used to estimate changes in mean outcome (SHC and IES-R with subscales) in the two odour score groups, and to assess possible differences in development over time. Adjustments were made for possible confounding from age (18-36, 37-44, 45-51 or 52-67 years in 2008), gender, smoking habits (non-smoker/daily smoker, time dependent, in 2008, 2010 and 2012, respectively), educational level (0, 1-3 or 4 or more years after nine years elementary school), and whether or not the participant was present during the explosion (1 kilometre or less from the explosion site vs more than 1 kilometre). An interaction term between group and measurement time were included to assess possible time-dependent differences between odour score groups.

Pearson correlation was used to assess the possible relation between odour score and distance to residency from the explosion site.

SPSS version 22 and STATA version 14 were used for the analyses, and the level of significance was set to 0.05.

3.2 Ethics

A written, informed consent was obtained from each participant (Appendix II), and the study was completed in accordance with the Helsinki Declaration [95]. The study was approved by the Regional Committee for Medical Ethics of Western Norway and Norwegian Social Science Data Services [15].

Withdrawal from the study was possible at any time, and the participants did not receive any kind of economic benefit. All participants were evaluated individually in the clinical health examinations. If referral to specialist health care was considered necessary, the participants were advised to contact their general practitioner presenting a written copy of the results from the clinical examination and an accompanying letter addressed to the general practitioner.

4 Summary of results

4.1 Studies based on proximity to the explosion site

Descriptive data

In the cross sectional study, conducted one and a half years after the accident, the exposed workers (n=147) comprised of 80% men, compared to 55% men in the control group (n=137). The exposed workers, defined as employees in the industrial area and/or clean-up workers, were significantly younger (mean age 43 vs 46 years, $p=0.02$), included more daily smokers (40% vs 21%), and fewer had attained higher education (29% vs 44%), compared to the controls.

In the follow-up, conducted five and a half years after the explosion, men still accounted for 80% of the exposed workers (n=106), but they were only marginally younger than the controls (n=97) (mean age 48 vs 50 years, $p=0.1$). During the study period, the proportions of daily smokers were reduced in both groups, but to a greater extent among the exposed workers (from 40% to 33% vs from 21% to 18% in exposed workers and controls, respectively). The fraction of participants holding a higher education increased to 46% among the controls, while it was reduced to 27% among the exposed workers.

Subjective health complaints

One and a half years after the explosion, the exposed workers had a significantly higher total SHC score, compared to the controls ($p<0.01$).

Analyses of the subscale scores found significant differences in scores between exposed workers and controls for the subjective neurological complaints subscale ($p<0.001$) after adjustments for gender, age, smoking habits and educational level. Of the seven items included in the subjective neurological subscale, five items; hot flushes, sleep problems, tiredness, dizziness and sadness/depression, showed significant differences between exposed workers and controls, with the higher score,

and hence more complaints, among the exposed workers (Figure 17). For the gastrointestinal, musculoskeletal, allergy or flu subscale scores, no significant differences in scores were found between exposed workers and controls.

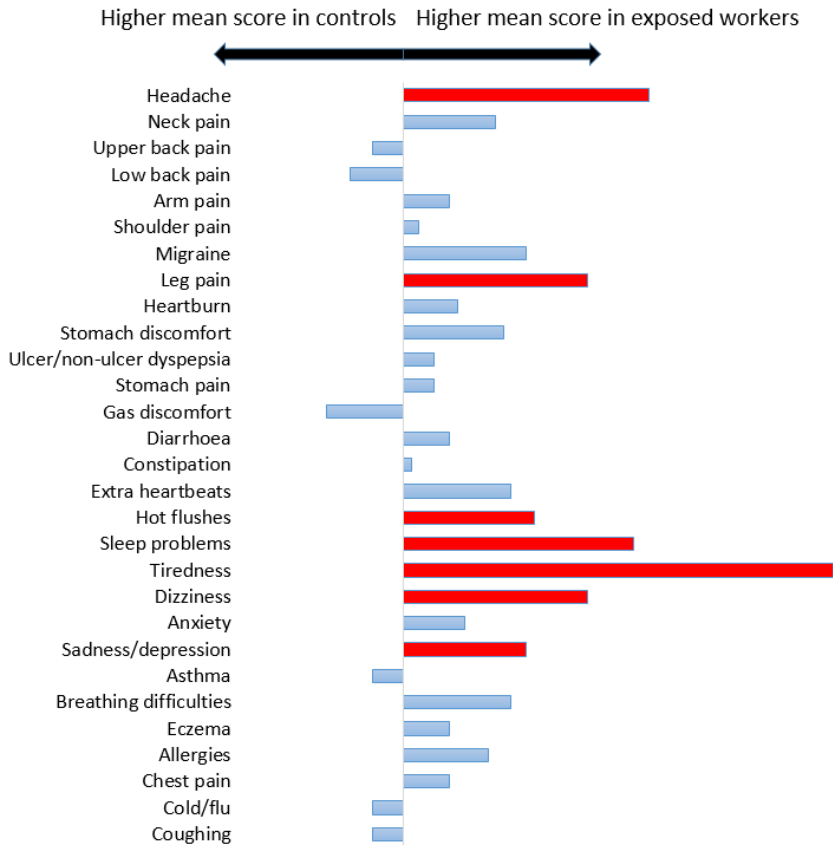


Figure 17: Mean differences in scores for single health complaints between exposed workers and controls, reported one and a half years after the explosion. Red bars indicate significant differences ($p < 0.05$).

In the longitudinal study, comprising data from one and a half and five and a half years post-disaster, significant reductions in total SHC score ($p < 0.01$), in subjective neurological ($p < 0.001$) (Figure 18), and in gastrointestinal subscale scores ($p < 0.01$) were found among the exposed workers, adjusted for gender, age, smoking habits, education level and proximity to the explosion. For the controls there were no significant changes. A significant interaction between exposure group and time, was

only found for the subjective neurological subscale, indicating that the changes from 2008 to 2012 were different between exposed workers and controls for this subscale only ($p < 0.05$) (Figure 18). Even though there was a significant decrease in the subjective neurological subscale score among the exposed workers, they still had a significantly higher score five and a half years after the explosion, compared to controls ($p < 0.01$). In 2012, exposed workers had significantly higher scores ($p < 0.05$) for the single items tiredness and sleep problems compared to controls.

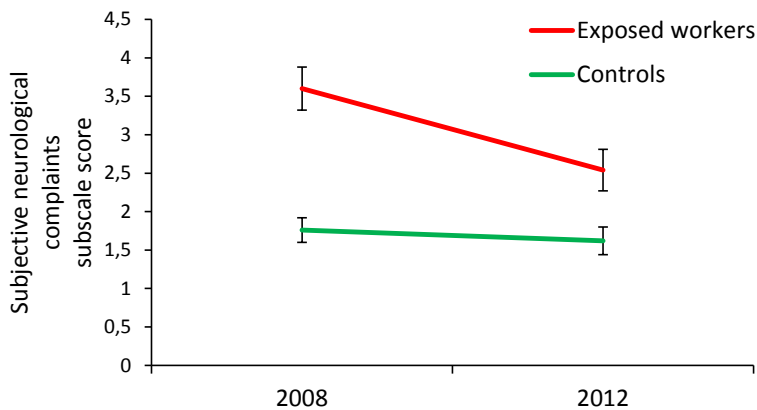


Figure 18: Mean subjective neurological complaints subscale scores with standard errors of the mean among exposed workers and controls, in 2008 and 2012.

4.2 Study based on perceived smell

Descriptive data

In the longitudinal study based on perceived smell, all employed adults were divided into the low odour score group ($n=253$) and the high odour score group ($n=233$) in 2008. More men than women participated, but the fractions of each gender were similar between the two odour score groups in all three surveys (2008, 2010 and 2012). There were no significant differences in age between the two groups (mean age 45 vs 43 in 2008, $p=0.09$), but the low odour score group had fewer daily smokers (27% vs 33% in 2008). There was also a tendency that the low odour score

group had a higher proportion of participants with an education of four years or more after elementary school (42% vs 37% in 2008). More participants in the high odour score group were present in the industrial area during the explosion, compared to those in the low odour score group (30% vs 7% in 2008). There was a weak-moderate negative correlation between odour score and distance to residency from explosion site (correlation coefficient -0.38, $p < 0.001$).

Subjective health complaints

Workers in the high odour score group reported significantly more subjective health complaints than workers who had a low odour score, before and after clean-up of the malodorous pollution ($p_{2008} < 0.001$, $p_{2010} = 0.002$ and $p_{2012} = 0.009$), adjusted for gender, age, smoking habits, education level and proximity to the explosion (Figure 19). During the study period, there were no significant interaction between odour score group and time, indicating no differences in change between the two odour score groups ($p = 0.16$) (Figure 19).

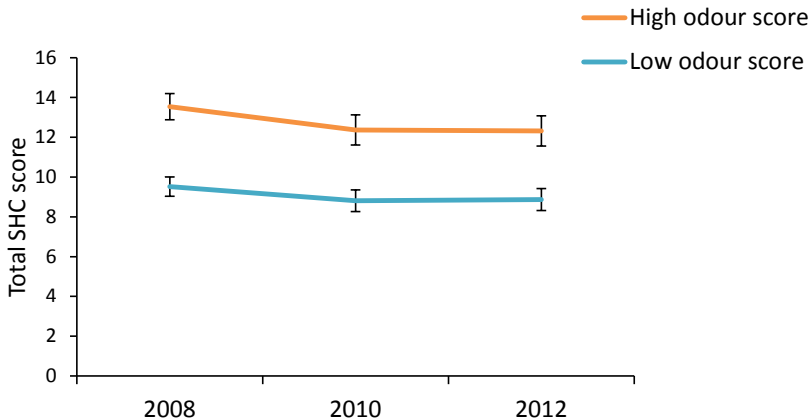


Figure 19: Mean total SHC scores with standard errors of the mean among participants in the high and low odour score groups, respectively, before and one and three years after clean-up of the malodorous pollution.

In the mixed effects models, participants who were present in the industrial area during the explosion had a significantly higher subjective neurological complaints

subscale score, compared to those who were not ($p=0.02$). Proximity to the explosion was not of significance for the total SHC score ($p=0.9$).

Post-traumatic stress symptoms

Participants in the high odour score group reported significantly more post-traumatic stress symptoms compared to those in the low odour score group, adjusted for gender, age, smoking habits, education level and proximity to the explosion before, and one and three years after clean-up of the malodorous pollution ($p_{2008}<0.001$, $p_{2010}<0.001$ and $p_{2012}=0.04$) (Figure 20). During the study period, there was a significant decrease in total IES-R scores among the participants in the high odour score group ($p<0.001$). There was a significant interaction between odour score group and time, indicating a difference in change in scores between the two odour score groups ($p<0.001$) (Figure 20).

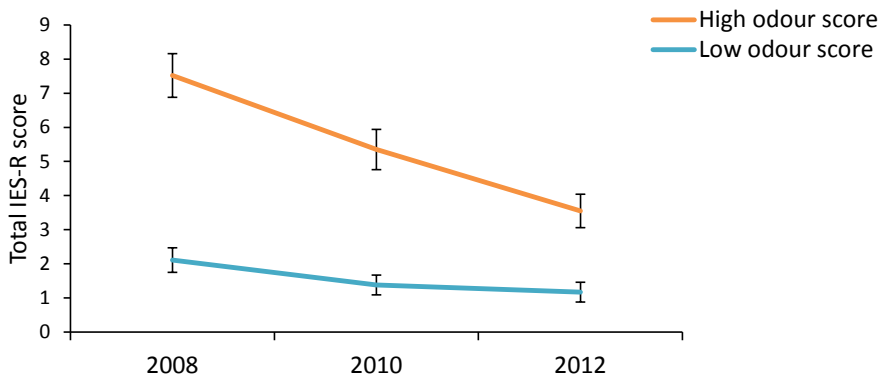


Figure 20: Mean total IES-R scores with standard error of the mean among participants in the high and low odour score groups, respectively, before and one and three years after clean-up of the malodorous pollution.

In the mixed effects models, participants who were present in the industrial area at the time of the accident had a significantly higher total IES-R score (<0.001), as well as subscale scores ($p<0.001$, $p<0.001$, $p<0.001$ for hyperarousal, avoidance and intrusion, respectively), compared to those who were not present during the accident.

5 Discussion

5.1 Main findings

5.1.1 Studies based on proximity to the explosion site

Employees in the industrial area and clean-up workers reported more subjective health complaints, mainly neurological symptoms, compared to controls, one and a half years after the explosion. Four years later, after the malodorous pollution was removed, there was an overall downward trend in health complaints among these workers, but they still reported more neurological symptoms than the controls.

5.1.2 Study based on perceived smell

Employed workers who had perceived the malodorous pollution for a longer period of months reported more subjective health complaints and post-traumatic stress symptoms compared to workers who had perceived the odour for fewer or no months. This difference lasted for at least three years after the clean-up of the malodorous pollution.

During the study period, the post-traumatic stress symptoms declined over time among the participants in the high odour score group, whereas the change of subjective health complaints did not differ over time between the two odour score groups.

5.2 Discussion of results

5.2.1 Comparison with previous studies including accidents

We found a higher prevalence of subjective health complaints, notably neurological symptoms, among employees in the industrial area where the accident happened, and

among clean-up workers. This is similar to results from studies one and a half years and four years after an explosion in a fireworks storehouse in a residential area in the Netherlands [11-13]. Rescue workers in the fireworks study, including those who participated in the clean-up following the accident, even had an increased number of sick leave days post disaster compared to 6 months before the accident [11]. Also the reduction of such health complaints over the four-year study period in our study is in line with the results from the fireworks study [13].

The higher prevalence of psychological symptoms and lower perception of physical health among the exposed workers in our study, are also in line with results from a cross sectional study performed among affected residents one year after the *Prestige* oil spill [55]. However, our study is not in line with another cross sectional study performed one and a half years after the *Prestige* oil spill, which found no differences in health related quality of life or psychological status between those who were personally affected by the oil spill when compared to controls. Economic compensations at an early stage, or a possible healthy worker bias were suggested as possible explanations in this study [59]. The decline of neurological complaints in our study is similar to results from a longitudinal study in the aftermath of the *Exxon Valdez* oil spill in Alaska. Following the oil spill disaster, high levels of event-related psychological stress were initially found among the residents. Community stress levels were reduced as time passed, but native Alaskan people still reported high levels of stress and social disruption three and four years after the accident [4, 56].

5.2.2 Comparison with previous studies including odour

We had no information about exposure levels of VOCs or sulphurous compounds shortly after the accident, but based on the few exposure measurement that were performed in the industrial area 2-3 weeks and 18 months following the explosion accident (Table 1) [1, 20, 22, 23] hazardous effects of the pollutants were unlikely in the present study, as such effects occur at much higher exposure levels (Table 3) [31, 32, 35-40, 42, 43].

Comparable to our study, people exposed to malodorous emissions of sulphurous air pollution from a pulp mill in Finland, reported more headache, depression and other psychological health complaints, even though the concentrations of hydrogen sulphide were below occupational exposure limits [30, 62].

Following accidents, few have studied health effects related to prolonged malodorous pollution like we did in our study. Our results are, however, comparable to findings in a cross sectional study of physical and mental symptoms among residents who experienced several years of malodorous air pollution due to an accidental mercaptan spill in Alabama, USA [29]. The residents who lived closest to a groundwater spring contaminated by mercaptans reported significantly more complaints, such as breathlessness, eye irritation, and agitated behaviour compared to controls who lived further away from the spring [29]. Most previous studies of health effects caused by malodorous chemical exposure have cross sectional designs, which makes assessments over time impossible [8, 29, 30, 62].

Despite the downward trend for subjective health complaints in our longitudinal study based on proximity to the explosion site, the exposed workers still had more neurological symptoms, compared to controls, after clean-up of the malodorous pollution. This is in line with the results following odour reduction in a petroleum refinery [60]. Also in this study the residents in the neighbourhood continued to report the same degree of health complaints, in spite of significantly reduced malodorous emissions from the refinery, and a decline in odour perception and annoyance by the participants [60].

In our study among employed workers dichotomized into odour score groups, we found that perception of the malodorous air pollution was a determinant of both subjective health complaints and post-traumatic stress symptoms before and even after clean-up. This mediating role of odour, on health complaints, was also suggested by a study in a petroleum refinery which implemented an odour reduction plan during the study period [67].

5.2.3 Possible mechanisms for health complaints

The sulphurous pollution following the explosion accident mainly comprised of compounds that are very potent odorants, but weak irritants, with irritation thresholds 1000 – 10 000 times higher than the corresponding odour thresholds [28] (Table 2). Based on the few air measurements from the area (Table 1) [22, 23], irritant mechanisms for the reported health complaints were less likely.

The presently described association between perceived odour, and physical and psychological symptoms, is presumably dependent on complex mechanisms which include both psychological and physiological responses [66, 73].

Apparently, the human olfactory sense has lost some of its importance through the evolution of the human being, but olfaction is still crucial for our ability to detect and identify potential environmental hazards [25, 96]. Odours with different hedonic tones provoke different feelings in humans, possibly dependent on how the stimulus is processed by the brain [76]. In an experimental study, large increases in amygdala activity were induced when the participants were exposed to the smell of highly aversive compounds including mercaptans [76], the same kind of compounds that were spread in the area during the explosion in Sløvåg. A smell can activate amygdala directly, without an initial, conscious processing by the olfactory cortex, and hence initiate unconscious, emotional responses to the smell [27]. Amygdala even modulates autonomic nervous system activity by influencing various physiological responses, such as heart rate, sweating and secretion of immunomodulating molecules [73].

The terms *bottom-up* and *top-down processing* are used in explanatory models on how odours are processed by the human nervous system [97, 98]. In *bottom-up processing*, perception of a stimulus is initiated by the stimulus itself, in this case an odour, which immediately can be perceived as pleasant or unpleasant, and by its intensity. In *top down processing*, the odour stimulus is analyzed according to previous knowledge, expectations and beliefs, and based on this interpretation perceived as hazardous or not (Figure 21) [97, 98]. Whether an odour is perceived as

hazardous or not, also seems to be crucial for an olfactory adaptation or a sensitization to occur [97, 99]. Typically, lasting odorous exposure leads to adaptation, but when told that an odour was potentially hazardous, test-persons did not adapt, but rather showed sensitization [97, 99].

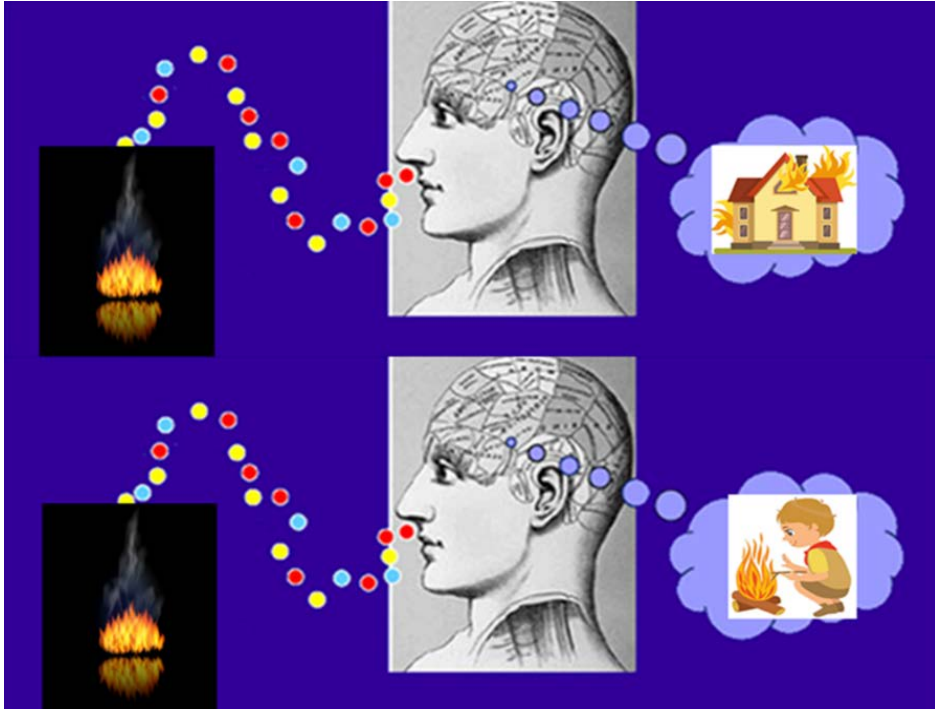


Figure 21: Interpretation based on previous experience is particularly important in connection with odorous exposure. In this figure, identical odorous exposure; in this case the smell of smoke from a bonfire, might result in fear, or a pleasant feeling dependent upon previous experience in the two persons.

Our study suggested that perceived odour was a determinant for both subjective health complaints and post-traumatic stress symptoms (Table 9). In previous epidemiological studies of subjective health complaints related to malodorous exposure, a mechanism mediated by odour perception and odour annoyance have been proposed [60, 64-68], and in a study of adverse health effects due to industrial and agricultural odours, health complaints were found to be exclusively mediated by

annoyance [69]. Annoyance is a negative emotion associated with any exposure believed to have an adverse effect [64], and involves an individual's perception, previous experiences, feelings and attitude towards this exposure [66]. People recently affected by major disasters including a chemical exposure often link their health complaints to the chemical exposure, even if a causal association, for instance exposure to hazardous levels of chemicals, is less likely [100]. A study among residents living close to a biofuel facility that emitted non-toxic levels of malodorous compounds concluded that both health complaints and annoyance were mediated by perceived pollution and health risk perception, and not directly by the exposure itself (Figure 22) [66]. Even worries about a possible health risk have been shown to increase physical symptoms among populations living close to hazardous waste sites [61].

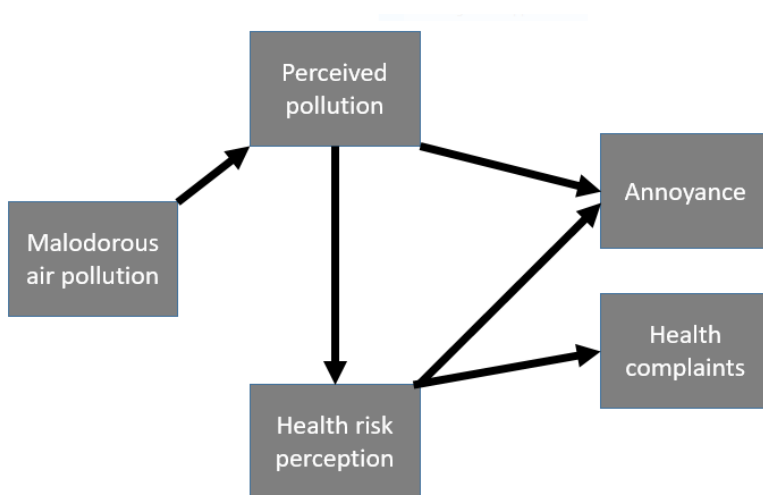


Figure 22: Health complaints might not be mediated by the malodorous pollution itself, but rather perceived pollution and health risk perception. Redrafted, modified version of a path-analytic model suggested by Claeson, 2012, fig. 2 [66].

In our study, it is likely that the incident-related foul odour could bring back memories of the accident, and result in anxiety or other stress-induced symptoms. The clean-up operation took more than two and a half years to complete, and

meanwhile the foul odour was persistently present, as a constant reminder of the explosion as well a cue to the possibility of a new, similar disaster. A term often used in studies involving odour is the *Proust phenomenon* [70, 73, 74]. The *Proust phenomenon* is the ability of a specific odour to evoke a specific memory [70, 73, 74]. Previous studies have shown that odour memories are more evocative than visual or verbal memories, and hence induce more emotional and detailed recollections [70]. Memories related to odours possibly also last for longer [70], and persistent stress-related symptoms, as we found in the high odour score group, might be the consequence.

Classical conditioning is another mechanism that could be of importance for the development of subjective health complaints among participants who experienced the accident and perceived the incident-related foul odour. Classical conditioning is a reflexive way of learning in which a stimulus, for instance a foul odour, gets the ability to cause a response that was originally caused by another stimulus. The natural response to the explosion accident might be fear, or other stress related symptoms. During conditioning the foul odour could acquire the capacity to evoke the same response. After conditioning the foul odour might by itself evoke a similar response through a conditioned reflex (Figure 23). Previous studies have suggested this kind of mechanism [72, 75, 77, 101, 102]. One experimental study put forward that aversive learning through conditioning increases the participant's sensitivity to the specific odour [101], and a single study has even suggested that perceived smells play a significant role in the pathophysiology of post-traumatic stress disorder (PTSD) [77]. Acquired fear due to classical conditioning theoretically wanes as time goes. However, one experimental study suggested that fear conditioned to odours extinguished slowly [72], and in soldiers who develop PTSD even an inability to extinguish the conditioned fear response has been shown [77].

Before conditioning:

Foul odour



No fear



Chemical accident



Natural reflex

Fear**During conditioning:**

Foul odour

+



Chemical accident



Natural reflex

Fear**After conditioning:**

Foul odour



Conditioned reflex

Fear

Figure 23: Through classical conditioning the foul incident-related odour could get the ability to cause a response that was originally caused by the explosion accident.

Odour is not the only factor that could be of importance for the development and persistence of psychological health complaints. At the sight of the burnt-down premises and big metal pieces from the destroyed tanks, intrusive memories could be evoked among those who lived close by or who frequently passed the area. Even pictures in different media might be potent visual triggers, and hence the lengthy media coverage emphasizing the possibility of adverse health effects might have been of importance for the persistent health complaints, even after clean-up. One experimental study found that visual cues induced more haunting or emotional memories than olfactory cues [74].

Proximity to the explosion site was also of importance for the manifestation of post-traumatic stress symptoms in our study based on perceived smell, as those who were at the site during the accident reported a higher degree of such symptoms (Table 9). This is in agreement with previous studies of post-traumatic stress reactions following accidents [102-104].

Time since the accident was of importance for post-traumatic stress symptoms as there was a significant decline of such symptoms over time among the participants in the high odour score group (Table 9). This is in agreement with previous clinical experience; that post-traumatic stress symptoms, in general, diminishes with time [103-105]. Time since the accident was of less importance for the change over time for subjective health complaints (Table 9).

Table 9: Suggested determinants for subjective health complaints and post-traumatic stress symptoms in the aftermath of a dramatic chemical explosion that emitted malodorous pollution.

Determinants	Subjective health complaints	Post-traumatic stress symptoms
Perceived incident-related odour	+	+
Proximity to explosion site ^a	-	+
Time passed since accident	+/-	+

^aBeing present at the accident site during the explosion.

5.3 Methodological considerations

5.3.1 Study design

The purpose of establishing a prospective cohort was to follow this population over four years, and thus be able to investigate possible long-term health effects and to study the development of symptoms over time [106-108]. The main advantages of a cohort study is that “exposure” can be identified before the outcome is measured, and the possibility to study multiple outcomes for a given “exposure” [108].

Paper I was a cross sectional study, performed to investigate a possible association between the exposure and health complaints among the affected population [1]. Paper I could only study associations, and not causality between the explosion accident and health complains [106]. Cross sectional studies are relatively easy to perform, and our study gave us the prevalence data we needed to evaluate the situation present in this population. Since the prevalence of health complaints among workers employed in the industrial area and clean-up workers was high, we decided to perform follow-up studies.

Therefore, papers II and III were longitudinal studies. In longitudinal studies, the cohort is followed over time, and data collected repetitively, and hence it was possible to study how the prevalence of health complaints changed among the different study groups as time passed, in Paper II and III [2, 3]. This is the main advantage of longitudinal designs.

In our studies there seem to be a link between the malodorous pollution and health complaints among the affected population. However, observational studies with a longitudinal design can only suggest possible causal links, whereas inference of a causal mechanism is not possible [106]. Disadvantages of longitudinal studies are that they usually take a long time to carry out, and hence, also are susceptible to loss to follow-up [106-108].

Qualitative methods using unstructured or semi-structured interviews have sometimes been used to assess different effects of malodorous environmental pollution [63, 93]. Such methods might also have been useful in our studies. However, they are very labour-intensive and only small cohorts could realistically be examined; thus the transfer value to other populations might be reduced [93].

5.3.2 Internal validity

Epidemiological studies are prone to random as well as systematic errors. Hence, it is important to consider alternative causes that may explain observations made in a study. *Bias* is another term for a systematic error. While the effect of random errors decreases with increased study size, the effect of a systematic error remains virtually constant, irrespective of study size. Biases can be divided into three broad categories: selection bias, information bias, and confounding [107].

Selection bias

Selection of study population

In epidemiological studies the selection of subjects is critical [108]. In the main cohort study, we invited all who were considered as possibly affected by the accident and by the malodorous pollution in the aftermath of the explosion, and defined them as exposed. Exposed inhabitants and workers were invited from a defined geographical area. Controls were selected from two, similar geographical areas more than 20 kilometers away. These were matched 1:1 by age and gender to the invited participants of the exposed group because age and gender typically are considered as strong confounders. From this main cohort we selected our study subjects for the studies based on proximity to the explosion site and the study based on perceived smell, respectively. Matching was done for the main cohort study, and not with the studies based on proximity to the explosion site or study based on perceived smell in mind. However, we have no reason to believe that matching especially done for these substudies would have changed our results significantly.

In a cohort study, it is important that both exposed and unexposed groups are selected from the same source population [108], and our use of controls from the same geographical area is therefore a strength. We considered using people living in an industrial area in another part of the country as controls, but decided against this because of possible differences in socio-economic parameters, and even in health status, between inhabitants in different parts of the country [109, 110]. Also for the study based on perceived smell, the participants in the two odour score groups were selected from the same source population (all employed workers aged 18-67).

Information about all the inhabitants was collected from the Norwegian National Registry [111], thus avoiding a self-selection of participants at this stage. Information about the workers in the exposed group was given by their respective employers, and hence this number of eligible subjects for the study was dependent on the completeness of the employer's registries. All participants were selected without us having previous knowledge of their health status.

In the study based on proximity to the explosion site, we decided not to include fire fighters and rescue personnel in our group of exposed workers to avoid possible biases introduced by a group of participants who supposedly could be different from the rest. We excluded all who reported that they had participated in firefighting because working on a scene of a disaster, is what fire fighters are trained for. Furthermore, fire fighters, and notably smoke divers, are specially selected for this kind of duty, and have to pass both health examinations and a physical test to achieve their fire fighter certificate.

However, in the study based on perceived odour, all employed workers were included, even the fire fighters, because supposedly fire fighters would also be affected by a foul odour. In 2008, the fire fighters were distributed with 65% (n=35) and 35% (n=19) into the low and high odours score groups, respectively (Table 8), and they accounted for 11% of the total sample. In order to assess a possible skewed distribution of health complaints, we did crude analyses in which we compared the total SHC score, the subjective neurological subscale score and total IES-R score

between fire fighters and the rest of the study population. There were no significant differences in total SHC score, subjective neurological subscale score or total IES-R score between the fire fighters and the rest of the study population in 2008, 2010 and 2012, respectively. Nevertheless, we could not rule out that their participation could have biased the result.

Another group that we excluded from all our studies in this doctoral thesis was adults who were not employed in 2008. This group included people who received sickness or disability benefits. Since we did not know if they were out of employment due to health complaints diagnosed before the accident, they were all excluded to avoid possible biases.

Response rates

Cohort studies are prone to low response rates, which can compromise the validity of the study [107, 112]. In the 2008-survey, the overall response rate was 72%, highest among workers potentially affected by the accident or involved in the clean-up operation (86 %), and lowest in the control group (59%) [15]. There are no strict rules on what a response rate ought to be, but at least 70-75% have been suggested [106]. We consider the response rates of our study to be acceptable. However, we had no information about those who did not respond. On one hand, they might have been those who were too sick to attend, leaving us with the healthiest participants, and hence, the possibility of a *healthy volunteer effect* [113], or, on the contrary; the non-responders could be those who had no complaints, and therefore considered the health survey as irrelevant for them to participate in.

Loss to follow up

In a longitudinal study, the validity can also be compromised if participants are lost to follow up [114]. A rule of thumb that the loss to follow-up should not exceed 20%, has been suggested [108], but in our studies the loss to follow-up in 2012 was 29% and 28% in the studies based on proximity to the explosion site and study based on perceived smell, respectively. In order to characterize those who were lost to follow up, we did crude analyses in which we compared the total SHC score, the subjective

neurological subscale score and total IES-R score in 2008 between those who were lost to follow up in 2012 and those who participated in 2008 as well as in 2012. In the longitudinal study based on proximity to the explosion site, there were no significant difference in total SHC score in 2008 between those who were lost to follow up when compared to those who participated in both surveys, but those who were lost to follow up had a significantly higher subjective neurological subscale score ($p=0.02$). This might have underestimated the effect on the subjective neurological subscale score in 2012. Furthermore, those who were lost to follow up were significantly younger ($p=0.01$). Since younger people tend to have better self-perceived health [109], loss of the youngest participants might have led to an overestimation of the health complaints among the participants in 2012. In the study based on perceived smell, there were no significant differences in total SHC score, subjective neurological subscale score or total IES-R score in 2008 between those who were lost to follow up and those who participated in 2012. Even in this study those who were lost to follow up were significantly younger ($p<0.001$).

Different loss to follow up in the exposed group and controls might also introduce bias [108]. In the longitudinal study based on proximity to the explosion site, the loss to follow-up in 2012 ($n=81$), were similar among the exposed workers (employees and clean-up workers) and the controls (28% and 29%, respectively). In the study based on perceived smell, the loss to follow-up in 2012 ($n=134$), was higher among the low odour score group compared to the high odour score group (30% vs 25%). If those who had least health complaints in the low odour score group lost interest, and decided not to participate in 2012, the loss to follow up might have underestimated the differences between the two odour score groups.

Healthy worker effect

In studies of health among workers, the phenomenon *healthy worker effect* is often encountered [107, 115]. This effect can cause both selection bias and confounding [107, 115]. In our studies, we aimed at minimizing biases introduced due to the healthy worker effect by using employed controls rather than a reference group from the general population.

Our study population differed from the general population because it comprised of the supposedly healthiest part of the population. The general population in addition includes many people who cannot work because of failing health. By studying only the healthiest, the effect of the exposure on health might have been underestimated.

Information bias

A systematic error may result if the information collected about, or from, the participants is wrong. If information is measured on a categorical scale, a participant will end up in an incorrect category if the variable is misclassified [107].

Misclassification of exposure

In the studies in this doctoral thesis, the participants could potentially be misclassified according to two different “exposure” categories; worker in the industrial area/clean-up worker vs control, and high vs low odour score group.

In the studies based on proximity to the explosion site, information about the participants was collected from the questionnaire in the 2008 survey, and the participants were grouped accordingly. The variability in incident-related exposure was large within the exposed group, but probably their chemical exposure due to the accident was higher than for all the controls. Nevertheless, due to the lack of objective exposure measures, we cannot exclude the possibility of exposure misclassification.

In the study based on perceived smell, the participants were grouped according to their odour score, a subjective measure developed especially for this study due to the lack of any suitable objective measurement of odour [93]. Those who were more annoyed by the foul odour might have a tendency to report perceived odour during a longer period of months, thus yielding a higher odour score. Nevertheless, since perceived smell is subjective sensation, an individual odour score is likely to be less prone to exposure misclassification than, for instance, distance to the odorous source [65].

Biased health information

We used validated questionnaires to assess symptoms among the study population. Because subjective health complaints and post-traumatic stress symptoms often have no, or only minimal clinical findings, a clinical health examination would be less useful than questionnaires to assess the health status of the population.

The results of our study might have been influenced by the extensive media coverage, including the possibility of a higher report of symptoms than without the media focus. A substantial negative effect due to perceived health risk communicated by the mass media has previously been shown in affected populations [116, 117].

In Norway, economical compensations are sometimes given from the authorities if an occupational accident causes a personal injury, illness or death [118, 119]. The expectancy of some kind of compensation for the health complaints in the aftermath of the accident might also have influenced the report of symptoms among the participants.

Recall bias

When subjective information is collected from participants in a survey, the information will be subject to the participants' ability to remember accurately. Participants directly affected by the explosion accident, would be liable to remember more details concerning the accident and the malodorous pollution, and possibly report more incident-related health effects. In this case a recall bias might result. A recall bias can overestimate or underestimate an effect [107].

To minimize recall bias, we used a validated instrument (SHC) that enquires about different subjective health complaints only during the previous 30 days, and regardless of the accident. For the post-traumatic stress symptoms we also used a validated questionnaire (IES-R). This instrument asked about such symptoms the previous seven days, but related to the specific accident. Most people are possibly capable of remembering any health complaints they have experienced the last week or the last month, thus lowering the chance of a recall bias. However, the IES-R

instrument asks for symptoms related to the specific accident, which might introduce another methodological problem; the difficulty in relating present stress symptoms to the accident when asked up to five and a half years post-disaster. We do not know how a possible recall bias might have affected the results of our studies, but participants directly affected by the accident, might have a tendency to report more symptoms related to the incident, thus overestimating an effect. Furthermore, we did not have any information about other traumatic incidents the participants might have experienced during the study period.

Common method bias

Observational studies based on questionnaires are prone to common method biases if the participants are asked about exposure and outcome in the same questionnaire [120]. The association between the exposure and the outcome tends to be overestimated in such cases, in particular in cross sectional studies [121].

During the surveys, great care was taken not to use the term “control” or “control group”, neither in the invitation letters or questionnaires (Appendixes I, III and IV), nor while examining the participants clinically. Instead we used the term “inhabitants” in the Gulen and Masfjorden municipalities. Nevertheless, the participants themselves knew if they were among those who were directly affected by the explosion accident and the following malodorous environmental pollution or not. This might have biased the results.

In our longitudinal studies, the exposure classifications were solely based on information collected from the questionnaire of the 2008 survey, whereas health outcomes were collected from all three surveys. Such a temporal separation or time lag between the exposure classification predictors and the health outcomes might have reduced the effect of a possible common method bias [120].

Confounding

A confounder is a factor that is associated with the outcome as well as the exposure. Confounding arises when the effect of exposure is mixed with the effect of another

variable, the confounder, and result in bias due to a confusion of effects [107]. Gender, age, smoking habits, and educational level are examples of factors known to be possible confounders for the development of SHC and PTSS [64, 92, 102, 103, 109, 122-128]. Even the proximity to the explosion site was a possible confounder the present study [102-104].

Gender

Previous studies of risk factors for persistent health complaints after traumatic incidents have shown that gender might affect the outcome. In longitudinal studies after a major explosion in a fireworks depot, women had more physical and psychological post-disaster symptoms [123, 129]. Also in a representative sample of the general Norwegian population, women were found to have a higher prevalence of subjective health complaints, and they reported more intense complaints, compared to men [92, 128]. In a study concerning annoyance and worry in a petrochemical industry, women proved to be more annoyed than men, by industrial air pollution, and even to be more worried about possible health effects due to the malodorous emissions [64]. In another study, women who did not see any benefits from a petroleum refinery also reported more general health complaints [67]. Previous studies have even suggested that women are superior to men in their ability to perceive or identify odours [125]. Former studies have also shown that women who experience a traumatic event, for unknown reason are at greater risk of developing PTSD, compared to men [122].

In our studies, we considered the number of participating women to be too low to allow analyses stratified on gender. However, in the studies based on proximity to the explosion site, there were no significant gender differences in the crude analyses of the total SHC score and subjective neurological complaints subscale scores. Neither did we find any significant gender differences in the crude analyses of total SHC score and total IES-R score in the study based on perceived odour. We used regression models and mixed effects models with adjustment for gender to control possible confounding by gender.

Smoking

Due to the many known negative health effects of tobacco smoking, it is reasonable to assume that smokers would report more health complaints compared to non-smokers, and hence, smoking is an important possible confounder that must be addressed.

In the present study, where malodorous exposure is a major issue, even the ability to perceive the odour is of importance. Previous studies have shown that current smokers were twice as likely to have an olfactory deficit than never-smokers [124]. From previous studies it is also known that tobacco smoking alters odour detection thresholds in a dose-related manner [124, 125], and causes long-term, but reversible adverse effects on the ability to smell [124]. Possibly this effect from smoking was of minor relevance for the smokers in our study due to the very low odour thresholds of the sulphurous compounds in question.

In the studies based on proximity to the explosion site, smokers had a significantly higher total SHC score in the crude analyses in 2008 as well as in 2012, when compared to non-smokers. They also had a significantly higher subjective neurological subscale score in 2008. In the study based on perceived smell, smokers had a significantly higher total SHC score in the crude analyses in 2008 and 2012. There were no significant differences in the crude total IES-R scores between smokers and non-smokers.

To control confounding due to smoking, we used regression models and mixed effects models with adjustment for smoking in all our analyses. Since the habit of smoking often change as time pass, we used information on smoking habits (daily smoker or non-smoker) from all three surveys (2008, 2010 and 2012) in the crude analyses and in the mixed effects models in the longitudinal studies.

Age

Self-perceived health tends to be rated lower with increasing age [109], and must therefore also be addressed as a possible confounding factor. In our studies, we

restricted the study population to adults of working age, which in Norway usually is 18-67 years. By this restriction we avoided the effect of increasingly negative perceived health among the oldest part of the population. We also used regression models and mixed effects models with adjustments for age to control confounding. The participants were grouped into four age categories each comprising a similar number of individuals.

Education

Statistics on self-reported health status among the population of the European Union (EU) showed that people with a high educational attainment perceived their health as better, compared to those with low educational attainment [109]. Furthermore, education was a significant factor when the associations between social inequalities and subjective health complaints were examined in five different occupational groups in Norway [128]. Hence, educational level was also a possible confounder in our study. To control confounding due to this factor, we used regression models and mixed effects models with adjustment for educational level, which was dichotomized into three groups.

5.3.3 External validity

External validity of a study is to what extent the research results of a sample can be generalized to make predictions about populations that were not studied [107, 130].

The participants of the studies included in this doctoral thesis, comprise of the supposedly healthiest part of the population. The results of our study are probably relevant if similar chemical accidents happen, in Norway or in other countries, and adults of working age are exposed to a malodorous, environmental pollution for a long time. Parts of the results are possibly also relevant in cases of long-lasting malodorous environmental pollution without an initial dramatic incident. Our results are mainly applicable for employed workers, and cannot directly be generalized to the general population.

6 Conclusions and recommendations

The overall aim of this study was to investigate long-term health effects among workers in the aftermath of a dramatic chemical explosion that emitted malodorous pollution in an industrial harbour area. The foul-smelling pollution mainly comprised of mercaptans and other sulphurous compounds, which have very low odour thresholds compared to their irritation or hazardous thresholds.

Conclusions

We found that employees in the industrial area and clean-up workers had more subjective health complaints, especially neurological symptoms, compared to controls living in areas more than 20 kilometres away, both one and a half, and five and a half years after the dramatic explosion. A decrease of complaints among exposed workers during the study period, could be due to the decreased exposure to malodorous pollutants, time passed since the accident, or both. Further investigations concluded that perception of malodorous environmental pollution was a determinant of both subjective health complaints and post-traumatic stress symptoms among employed workers, before and even after the pollution was eliminated.

Recommendations

Preparedness for chemical accidents

The nature of industrial disasters such as the explosion in the industrial area in Sløvåg is that they happen unexpectedly. Preparedness is therefore of utmost importance in order to minimize the environmental and human consequences of such accidents. To be prepared, every company, and in particular companies handling hazardous chemicals and inflammable compounds, are instructed to have an emergency plan in case of accidents [131]. The local municipality also have a responsibility when it comes to environmental politics and preparedness in case of disasters [132]. The investigation following the accident in Sløvåg revealed several weaknesses in the preparedness plans for environmental accidents among both the tank company and the local municipality [133].

In the aftermath of the explosion accident in Sløvåg, it has been questioned if it is reasonable that all of Norway's more than 400 municipalities [134], regardless of numbers of inhabitants, should be instructed to have the professional competence and the resources to handle big disasters [132]. According to the new Norwegian Public Health Act, which was revised after the explosion accident [135], the Norwegian National Health Institute is now instructed to assist municipalities when major chemical accidents happen [132]. The new regulation also instructs the local health care services to report chemical accidents with potential health effects to the national health authorities [132].

Risk communication

When chemical accidents happen, it is reasonable that the affected population are worried and immediately requests reliable information about consequences, possible health risk, and advice on how to respond. The population living in the vicinity of the industrial area in Sløvåg proved to be no different, especially when they experienced different health complaints shortly after the explosion. At this stage following an accident, proper risk communication is of major importance. All companies and all municipalities should have a plan for risk and crisis communication. In all risk communication it is important to take potential worries seriously. Trustworthiness and confidence is essential, and conflicting messages should be avoided, especially from specialists and authorities [136]. Furthermore, the mass media have a special responsibility when it comes to rapid distribution of reliable information [136].

Responsibilities of national supervisory authorities

The investigation following the explosion accident in the industrial area in Sløvåg also revealed irregularities in the oil tank company's reporting procedures to the national supervisory authorities, and the authorities' lack of inspections of the oil tank company, even after a notice of possible illegal activity had been given [133]. Better routines among both the oil tank company, and the national supervisory authorities as well as better cooperation between the different national supervisory authorities are of importance to avoid similar accidents in the future [18]. Furthermore, better

cooperation between local and national authorities, and between the different national authorities might have reduced the long term consequences for the affected population.

Other recommendations based on the results from the study

Populations recently affected by an industrial disaster frequently report acute accident-related physical and psychological symptoms. Our study suggests long term health effects in the aftermath of the malodorous pollution, even after clean-up. As a consequence, health personnel should be aware that health complaints might be related to polluting episodes even when exposure levels are below occupational exposure limits.

Following the explosion in the oil tank in Sløvåg, it took more than two years to finish the clean-up operation. Local and national authorities should prioritize clean-up after polluting episodes because early clean-up seems to be important to avoid persistent health effects after malodorous chemical spills.

Recommendations concerning research strategies after chemical accidents

In order to study health effects in the aftermath of chemical accidents, it is of major importance to characterize the chemical composition of the pollution and measure relevant exposure levels as soon as possible after the incident. Knowledge about the exposure and potential health effects should be used to target the research. If possible, objective measures of health should be included. Longitudinal cohort studies are useful to study health effects and possible development of such effects over time, and should be performed with the first survey as soon as possible after the accident. Furthermore, the research should be performed by scientists with competence within epidemiology, chemical exposure, and health effects.

7 References

1. Tjalvin, G., et al., *Subjective Health Complaints Among Workers in the Aftermath of an Oil Tank Explosion*. Arch Environ Occup Health, 2015. **70**(6): p. 332-40.
2. Tjalvin, G., et al., *Health complaints after a malodorous chemical explosion: a longitudinal study*. Occup Med (Lond), 2015. **65**(3): p. 202-9.
3. Tjalvin, G., et al., *Odour as a determinant of persistent symptoms after a chemical explosion, a longitudinal study*. Ind Health, 2017. **55**(2): p. 127-137.
4. Aguilera, F., et al., *Review on the effects of exposure to spilled oils on human health*. J Appl Toxicol, 2010. **30**(4): p. 291-301.
5. Dhara, V.R. and R. Dhara, *The Union Carbide disaster in Bhopal: a review of health effects*. Arch Environ Health, 2002. **57**(5): p. 391-404.
6. Harada, M., *Minamata disease: methylmercury poisoning in Japan caused by environmental pollution*. Crit Rev Toxicol, 1995. **25**(1): p. 1-24.
7. Pesatori, A.C., et al., *Short- and long-term morbidity and mortality in the population exposed to dioxin after the "Seveso accident"*. Ind Health, 2003. **41**(3): p. 127-38.
8. Ackermann-Lieblich, U.A., C. Braun, and R.C. Rapp, *Epidemiologic analysis of an environmental disaster: the Schweizerhalle experience*. Environ Res, 1992. **58**(1): p. 1-14.
9. Morgan, O., et al., *Exposures and reported symptoms associated with occupational deployment to the Buncefield fuel depot fire, England 2005*. Occup Environ Med, 2008. **65**(6): p. 404-11.
10. van Kamp, I., et al., *Physical and mental health shortly after a disaster: first results from the Enschede firework disaster study*. Eur J Public Health, 2006. **16**(3): p. 253-9.
11. Dirkzwager, A.J., C.J. Yzermans, and F.J. Kessels, *Psychological, musculoskeletal, and respiratory problems and sickness absence before and after involvement in a disaster: a longitudinal study among rescue workers*. Occup Environ Med, 2004. **61**(10): p. 870-2.
12. Grievink, L., et al., *A longitudinal comparative study of the physical and mental health problems of affected residents of the firework disaster Enschede, The Netherlands*. Public Health, 2007. **121**(5): p. 367-74.
13. van den Berg, B., et al., *Symptoms and related functioning in a traumatized community*. Arch Intern Med, 2005. **165**(20): p. 2402-7.
14. Tande, R.M., et al., *Rapport om helseplager i Gulen og Masfjorden kommunar etter ulukka i Vest Tank sitt anlegg i Sløvåg 24.05.2007. [Report on subjective health complaints in Gulen and Masfjorden municipalities subsequent to the accident at the Vest Tank plant in Sløvåg 24 May 2007] (In Norwegian)*. 2008: Gulen/Masfjorden, Norway.
15. Hollund, B.E., et al., *Helseundersøkelse etter Sløvåg-ulykken. Presentasjon av resultatene etter første undersøkelse 2008-2009. [Health assessment after the Sløvåg accident. Results from the initial survey in 2008-2009] (In Norwegian)*. 2009, Haukeland University Hospital/University of Bergen: Bergen, Norway.

16. Skjold, T., et al., *Accident investigation following the Vest Tank explosion at Sløvåg*. 2008, Gexcon: Bergen, Norway.
17. Okkenhaug, G., *Miljøteknisk undersøkelse etter eksplosjon og brann 24. mai 2007 [Geotechnical examination of the environment following explosion and fire 24th May 2007] (In Norwegian)*. 2007, The Norwegian Geotechnical Institute (NGI): Oslo, Norway.
18. *Vest Tank-ulykken. Erfaringer fra myndighetenes samlede håndtering av Vest Tank-ulykken i Gulen kommune [Summary of the authorities' collective management of the Vest Tank accident in Gulen municipality] (In Norwegian)*. 2007, The Directorate for Civil Protection and Emergency Planning: Tønsberg, Norway.
19. *Crude oils have different quality characteristics*. U.S. Energy Information Administration (EIA), US Department of Energy. 26.06.2013; Available from: <http://www.eia.gov/todayinenergy/detail.php?id=7110>.
20. *Miljømedisinsk vurdering av kjemikalieulykken ved Vest Tank 24.5.2007 i Gulen [Environmental medicine assessment of the chemical accident at Vest Tank 24 May 2007 in Gulen] (In Norwegian)*. The Norwegian Institute of Public Health: Oslo, Norway.
21. *Tankanlegget i Sløvåg er tomt [The plant in Sløvåg has been emptied] (In Norwegian)*. Bergensavisen [Newspaper] 2010 11.02.2010; Available from: <https://www.ba.no/gulen-eksplosjonen/tankanlegget-i-slovag-er-tomt/s/1-41-4855447>.
22. Rasmussen, S., *Luftprøver for analyse av svovelholdige forbindelser og løsemidler, Vest Tank, juni 2007 [Air samples for analysis of sulphurous compounds and solvents, Vest Tank, June 2007] (In Norwegian)*. 2007, X-lab: Bergen, Norway.
23. Westby, M., Hetland, S., *Kartlegging av diffuse utslipp til luft fra tank 61 og 63 ved Aleksela, Sløvåg, November 2008 [Mapping of emissions to the air from tanks 61 and 63 at Aleksela, Sløvåg, November 2008] (In Norwegian)*. 2008, Eurofins Norge: Oslo, Norway.
24. Hornung, R.W. and L.D. Reed, *Estimation of Average Concentration in the Presence of Nondetectable Values*. Applied occupational and environmental hygiene, 1990. **5**(1): p. 46-51.
25. Patel, R.M. and J.M. Pinto, *Olfaction: anatomy, physiology, and disease*. Clin Anat, 2014. **27**(1): p. 54-60.
26. Dalton, P., *Odor, irritation and perception of health risk*. Int Arch Occup Environ Health, 2002. **75**(5): p. 283-90.
27. Krusemark, E.A., et al., *When the sense of smell meets emotion: anxiety-state-dependent olfactory processing and neural circuitry adaptation*. J Neurosci, 2013. **33**(39): p. 15324-32.
28. Shusterman, D., *Odor-associated health complaints: competing explanatory models*. Chem Senses, 2001. **26**(3): p. 339-43.
29. Behbod, B., et al., *Community Health Assessment Following Mercaptan Spill: Eight Mile, Mobile County, Alabama, September 2012*. J Public Health Manag Pract, 2013. **20**(6): p. 632-9.

30. Partti-Pellinen, K., et al., *The South Karelia Air Pollution Study: effects of low-level exposure to malodorous sulfur compounds on symptoms*. Arch Environ Health, 1996. **51**(4): p. 315-20.
31. *Hydrogen sulfide: TLV Chemical Substances*. 7 ed. American Conference of Governmental Industrial Hygienists. 2010, Cincinnati, Ohio, USA.
32. Guidotti, T.L., *Hydrogen sulfide: advances in understanding human toxicity*. Int J Toxicol, 2010. **29**(6): p. 569-81.
33. *Air quality guidelines for Europa*, in *WHO Regional Publications, European Series*. 2000, World Health Organization Regional Office for Europe: Copenhagen, Denmark. p. 146-148.
34. Sandmeyer, E., *Organic Sulfur Compounds*, in *Patty's Industrial Hygiene and Toxicology*, G. Clayton and F. Clayton, Editors. 1981, John Wiley & Sons: New York, USA. p. 2061-2119.
35. *Addendum to the Toxicological Profile for Methyl Mercaptan (1992)*. in *Toxicological profiles*. 2014, Agency for Toxic Substances and Disease Registry Division of Toxicology and Human Health Sciences: Atlanta, Georgia, USA.
36. *n-Butyl mercaptan: TLV Chemical Substances*. 7 ed. American Conference of Governmental Industrial Hygienists. 2001, Cincinnati, Ohio, USA.
37. *Ethyl mercaptan: TLV Chemical Substances*. 7 ed. American Conference of Governmental Industrial Hygienists. 2004, Cincinnati, Ohio, USA.
38. *Methyl mercaptan: TLV Chemical Substances*. 7 ed. American Conference of Governmental Industrial Hygienists. 2004, Cincinnati, Ohio, USA.
39. *Propyl mercaptan*. TOXNET, US National Library of Medicine; Available from: <https://toxnet.nlm.nih.gov/cgi-bin/sis/search2/r?dbs+hsdb:@term+@rn+@rel+107-03-9>.
40. *Sulfur dioxide: TLV Chemical Substances*. 7 ed. American Conference of Governmental Industrial Hygienists. 2009, Cincinnati, Ohio, USA.
41. *What does VOC mean?* Eurofins Scientific 25.10.2016; Available from: <http://www.eurofins.com/voc.aspx>.
42. Sandmeyer, E., *Aliphatic Hydrocarbons*, in *Patty's Industrial Hygiene and Toxicology*, G. Clayton and F. Clayton, Editors. 1981, John Wiley & Sons: New York, USA. p. 3175-3220.
43. Sandmeyer, E., *Aromatic Hydrocarbons*, in *Patty's Industrial Hygiene and Toxicology*, G. Clayton and F. Clayton, Editors. 1981, John Wiley & Sons: New York, USA. p. 3253-3431.
44. *Svært giftig oljeslam etter Vest Tank-eksplosjon [The Vest Tank explosion leaves behind very toxic oil-base mud] (In Norwegian)*. VG [Newspaper] 07.06.2008; Available from: <http://www.vg.no/nyheter/innenriks/svaert-giftig-oljeslam-etter-vest-tank-eksplosjon/a/501613/>.
45. *Mener Vest Tank løy om avfall [Believes Vest Tank lied about waste] (In Norwegian)*. VG [Newspaper] 31.05.2008; Available from: <http://www.vg.no/nyheter/innenriks/miljoevern/mener-vest-tank-loey-om-avfall/a/195859/>.
46. *Helseplager ett år etter eksplosjon [Health issues one year after explosion] (In Norwegian)*. VG [Newspaper] 21.05.2008; Available from:

- <http://www.vg.no/forbruker/helse/helse-og-medisin/helseplager-ett-aar-etter-eksplosjon/a/527497/>.
47. *Act Concerning Protection Against Pollution and Concerning Waste (Pollution Control Act)* Ministry of Climate and Environment, Oslo, Norway [Legal rule] 20.06.2003; Available from: <https://www.regjeringen.no/en/dokumenter/pollution-control-act/id171893/>.
 48. *Act relating to Working Environment, Working Hours and Employment Protection, etc. (Working Environment Act)*. Directorate of Labour Inspection, Trondheim, Norway [Legal rule] 18.12.2015; Available from: <http://www.arbeidstilsynet.no/binfil/download2.php?tid=92156>.
 49. *Act relating to the Prevention of Fire, Explosion and Accidents involving Hazardous Substances and the Fire Services (Fire and Explosion Prevention Act)*. Ministry of Justice and Public Security, Oslo, Norway [Legal rule] 14.06.2002; Available from: <http://dsbinfo.no/Global/Publikasjoner/Tidligere/Andre/Act%20relating%20to%20the%20Prevention%20of%20Fire.pdf>.
 50. *Høyesterett – straffutmåling for brudd på forurensningsloven, arbeidsmiljøloven og brann- og eksplosjonsvernloven [Supreme Court of Norway – sentencing following violation of the Pollution Control Act, the Working Environment Act and the Fire and Explosion Prevention Act] (In Norwegian)*. Supreme Court of Norway, Oslo, Norway 24.01.2012; Available from: https://lovdata.no/artikkel/hoyesterett_straffutmaling_for_brudd_pa_forurensningsloven_arbeidsmiljolooven_og_brann-og_eksplosjonsvernloven/180.
 51. *Tidenes strengeste miljødom i Høyesterett [The strictest environmental conviction ever by the Norwegian Supreme Court] (In Norwegian)*. Norwegian National Authority for Investigation and Prosecution of Economic and Environmental Crime, Oslo, Norway 12.04.2012; Available from: <http://www.okokrim.no/tidenes-strengeste-miljoedom-i-hoyesterett.416269.no.html>.
 52. *Høyesterett økte straffen for Vest Tank-leder [The Norwegian Supreme Court levied tougher conviction for Vest Tank manager] (In Norwegian)*. Norwegian Environment Agency, Trondheim, Norway 20.01.2012; Available from: http://www.miljodirektoratet.no/no/Nyheter/Nyheter/Old-klif/2012/Januar_2012/Hoyesterett_oke_straffen_for_Vest_Tank_leder/.
 53. *Styreleder i Vest Tank dømt til fengsel [Prison sentence for chairman of the board of Vest Tank] (In Norwegian)*. TV2 [Newspaper] 08.03.2013; Available from: <http://www.tv2.no/a/4004388/>.
 54. Elklit, A., *Psychological consequences of a firework factory disaster in a local community*. Soc Psychiatry Psychiatr Epidemiol, 2007. **42**(8): p. 664-8.
 55. Sabucedo, J.M., et al., *Symptomatic profile and health-related quality of life of persons affected by the Prestige catastrophe*. Disasters, 2010. **34**(3): p. 809-20.
 56. Gill, D.A. and J.S. Picou, *Technological disaster and chronic community stress*. Society & Natural Resources, 1998. **11**(8): p. 795-815.

57. Elklit, A. and D.M. Christiansen, *Predictive factors for somatization in a trauma sample*. Clin Pract Epidemiol Ment Health, 2009. **5**: p. 1.
58. van den Berg, B., et al., *Disaster exposure as a risk factor for mental health problems, eighteen months, four and ten years post-disaster--a longitudinal study*. BMC Psychiatry, 2012. **12**: p. 147.
59. Carrasco, J.M., et al., *Health-related quality of life and mental health in the medium-term aftermath of the Prestige oil spill in Galiza (Spain): a cross-sectional study*. BMC Public Health, 2007. **7**: p. 245.
60. Luginaah, I.N., et al., *A longitudinal study of the health impacts of a petroleum refinery*. Soc Sci Med, 2000. **50**(7-8): p. 1155-66.
61. Shusterman, D., et al., *Symptom prevalence and odor-worry interaction near hazardous waste sites*. Environ Health Perspect, 1991. **94**: p. 25-30.
62. Haahtela, T., et al., *The South Karelia Air Pollution Study: acute health effects of malodorous sulfur air pollutants released by a pulp mill*. Am J Public Health, 1992. **82**(4): p. 603-5.
63. Lowman, A., et al., *Land application of treated sewage sludge: community health and environmental justice*. Environ Health Perspect, 2013. **121**(5): p. 537-42.
64. Axelsson, G., et al., *Annoyance and worry in a petrochemical industrial area - prevalence, time trends and risk indicators*. Int J Environ Res Public Health, 2013. **10**(4): p. 1418-38.
65. Blanes-Vidal, V., *Air pollution from biodegradable wastes and non-specific health symptoms among residents: direct or annoyance-mediated associations?* Chemosphere, 2015. **120**: p. 371-7.
66. Claeson, A.S., et al., *The role of perceived pollution and health risk perception in annoyance and health symptoms: a population-based study of odorous air pollution*. Int Arch Occup Environ Health, 2013. **86**(3): p. 367-74.
67. Luginaah, I.N., et al., *Community reappraisal of the perceived health effects of a petroleum refinery*. Soc Sci Med, 2002. **55**(1): p. 47-61.
68. Steinheider, B., *Environmental odours and somatic complaints*. Zentralbl Hyg Umweltmed, 1999. **202**(2-4): p. 101-19.
69. Sucker, K., R. Both, and G. Winneke, *Review of adverse health effects of odours in field studies*. Water Sci Technol, 2009. **59**(7): p. 1281-9.
70. Chu, S. and J.J. Downes, *Odour-evoked autobiographical memories: psychological investigations of proustian phenomena*. Chem Senses, 2000. **25**(1): p. 111-6.
71. Croy, I., et al., *PTSD, but not childhood maltreatment, modifies responses to unpleasant odors*. Int J Psychophysiol, 2010. **75**(3): p. 326-31.
72. Leer, A., et al., *Odors eliciting fear: a conditioning approach to Idiopathic Environmental Intolerances*. J Behav Ther Exp Psychiatry, 2011. **42**(2): p. 240-9.
73. Matsunaga, *Psychological and physiological responses to odor-evoked autobiographic memory*. Activitas Nervosa Superior Rediviva, 2011. **53**(3): p. 114-120.
74. Toffolo, M.B., M.A. Smeets, and M.A. van den Hout, *Proust revisited: odours as triggers of aversive memories*. Cogn Emot, 2012. **26**(1): p. 83-92.

-
75. Vermetten, E. and J.D. Bremner, *Olfaction as a traumatic reminder in posttraumatic stress disorder: case reports and review*. J Clin Psychiatry, 2003. **64**(2): p. 202-7.
 76. Zald, D.H. and J.V. Pardo, *Emotion, olfaction, and the human amygdala: amygdala activation during aversive olfactory stimulation*. Proc Natl Acad Sci U S A, 1997. **94**(8): p. 4119-24.
 77. Cortese, B.M., K. Leslie, and T.W. Uhde, *Differential odor sensitivity in PTSD: Implications for treatment and future research*. J Affect Disord, 2015. **179**: p. 23-30.
 78. Tjalvin, G., et al., *Helseundersøkelse etter Sløvåg-ulykken. Resultatene etter helseundersøkelsene i 2008 og 2012. [Health assessment following the Sløvåg accident. Results after surveys in 2008 and 2012] (In Norwegian)*. 2014, Haukeland University Hospital/University of Bergen: Bergen, Norway.
 79. Aumo, L., et al., *Helseundersøkelse 2 etter Sløvåg-ulykken. Presentasjon av resultatene etter spørreskjemaundersøkelsen i 2010-2011. [Health assessment 2 following the Sløvåg accident. Results from the questionnaire survey in 2010-11] (In Norwegian)*. 2011, Haukeland University Hospital/University of Bergen: Bergen, Norway.
 80. Moen, B.E., et al. *Helseplager blant barn i Sløvåg som opplevde en oljetankeplosion i sitt nærmiljø [Health complaints among children who experienced an oil tank explosion in Sløvåg] (In Norwegian)*. Sykepleien Forskning 2013 27.09.2013; Available from: <https://sykepleien.no/forskning/2013/07/helseplager-blant-barn-i-slovag-som-opplevde-en-oljetankeplosion-i-sitt>.
 81. *Standardized questionnaire on respiratory symptoms (ATS-DLD-78A)*. 1994, American Thoracic Society Division of Lung Diseases.
 82. Chalder, T., et al., *Development of a fatigue scale*. J Psychosom Res, 1993. **37**(2): p. 147-53.
 83. DeSalvo, K.B., et al., *Mortality prediction with a single general self-rated health question. A meta-analysis*. J Gen Intern Med, 2006. **21**(3): p. 267-75.
 84. Eriksen, H.R., C. Ihlebaek, and H. Ursin, *A scoring system for subjective health complaints (SHC)*. Scand J Public Health, 1999. **27**(1): p. 63-72.
 85. Wasserfallen, J.B., et al., *Development and validation of a rhinoconjunctivitis and asthma symptom score for use as an outcome measure in clinical trials*. J Allergy Clin Immunol, 1997. **100**(1): p. 16-22.
 86. Weiss, D., *The impact of event scale – revised*, in *Assessing psychological trauma and PTSD: A practitioner's handbook. Second edition*. 2004, Guilford Press: New York, USA. p. 168-189.
 87. Leiknes KA, M.E., Leganger S, *MINI internasjonalt neuropsykiatrisk intervju [MINI International Neuropsychiatric Interview] Norwegian version 5.0.0*. 2007, Sheehan DV & Lecrubier Y, 1992-2006.
 88. Granslo, J.T., et al., *Airway symptoms and lung function in the local population after the oil tank explosion in Gulen, Norway*. BMC Pulm Med, 2012. **12**: p. 76.

89. Granslo, J.T., et al., *Airway symptoms and lung function among male workers in an area polluted from an oil tank explosion*. J Occup Environ Med, 2014. **56**(9): p. 953-8.
90. Granslo, J.T., et al., *A follow-up study of airway symptoms and lung function among residents and workers 5.5 years after an oil tank explosion*. BMC Pulm Med, 2017. **17**(1): p. 18.
91. Moen, B.E., et al., *Can air pollution affect tear film stability? A cross-sectional study in the aftermath of an explosion accident*. BMC Public Health, 2011. **11**: p. 235.
92. Ihlebaek, C., H.R. Eriksen, and H. Ursin, *Prevalence of subjective health complaints (SHC) in Norway*. Scand J Public Health, 2002. **30**(1): p. 20-9.
93. Hayes, J.E., R.J. Stevenson, and R.M. Stuetz, *The impact of malodour on communities: A review of assessment techniques*. Science of The Total Environment, 2014. **500**: p. 395-407.
94. *Diagnostic and Statistical Manual of Mental Disorders*. Fourth Edition, Text Revision. Washington, DC, USA, American Psychiatric Association. 2000.
95. World Medical Association, *World Medical Association Declaration of Helsinki: Ethical Principles for Medical Research Involving Human Subjects*. JAMA, 2013. **310**(20): p. 2191-2194.
96. McGann, J.P., *Poor human olfaction is a 19th-century myth*. Science, 2017. **356**(6338).
97. Dalton, P., *Odor perception and beliefs about risk*. Chem Senses, 1996. **21**(4): p. 447-58.
98. Smeets, M.A. and P.H. Dalton, *Evaluating the human response to chemicals: odor, irritation and non-sensory factors*. Environ Toxicol Pharmacol, 2005. **19**(3): p. 581-8.
99. Andersson, L., et al., *The influence of health-risk perception and distress on reactions to low-level chemical exposure*. Front Psychol, 2013. **4**: p. 816.
100. Engel, C.C., Jr., J.A. Adkins, and D.N. Cowan, *Caring for medically unexplained physical symptoms after toxic environmental exposures: effects of contested causation*. Environ Health Perspect, 2002. **110** Suppl 4: p. 641-7.
101. Ahs, F., et al., *Aversive learning increases sensory detection sensitivity*. Biol Psychol, 2013. **92**(2): p. 135-41.
102. Keane, T.M., A.D. Marshall, and C.T. Taft, *Posttraumatic stress disorder: etiology, epidemiology, and treatment outcome*. Annu Rev Clin Psychol, 2006. **2**: p. 161-97.
103. Javidi, H. and M. Yadollahie, *Post-traumatic Stress Disorder*. Int J Occup Environ Med, 2012. **3**(1): p. 2-9.
104. Neria, Y., A. Nandi, and S. Galea, *Post-traumatic stress disorder following disasters: a systematic review*. Psychol Med, 2008. **38**(4): p. 467-80.
105. Skogstad, M., et al., *Work-related post-traumatic stress disorder*. Occup Med (Lond), 2013. **63**(3): p. 175-82.
106. Altman, D.G., *Practical statistics for medical research*. 1 ed. 1991, London, UK: Chapman & Hall/CRC.
107. Rothman, K.J., *Epidemiology: An Introduction*. 2 ed. 2012, New York, USA: Oxford University Press, Inc.

-
108. Song, J.W. and K.C. Chung, *Observational studies: cohort and case-control studies*. *Plast Reconstr Surg*, 2010. **126**(6): p. 2234-42.
 109. *Self-perceived health statistics*. Statistics Explained. Eurostat, European Commission, Luxembourg; Available from: http://ec.europa.eu/eurostat/statistics-explained/index.php/Self-perceived_health_statistics#Self-perceived_health.
 110. *Health, care and social relations, survey on living conditions, 2015*. Statistics Norway, Oslo/Kongsvinger, Norway 20.06.2016; Available from: <https://www.ssb.no/en/helse/statistikker/helseforhold/hvert-3-aar/2016-06-20>.
 111. *The Norwegian National Registry*. The Norwegian Tax Administration, Norway; Available from: <http://www.skatteetaten.no/en/person/National-Registry/This-is-the-National-Registry/>.
 112. Grievink, L., et al., *The importance of estimating selection bias on prevalence estimates shortly after a disaster*. *Ann Epidemiol*, 2006. **16**(10): p. 782-8.
 113. Lindsted, K.D., et al., *Healthy volunteer effect in a cohort study: temporal resolution in the Adventist Health Study*. *J Clin Epidemiol*, 1996. **49**(7): p. 783-90.
 114. Dijkema, M.B., et al., *Determinants of response in a longitudinal health study following the firework-disaster in Enschede, The Netherlands*. *Eur J Epidemiol*, 2005. **20**(10): p. 839-47.
 115. Shah, D., *Healthy worker effect phenomenon*. *Indian J Occup Environ Med*, 2009. **13**(2): p. 77-9.
 116. Guidotti, T.L., *The cancer non-epidemic of county 20: case study of an epidemiological mistake*. *Public Health Rev*, 1991. **19**(1-4): p. 179-90.
 117. Guidotti, T.L. and S. Abercrombie, *Voices of leadership in a community under stress: personal observations by officials on an epidemiologic mistake*. *J Public Health Med*, 1994. **16**(4): p. 381-8.
 118. *Lov om folketrygd (Folketrygdloven) [the National Insurance Act] (In Norwegian)*. Ministry of Labour and Social Affairs, Oslo, Norway [Legal rule] 2015 01.05.1997; Available from: <https://lovdata.no/dokument/NL/lov/1997-02-28-19>.
 119. *Occupational injury and illness*. Norwegian Labour and Welfare Service (NAV), Norway 19.04.2016; Available from: <https://www.nav.no/en/Home/Benefits+and+services/Relatert+informasjon/occupational-injury-and-illness#chapter-4>.
 120. Podsakoff, P.M., et al., *Common method biases in behavioral research: a critical review of the literature and recommended remedies*. *J Appl Psychol*, 2003. **88**(5): p. 879-903.
 121. Kristensen, P., *Avhengige målefeil i observasjonsstudier [Bias from dependent errors in observational studies]*. *Tidsskr Nor Laegeforen*, 2005. **125**(2): p. 173-5.
 122. Breslau, N., *The epidemiology of trauma, PTSD, and other posttrauma disorders*. *Trauma Violence Abuse*, 2009. **10**(3): p. 198-210.
 123. Dirkzwager, A.J., et al., *Risk factors for psychological and physical health problems after a man-made disaster. Prospective study*. *Br J Psychiatry*, 2006. **189**: p. 144-9.

-
124. Frye, R.E., B.S. Schwartz, and R.L. Doty, *Dose-related effects of cigarette smoking on olfactory function*. JAMA, 1990. **263**(9): p. 1233-6.
 125. Greenberg, M.I., J.A. Curtis, and D. Vearrier, *The perception of odor is not a surrogate marker for chemical exposure: a review of factors influencing human odor perception*. Clin Toxicol (Phila), 2013. **51**(2): p. 70-6.
 126. Kaloupek, D.G., et al., *Common Data Elements for Posttraumatic Stress Disorder Research*. Archives of Physical Medicine and Rehabilitation, 2010. **91**(11): p. 1684-1691.
 127. van den Berg, B., et al., *Medically unexplained physical symptoms in the aftermath of disasters*. Epidemiol Rev, 2005. **27**: p. 92-106.
 128. Ihlebaek, C. and H.R. Eriksen, *Occupational and social variation in subjective health complaints*. Occup Med (Lond), 2003. **53**(4): p. 270-8.
 129. van den Berg, B., et al., *Risk factors for physical symptoms after a disaster: a longitudinal study*. Psychol Med, 2008. **38**(4): p. 499-510.
 130. Steckler, A. and K.R. McLeroy, *The importance of external validity*. Am J Public Health, 2008. **98**(1): p. 9-10.
 131. *Forskrift om tiltak for å forebygge og begrense konsekvensene av storulykker i virksomheter der farlige kjemikalier forekommer (Storulykkeforskriften) [Major Accident Regulations] (In Norwegian)*. Ministry of Justice and Public Security, Oslo, Norway [Regulation] 01.06.2017; Available from: <https://lovdata.no/dokument/SF/forskrift/2016-06-03-569>.
 132. *The Norwegian Public Health Act (Public Health Act)*. Ministry of Health and Care Services, Oslo, Norway [Legal rule] 01.01.2012; Available from: https://www.regjeringen.no/globalassets/upload/hod/hoeringer-fha_fos/123.pdf.
 133. Lervåg, K. *Tilsyn uten ansvar [Supervision without accountability] (In Norwegian)*. Bergens Tidende [Feature article] 15.03.2010; Available from: <http://www.uib.no/filearchive/tilsyn-uten-ansvar-kronikk-i-bt-15-03-10.pdf>.
 134. *Nå har vi 426 kommuner i Norge [Currently there are 426 municipalities in Norway] (In Norwegian)*. 2017; Available from: <http://kommunal-rapport.no/kommunestruktur/2017/01/na-har-vi-426-kommuner-i-norge>.
 135. *Staten lærde av Sløvåg [The Norwegian central authorities learned from Sløvåg] (In Norwegian)*. NRK [Newspaper] 29.10.2010; Available from: <https://www.nrk.no/sognogfjordane/staten-laerde-av-slovag-1.7357924>.
 136. Simonsen, A. *Risikokommunikasjon [Risk communication] (In Norwegian)*. Norsk kommunikasjonsforening [Norwegian Communication Association], Oslo, Norway 2009; Available from: <https://www.kommunikasjon.no/fagstoff/krisekommunikasjon/risiko-og-krisekommunikasjon>.

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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References

1. Pesatori AC, Consonni D, Bachetti S, Zocchetti C, Bonzini M, Baccarelli A, Bertazzi PA. Short- and long-term morbidity and mortality in the population exposed to dioxin after the "Seveso accident". *Industrial health* 2003, **41**:127-138.
2. Dhara VR, Dhara R. The Union Carbide disaster in Bhopal: a review of health effects. *Archives of environmental health* 2002, **57**:391-404.
3. Aguilera F, Mendez J, Pasaro E, Laffon B. Review on the effects of exposure to spilled oils on human health. *Journal of applied toxicology : JAT* 2010, **30**:291-301.
4. Harada M. Minamata disease: methylmercury poisoning in Japan caused by environmental pollution. *Critical reviews in toxicology* 1995, **25**:1-24.
5. Morgan O, Verlander NQ, Kennedy F, Moore M, Birch S, Kearney J, Lewthwaite P, Lewis R, O'Brian S, Osman J *et al.* Exposures and reported symptoms associated with occupational deployment to the Buncefield fuel depot fire, England 2005. *Occupational and environmental medicine* 2008, **65**:404-411.
6. Ackermann-Liebrich UA, Braun C, Rapp RC. Epidemiologic analysis of an environmental disaster: the Schweizerhalle experience. *Environmental research* 1992, **58**:1-14.
7. van Kamp I, van der Velden PG, Stellato RK, Roorda J, van Loon J, Kleber RJ, Gersons BB, Lebret E. Physical and mental health shortly after a disaster: first results from the Enschede firework disaster study. *European journal of public health* 2006, **16**:253-259.
8. van den Berg B, Grievink L, Stellato RK, Yzermans CJ, Lebret E. Symptoms and related functioning in a traumatized community. *Archives of internal medicine* 2005, **165**:2402-2407.
9. Folkehelseinstituttet. Miljømedisinsk vurdering av kjemikalieulykken ved Vest Tank 24.5.2007 i Gulen (In Norwegian)
10. Rasmussen S. Luftprøver for analyse av svovelholdige forbindelser og løsemidler, Vest Tank, juni 2007. (In Norwegian)

11. Granslo JT, Bratveit M, Hollund BE, Irgens A, Svanes C, Mageroy N, Moen BE. Airway symptoms and lung function in the local population after the oil tank explosion in Gulen, Norway. *BMC pulmonary medicine* 2012, **12**:76.
12. Tjalvin G, Hollund BE, Lygre SH, Moen BE, Bratveit M. Subjective Health Complaints Among Workers in the Aftermath of an Oil Tank Explosion. *Arch Environ Occup Health* 2014:0.
13. Moen BE, Norback D, Wieslander G, Bakke JV, Mageroy N, Granslo JT, Irgens A, Bratveit M, Hollund BE, Aasen T. Can air pollution affect tear film stability? A cross-sectional study in the aftermath of an explosion accident. *BMC public health* 2011, **11**:235.
14. Tande RM, Norman T, Asheim TK, Midtbø M, Berg AL. Rapport om helseplager i Gulen og Masfjorden kommunar etter ulukka i Vest Tank sitt anlegg i Sløvåg 24.05.2007. (In Norwegian)
15. Westby M, Hetland, S. Kartlegging av diffuse utslipp til luft fra tank 61 og 63 ved Aleksela, Sløvåg, November 2008. (In Norwegian)
16. Smid GE, van der Velden PG, Lensvelt-Mulders GJ, Knipscheer JW, Gersons BP, Kleber RJ. Stress sensitization following a disaster: a prospective study. *Psychological medicine* 2012, **42**:1675-1686.
17. van den Berg B, Grievink L, van der Velden PG, Yzermans CJ, Stellato RK, Lebre E, Brunekreef B. Risk factors for physical symptoms after a disaster: a longitudinal study. *Psychological medicine* 2008, **38**:499-510.
18. Behbod B, Parker EM, Jones EA, Bayleyegn T, Guarisco J, Morrison M, McIntyre MG, Knight M, Eichold B, Yip F. Community Health Assessment Following Mercaptan Spill: Eight Mile, Mobile County, Alabama, September 2012. *Journal of public health management and practice : JPHMP* 2013.
19. Luginaah IN, Taylor SM, Elliott SJ, Eyles JD. A longitudinal study of the health impacts of a petroleum refinery. *Social science & medicine (1982)* 2000, **50**:1155-1166.

20. Claeson AS, Liden E, Nordin M, Nordin S. The role of perceived pollution and health risk perception in annoyance and health symptoms: a population-based study of odorous air pollution. *International archives of occupational and environmental health* 2013, **86**:367-374.
21. Eriksen HR, Ihlebaek C, Ursin H. A scoring system for subjective health complaints (SHC). *Scandinavian journal of public health* 1999, **27**:63-72.
22. Ihlebaek C, Eriksen HR, Ursin H. Prevalence of subjective health complaints (SHC) in Norway. *Scandinavian journal of public health* 2002, **30**:20-29.
23. ACGIH. n-Butyl mercaptan: TLV Chemical Substances, 7 edn. Cincinnati, Ohio; 2001.
24. ACGIH. Ethyl mercaptan: TLV Chemical Substances, 7 edn. Cincinnati, Ohio; 2004.
25. ACGIH. Methyl mercaptan: TLV Chemical Substances, 7 edn. Cincinnati, Ohio; 2004.
26. Guidotti TL. Hydrogen sulfide: advances in understanding human toxicity. *International journal of toxicology* 2010, **29**:569-581.
27. Engel CC, Jr., Adkins JA, Cowan DN. Caring for medically unexplained physical symptoms after toxic environmental exposures: effects of contested causation. *Environmental health perspectives* 2002, **110 Suppl 4**:641-647.
28. Smeets MA, Dalton PH. Evaluating the human response to chemicals: odor, irritation and non-sensory factors. *Environmental toxicology and pharmacology* 2005, **19**:581-588.

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 ^a n (=147)	Controls ^b n (=137)	Exposed workers ^a n (=106)	Controls ^b 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)

^aExposed workers defined as employees in the industrial area at the time of the explosion and/or clean-up workers (aged 18-67 in 2008).

^bControls 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^a and controls^b

	2008	2012	Mean Difference :Time ^c	95 % CI for mean difference	p-value	p-value for Group*Time interaction
Total SHC Score						
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) ^d	-4.07	-2.60				
95% CI	(-6.80, -1.34)	(-5.50, 0.30)				
p-value	<0.01	NS				
Subjective neurological complaints						
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				
Flu						
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				
Musculo-skeletal complaints						
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				

^aExposed workers defined as employees in the industrial area at the time of the explosion and/or clean-up workers (aged 18-67 in 2008).

^bControls 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.

^cMean 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.

^dMean 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.

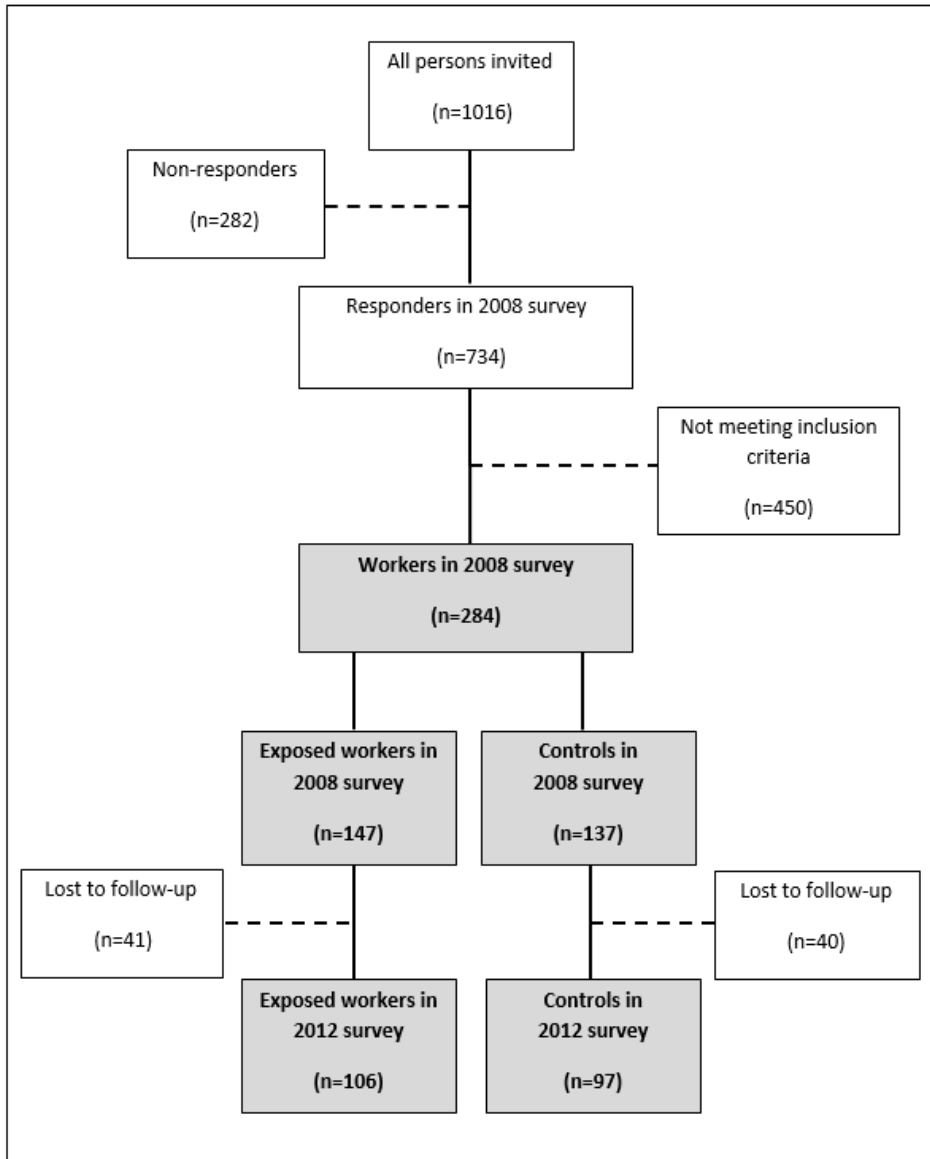


Figure 1: The main study population and participants included in this study (shaded grey). Inclusion criteria: Employees in the industrial area at the time of the explosion and/or clean-up workers (aged 18-67 in 2008), defined as exposed workers. Controls defined as working inhabitants (aged 18-67 in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

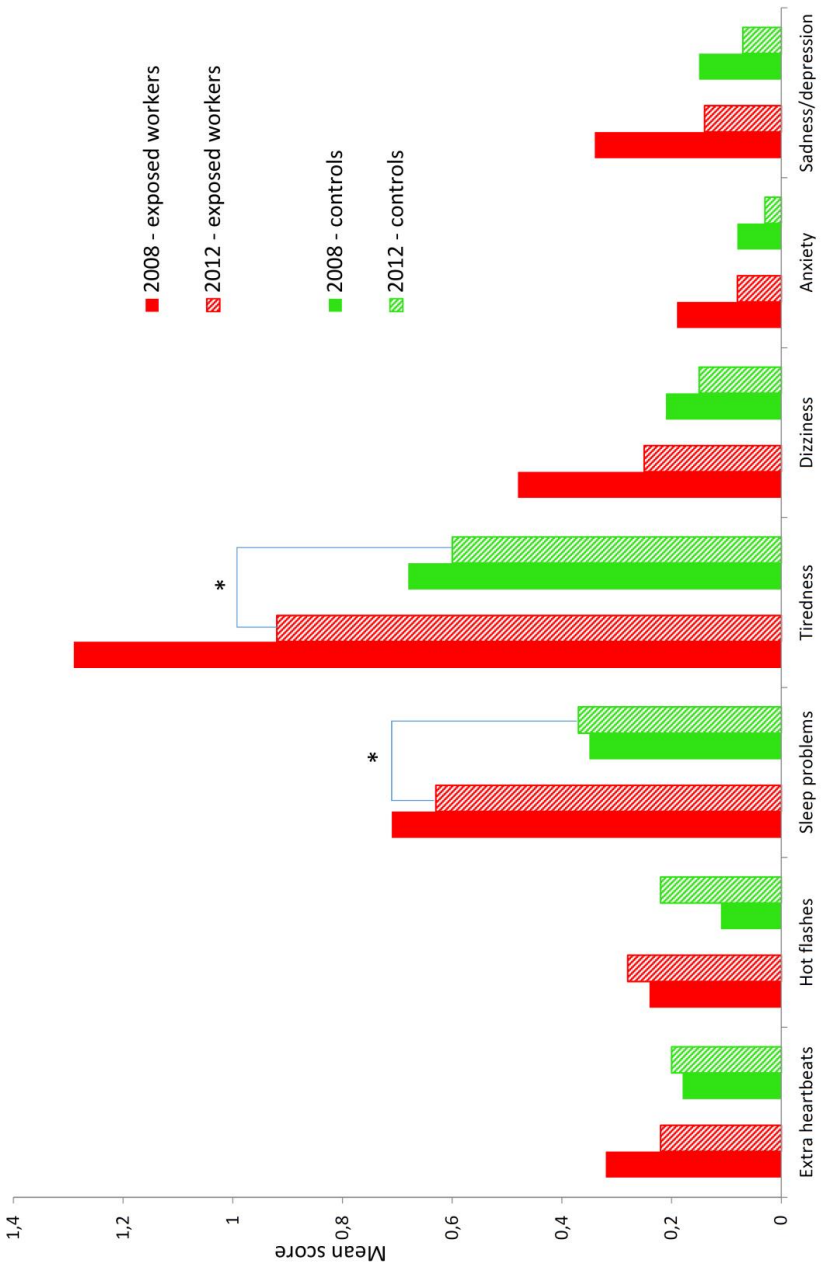


Figure 2: Mean scores for the single items within the subjective neurological subscale among exposed workers and controls in 2008 and 2012. Asterisk indicates a significant difference in score between exposed workers and controls in 2012 ($P < 0.05$), adjusted for gender, age, smoking habits, proximity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

Odour as a determinant of persistent symptoms after a chemical explosion, a longitudinal study

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Abstract: Foul-smelling environmental pollution was a major concern following a chemical workplace explosion. Malodorous pollution has previously been associated with aggravated physical and psychological health, and in persons affected by a trauma, an incidence-related odour can act as a traumatic reminder. Olfaction may even be of significance in the development and persistence of post-traumatic stress symptoms (PTSS). The present longitudinal study assessed whether perceived smell related to malodorous environmental pollution in the aftermath of the explosion was a determinant of subjective health complaints (SHC) and PTSS among gainfully employed adults, when the malodorous pollution was present, and after pollution clean-up. Questionnaire data from validated instruments were analysed using mixed effects models. Individual odour scores were computed, and the participants (n=486) were divided into high and low odour score groups, respectively. Participants in the high odour score group (n=233) reported more SHC and PTSS than those in the low odour score group (n=253), before and even after the pollution was eliminated. These associations lasted for at least three years after the pollution was removed, and might indicate that prompt clean-up is important to avoid persistent health effects after malodorous chemical spills.

Key words: Odour, Chemical explosion, Subjective health complaints, Post-traumatic stress symptoms, Industrial accident

Introduction

Malodorous environmental pollution was a major concern following an explosion in an oil tank containing low quality gasoline and a sulphurous waste product in an industrial harbour area in Norway in May 2007¹. Many workers were present in the industrial area during the explosion, some only a few metres away from the tank. Despite this, no lives were lost, and there were no serious injuries caused by the accident. The first explosion was

followed by a second explosion, and a fire that emitted black smoke which remained in the air for several hours, and a foul-smelling pollution was spread in the industrial area and to the residential areas close by². Part of the area around the explosion site was covered with sludge from the tanks. The clean-up operation was tedious, as polluted soil was found several kilometres from the explosion site.

Employees in the industrial area and near-by inhabitants complained about the putrid smell for months after the accident. They reported the following health complaints to their local health care service: sore and irritated eyes, sore throat, cough, headache, sleep problems, and nausea, which they related to the pollution caused by the explosion¹. The accident and the malodorous pollution received

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considerable attention in national media, emphasizing the possibility of toxic health effects due to the pollution. The sulphurous odour was continuously present, and odour intensity fluctuated only due to meteorological conditions such as wind direction and velocity, and temperature^{2,3}). After the initial clean-up, large amounts of the pollutants were stored in tanks and big bags in the industrial harbour area. The last remnants of the solid pollutants were shipped by boat for destruction from the industrial harbour in February 2010.

Low levels of different sulphurous compounds, including mercaptans (methyl mercaptan: 0.006 ppm, ethyl mercaptan: 0.022 to 0.056 ppm and propyl mercaptan: 0.008 ppm), were detected in air samples from the industrial area 2–3 weeks after the incident^{2–4}). One and a half years after the explosion, both hydrogen sulphide (0.03 to higher than 2.7 ppm) and different mercaptans (methyl mercaptan: less than 0.010 to 0.61 ppm, ethyl mercaptan: less than 0.008 to 2.24 ppm, propyl mercaptan: less than 0.006 to 0.16 ppm and butyl mercaptan: less than 0.005 to 0.03 ppm) were detected in air samples taken at the top of two tanks containing sludge and wash water from tank cleaning or sludge mixed with water from the fire extinction after the explosion^{2–5}).

A cross sectional study performed when the pollution was still present found that employees and clean-up workers in the industrial area had significantly more subjective health complaints compared to controls³). A longitudinal study indicated that the removal of the malodorous pollution during the study period was associated with a reduction of the subjective health complaints among the workers in the industrial area⁶). However, these workers still reported significantly more subjective neurological complaints compared to controls⁶). In both studies, perception of the incidence-related smell was suggested to be of importance for the development of SHC^{3,6}), but this possible association was not examined.

Exposure to malodorous pollution has previously been associated with physical and psychological health problems^{7–10}). Even very low levels of exposure to sulphurous compounds has been shown to cause adverse health effects^{7,10}). In persons previously affected by a traumatic incident involving an odour specifically related to the incident, this odour can act as a traumatic reminder¹¹). It has even been suggested that olfaction can be of significance in the development and persistence of post-traumatic stress disorder (PTSD)¹²).

In the present study, we wanted to investigate whether the perception of smell related to malodorous environmen-

tal pollution was a determinant of persistent adverse health outcomes. We also wanted to study a possible association between perception of the specific odour and subjective psychological distress in response to the traumatic incident. The aim of the present study was to assess whether perceived smell related to a malodorous environmental pollution following a chemical explosion was a determinant of SHC and PTSS among gainfully employed adults, when the malodorous pollution was still present, as well as after pollution clean-up.

Subjects and Methods

In 2008, one and a half years after the accident in the industrial harbour, authorities initiated a comprehensive health examination among the affected population. All employees in the industrial harbour area, rescue personnel, fire fighters, clean-up personnel and all residents above the age of two years and living within a distance of 6 km from the explosion site were invited to participate. The examination also included inhabitants living in the same geographical area, but more than 20 km away, - and hence not directly affected by the disaster. These persons were matched by age and gender to the employees and residents close to the industrial area. In total, 1016 persons were invited in 2008 (responders $n=734$, 72%) (Fig. 1). The 2008 survey consisted of a questionnaire and a clinical examination. In 2010, a questionnaire survey was conducted (responders $n=554$, 76% of the responders in 2008) and in 2012, a survey similar to the 2008 survey was performed (responders $n=506$, 69% of the responders in 2008).

In the present study, we included all adults from the main cohort, aged between 18 and 67, and who were gainfully employed in 2008 (Fig. 1). We decided to exclude all who were not gainfully employed in 2008 (including 41 persons who received sickness or disability benefits) to avoid possible biases introduced by participants who were out of work due to illnesses diagnosed before the explosion accident.

In the 2008 survey, the participants were asked if they had noticed a characteristic putrid smell originating in the industrial area in the aftermath of the explosion (yes/no). If yes, they were asked to indicate the months in the period between May 2007 and August 2008 (a total of 16 months) during which they had been aware of the odour (Fig. 2). Because no suitable method for objective measurement of malodorous pollutants exists, and using geographical area or distance to odour source as an exposure measure is prone to exposure misclassifications¹³), an individual odour

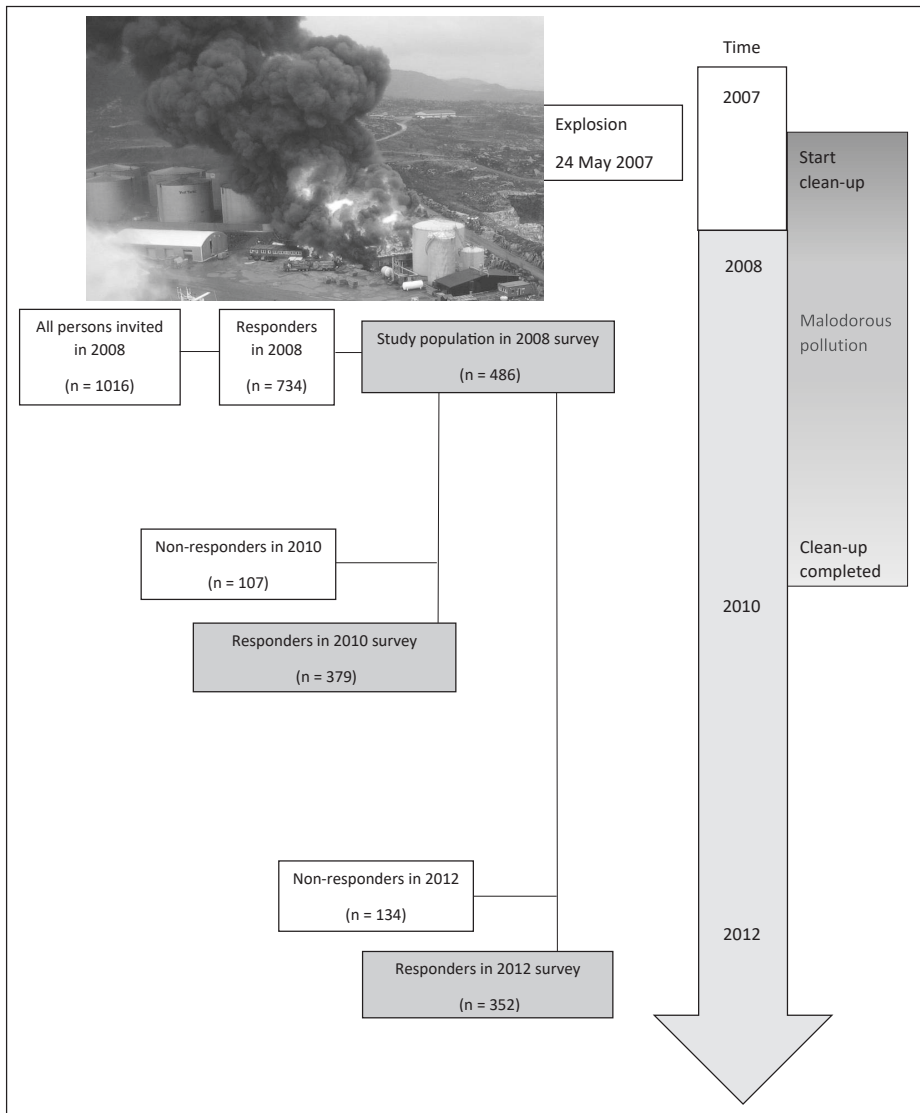


Fig. 1. The present study is a part of a comprehensive study started in 2008 after a chemical explosion in May 2007. The study population (shaded grey), comprised all adults (18–67) from the main cohort who were gainfully employed in 2008. These participants were surveyed when the malodorous pollution was present in the area (in 2008), as well as 1 and 3 years after it was removed (in 2010 and 2012, respectively).

Photo: Lars Fossedal

score was developed as a proxy for perceived smell related to the incidence. This odour score was computed as the percentage of months each participant had noticed the specific foul odour in the 2008 assessment, giving a maximum

score of 100. The participants were grouped according to their odour score, and not according to where they worked or lived. The study population was divided into two groups by the odour score median (31.25), giving the high odour

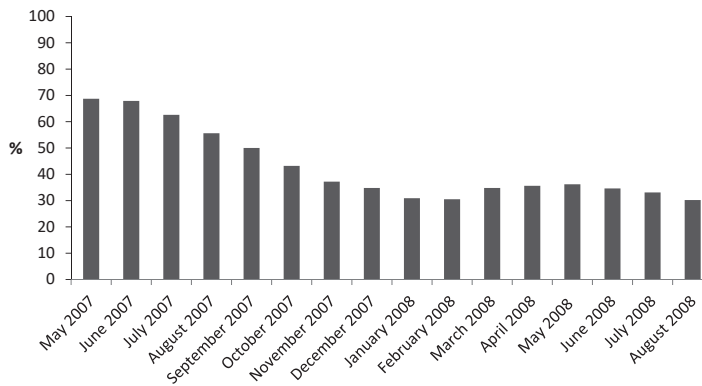


Fig. 2. Percentage of participants ($n=486$) who reported the characteristic odour at some time each month between May 2007 and August 2008.

score and low odour score groups, with mean scores 77.8 and 10.7, respectively. This odour group assignment was maintained throughout the follow-up assessments.

We used questionnaire data from the surveys performed in 2008, 2010 and 2012 in the analyses. Identical instruments were used to survey health outcomes in 2008, 2010 and 2012, respectively.

Subjective health complaints were measured by The Subjective Health Complaints Inventory (SHC) a validated instrument that measures 29 common physical and psychological symptoms experienced during the preceding 30 days¹⁴. This instrument includes symptoms, even with no or minimal clinical findings, which is of importance when surveying the assumedly healthiest part of the population. The respondents were asked to grade the intensity of each item experienced during the previous 30 days by using a Likert scale from 0 (no complaints) to 3 (severe complaints). A higher score indicates a higher number of complaints and/or a higher degree of complaints. Based on previous factor analysis, the 29 items have been grouped into five subscales: Musculoskeletal complaints (eight items: headache, neck pain, upper back pain, low back pain, arm pain, shoulder pain, migraine and pain in the feet), subjective neurological complaints (seven items: extra heartbeats, hot flushes, sleep problems, tiredness, dizziness, anxiety and sadness/depression), gastrointestinal complaints (seven items: heartburn, stomach discomfort, ulcer/non-ulcer dyspepsia, stomach pain, gas discomfort, diarrhoea and constipation), allergy (five items: asthma, breathing difficulties, eczema, allergies and chest pain), and flu (two items: cold/flu and coughing)¹⁴. The maximum total sum score was 87.

To study a possible association between perception of the specific odour and subjective psychological distress in response to the explosion we used the Impact of Event Scale-Revised (IES-R), a validated instrument that measures current (previous 7 days) subjective distress in response to a specific traumatic event¹⁵. This instrument is a short, self-report questionnaire that is easily scored. IES-R correlates well with the Diagnostic and Statistical Manual of Mental Disorders (4th Edition) criteria for post-traumatic stress disorder (PTSD)^{16, 17}, but the diagnosis cannot be made based on IES-R score alone. The instrument can be used repeatedly to assess progress or regress of post-traumatic stress symptoms. The responders were asked to indicate how much they were distressed or bothered by 22 listed difficulties by using a Likert scale from 0 (not at all) to 4 (extremely). A higher score indicates a higher degree of distress. The 22 items have previously been grouped into three subscales or response sets: intrusion (intrusive thoughts, nightmares, intrusive feelings and imagery associated with the traumatic event), avoidance (avoidance of feelings and situations, numbing of responsiveness), and hyperarousal (anger and irritability, hypervigilance, difficulty concentrating, heightened startle). The maximum total sum score was 88.

From the questionnaire in 2008, we used data about gender, age, educational level (0, 1–3 or 4 or more years after nine years of elementary school) and proximity to the explosion (1 km or less was used to classify the participants as present in the industrial area during the explosion). We also collected information about working status for the participants (worker/have a job or not) in 2008, and how far away from the explosion site they lived (kilo-

metres). For smoking habits (non-smoker/daily smoker) we used data from the surveys in 2008, 2010 and 2012, respectively. In the 2010 and 2012 surveys, the participants were asked if they had experienced the characteristic odour the previous month (yes/no).

Statistics

Mean total scores and mean subscale scores were calculated from the scores of each item in the SHC and IES-R instruments, respectively. Some participants did not answer all the questions. A missing score for an item was substituted by the mean score of the valid items within the respective subscale for that individual. A subscale was regarded as invalid for an individual if more than half of the items within a SHC subscale were missing¹⁴⁾ and if more than two items within a IES-R subscale were missing.

A study design with repeated measures imposes correlated data. We used mixed effects models (MEM) with random intercept and slope to account for such dependencies when estimating differences in mean outcomes in the odour score groups and to assess possible difference in development/change over time. In all the analyses we adjusted for age (18–36, 37–44, 45–51 or 52–67 years), gender, smoking habits (non-smoker/daily smoker, time dependent, in 2008, 2010 and 2012, respectively), educational level (0, 1–3 or 4 or more years after nine years elementary school), and whether or not the participant was present in the industrial area during the explosion (>1 km or ≤1 km), as these factors are known to be possible confounding factors for the development of SHC as well as PTSS^{18–26)}. To assess possible time-dependent differences between odour score groups, we included an interaction term between group and measurement time.

Because living close to the industrial area, and hence near the odorous source, could be associated with a higher degree of odour perception among the participants, we assessed by correlation analysis (Pearson correlation) the possible relation between odour score and distance to residency from explosion site.

We applied IBM SPSS Statistics version 22 and STATA version 14 for the analyses, and the level of significance was set to 0.05.

Each participant gave informed consent. The study was conducted in accordance with the Helsinki Declaration. The study was approved by the Regional Committee for Medical Ethics of Western Norway and Norwegian Social Science Data Services.

Results

Characteristics of the participants

The present study, which comprises adults between the age of 18 and 67 who were gainfully employed in 2008, included a total of 486 participants in the 2008 survey, 253 in the low odour score group and 233 in the high odour score group. For 2010 and 2012, the total numbers were 379 and 352, respectively (Table 1 and Fig. 1). In all three surveys, more men than women participated in the study (Table 1). In the 2008 survey, 24% of the participants were employed in the industrial area at the time of the disaster, 18% were present in the industrial area (<1 km) during the explosion and 11% participated in the clean-up operation (Table 1). In 2008, before the malodorous pollution was removed from the area, 81% of the participants (n=394) reported that they had noticed the characteristic putrid smell after the explosion. 1 and 3 years after clean-up (in 2010 and 2012), only 2% (n=9) and 3% (n=12), respectively, had been aware of the odour the previous month (Table 1).

A weak negative correlation was found for odour score and distance to residency from explosion site (correlation coefficient -0.38 , $p < 0.001$).

Subjective health complaints

When the malodorous pollution was present in the area, as well as 1 and 3 years after clean-up, participants who had a high odour score reported significantly more SHC ($p < 0.001$, $p = 0.002$, $p = 0.009$ in 2008, 2010 and 2012, respectively) compared to those in the low odour score group, adjusted for gender, age, smoking habits, education level and proximity to the explosion (Table 2 and Fig. 3).

During the study period, there was a significant decrease in total SHC score among participants in the high odour score group ($p = 0.02$), but no significant interaction between odour score group and time, indicating no differences in change between the two odour score groups ($p = 0.16$) (Table 2 and Fig. 3). For the subjective neurological subscale score, however, there was a significant reduction, with a significant interaction between odour score and time, indicating a difference in change in scores between the two odour score groups ($p = 0.04$) (Table 2).

In the mixed effects models, proximity to the explosion was not of significance for the total SHC score ($p = 0.84$). However, it was of significance for the occurrence of subjective neurological complaints as those who were present in the industrial area during the explosion had a significantly higher score on this subscale ($p = 0.02$), compared to those who were not at the explosion site (results not shown).

Table 1. Descriptive data among 486 participants studied in the aftermath of a chemical explosion, when malodorous pollution was present in the industrial area (2008), as well as 1 and 3 years after clean-up (2010 and 2012, respectively).

	2008			2010			2012		
	Total	Low odour score ^a	High odour score ^a	Total	Low odour score ^a	High odour score ^a	Total	Low odour score ^a	High odour score ^a
Participants	486	253	233	379	197	182	352	178	174
Men, n (%)	314 (65)	164 (65)	150 (64)	239 (63)	123 (62)	116 (64)	216 (61)	108 (61)	108 (62)
Women, n (%)	172 (35)	89 (35)	83 (36)	140 (37)	74 (38)	66 (36)	136 (39)	70 (39)	66 (38)
Age in 2008, mean (median) min-max	43.8 (45) 18–67	44.7 (46) 18–67	42.9 (44) 18–67	45.4 (46) 19–67	46.0 (47) 19–67	44.8 (45) 19–67	45.0 (46) 18–67	45.86 (47) 18–67	44.24 (45) 19–67
18–36, n (%)	135 (28)	65 (26)	70 (30)	84 (22)	40 (20)	44 (24)	80 (23)	38 (21)	42 (24)
37–44, n (%)	107 (22)	53 (21)	54 (23)	84 (22)	40 (20)	44 (24)	79 (22)	36 (20)	43 (25)
45–51, n (%)	112 (23)	62 (25)	50 (22)	92 (24)	53 (27)	39 (21)	89 (25)	47 (26)	42 (24)
52–67, n (%)	132 (27)	73 (29)	59 (25)	119 (31)	64 (33)	55 (30)	104 (30)	57 (32)	47 (27)
Educational level in 2008									
0 years after elementary school, n (%)	47 (10)	28 (11)	19 (8)	39 (11)	24 (12)	15 (9)	33 (10)	21 (12)	12 (7)
1–3 years after elementary school, n (%)	242 (51)	117 (47)	125 (55)	186 (50)	93 (48)	93 (53)	173 (50)	79 (45)	94 (56)
4 years or more after elementary school, n (%)	186 (39)	103 (42)	83 (37)	145 (39)	76 (39)	69 (39)	137 (40)	75 (43)	62 (37)
Smoking habits									
Non-smoker, n (%)	331 (70)	179 (73)	152 (67)	264 (77)	137 (77)	127 (77)	263 (78)	137 (79)	126 (76)
Daily smoker, n (%)	139 (30)	65 (27)	74 (33)	77 (23)	40 (23)	37 (23)	76 (22)	37 (21)	39 (24)
Employed in the industrial area at the time of the explosion, n (%)	115 (24)	13 (5)	102 (44)	86 (23)	8 (4)	78 (43)	87 (25)	8 (5)	79 (45)
Clean-up worker, n (%)	52 (11)	17 (7)	35 (15)	41 (11)	15 (8)	26 (14)	38 (11)	12 (7)	26 (15)
Proximity to the explosion ^b									
≤ 1 km, n (%)	87 (18)	17 (7)	70 (30)	64 (17)	10 (5)	54 (30)	66 (19)	10 (6)	56 (32)
> 1 km, n (%)	399 (82)	236 (93)	163 (70)	315 (83)	187 (95)	128 (70)	286 (81)	168 (94)	118 (68)
Odour score ^a , mean (median) min-max	42.78 (31.25) 0–100	10.67 (6.25) 0–31.25	77.80 (81.25) 37.50–100	42.81 (31.25) 0–100	11.39 (6.25) 0–31.25	76.82 (81.25) 37.50–100	44.46 (31.25) 0–100	11.27 (9.38) 0–31.25	78.41 (87.50) 37.50–100
Reported the characteristic odour sometimes after the explosion, n (%)	394 (81)	162 (64)	232 (100)						
Reported the characteristic odour the previous month, n (%)	1147 (10)	9.52 (8) 0–41	13.54 (11.39) 0–46	10.50 (8.29) 0–49.71	8.84 (7.23) 0–41.43	12.00 (9.32) 0–49.71	10.58 (8.06) 0–47.53	8.87 (7.25) 0–40.28	12.26 (8.86) 0–47.53
Subjective neurological score ^c , mean (median) min-max	2.43 (2) 0–17	1.83 (1) 0–9	3.07 (2) 0–17	2.19 (1) 0–15.75	1.83 (1) 0–15	2.37 (2) 0–11.20	2.23 (2) 0–13	1.85 (1) 0–13	2.62 (2) 0–12
Total IES-R score ^d , mean (median) min-max	4.70 (1) 0–61	2.11 (0) 0–61	7.52 (4) 0–45	3.28 (0) 0–42.71	1.38 (0) 0–37.40	5.17 (2) 0–42.71	2.34 (0) 0–36	1.17 (0) 0–25	3.55 (0) 0–36

^a Odour score computed as the percentage of months each participant had noticed the specific foul odour. The participants were divided by the odour score median into the low odour score and the high odour score groups, respectively. ^b Proximity of 1 km or less was used to classify the participants as present in the industrial area during the explosion. ^c Scores from the Subjective Health Complaints Inventory (SHC). ^d Scores from the Impact of Event Scale Revised (IES-R).

Table 2. Outcomes comparing the high and low odour score groups^a in 2008, 2010 and 2012, and within the odour score groups^a from 2008 to 2012.

	2008	2010	2012	2012 vs 2008			<i>p</i> for interaction
				MD ^b (95% CI)	SMD ^c	<i>p</i>	
Total SHC score^d							
High odour score ^a	13.54	12.37	12.32	-1.35 (-2.52, -0.18)	-2.26	0.02	0.16
Low odour score ^a	9.52	8.81	8.87	-0.19 (-1.32, 0.94)	-0.32	0.75	
MD ^b (95% CI)	3.70 (2.03, 5.37)	2.83 (1.05, 4.61)	2.54 (0.63, 4.45)				
SMD ^c	4.34	3.12	2.61				
<i>p</i>	<0.001	0.002	0.009				
Subjective neurological complaints score^d							
High odour score ^a	3.07	2.51	2.61	-0.42 (-0.77, -0.07)	-2.35	0.02	0.04
Low odour score ^a	1.83	1.89	1.85	0.08 (-0.26, 0.39)	0.48	0.63	
MD ^b (95% CI)	1.02 (0.56, 1.49)	0.53 (0.02, 1.03)	0.52 (-0.02, 1.06)				
SMD ^c	4.29	2.04	1.88				
<i>p</i>	<0.001	0.04	0.06				
Total IES-R score^e							
High odour score ^a	7.52	5.35	3.55	-4.16 (-5.19, -3.14)	-7.99	<0.001	<0.001
Low odour score ^a	2.11	1.38	1.17	-0.81 (-1.79, 0.16)	-1.63	0.10	
MD ^b (95% CI)	4.59 (3.23, 5.95)	2.94 (1.68, 4.20)	1.24 (0.05, 2.44)				
SMD ^c	6.62	4.56	2.04				
<i>p</i>	<0.001	<0.001	0.04				

^a Odour score computed as the percentage of months each participant had noticed the specific foul odour. The participants were divided by the odour score median (31.25) into the high odour score and the low odour score groups, respectively.

^b Mean difference.

^c Standardized mean difference.

^d Scores from the Subjective Health Complaints Inventory (SHC).

^e Scores from the Impact of Event Scale Revised (IES-R).

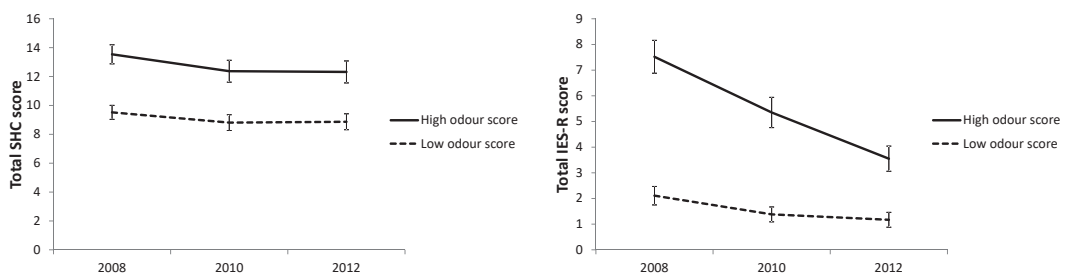


Fig. 3. Total mean scores with standard errors of the mean of The Subjective Health Complaints Inventory (SHC) and Impact of Event Scale Revised (IES-R) among participants in the high and low odour score groups, respectively, when the pollution was present in the area (2008), as well as 1 and 3 years after pollution clean-up (2010 and 2012).

Post-traumatic stress symptoms

Compared to participants in the low odour score group, those who had a high odour score reported significantly more PTSS ($p < 0.001$) when the pollution was still pres-

ent in the industrial area, adjusted for gender, age, smoking habits, education level and proximity to the explosion (Table 2 and Fig. 3). This difference was also present 1 and 3 years after the pollution was eliminated ($p < 0.001$,

$p=0.04$ in 2010 and 2012, respectively) (Table 2 and Fig. 3).

During the study period, there was a significant decrease in total IES-R score among those who had a high odour score ($p<0,001$). There was a significant interaction between exposure group and time, indicating a difference in change in scores between the two odour score groups ($p<0.001$) (Table 2 and Fig. 3).

In the mixed effects models, proximity to the explosion was of significance for the occurrence of PTSS. Those who were present in the industrial area during the explosion had a significantly higher total IES-R-score (<0.001), and subscale scores ($p<0.001$, $p<0.001$, $p<0.001$ for hyperarousal, avoidance and intrusion, respectively), compared to those who were not present at the explosion site (results not shown).

Discussion

In this longitudinal study, participants who had perceived the foul odour for a longer period of months repeatedly reported more SHC and PTSS than those who had perceived the odour for fewer or no months. Significant differences were found both when the malodorous pollution was present and after pollution clean-up.

The increased prevalence of reported symptoms in the high-odour score group is in line with previous studies of health effects related to malodorous emissions. Adverse health effects were found among residents who were exposed to low levels of sulphurous emissions from a pulp mill¹⁰, and in the aftermath of a fire in an agrochemical storage house⁹. Few have studied health effects of long-lasting malodorous pollution followings accidents, but results comparable to ours were found in a cross-sectional study of physical and psychological health complaints following several years of malodorous exposure in the aftermath of a mercaptan spill⁷. Most previous studies of health effects due to malodorous, chemical air pollution have cross-sectional designs, making assessments over time impossible^{7,9,10}.

In the present study, the participants in the high odour score group reported the same amount of subjective health complaints, even after pollution clean-up. A similar effect was found in a longitudinal study of health complaints among residents living close to a petroleum refinery, which implemented odour reduction measures during the study period^{8,27}. A mechanism deriving from perceptual and behavioural sensitization was hypothesized to be the cause of the persistence of symptoms in that study²⁷.

In the present study, the posttraumatic stress symptoms declined over time among participants who reported long-lasting perception of the accident-related odour. To our knowledge, there are no other longitudinal studies of PTSS following chemical accidents in which malodorous pollution is a major issue, but in general, PTSS diminishes with time²⁸.

The mechanisms behind the reported association between perceived odour and subjective health complaints in the present study are presumably complex and involve both psychological and physiological responses^{29,30}. Through evolution, the human olfactory sense seems to have lost some of its importance, but olfaction is still essential for humans' ability to detect potential hazards in the environment³¹. Odours elicit emotions in humans depending on how the stimulus is processed by the brain⁸. An olfactory stimulus can activate amygdala directly through neural communication³⁰ even without involving initial processing by the olfactory cortex³².

Previous studies of the development of SHC following odorous exposure have suggested a mechanism mediated by odour perception and odour annoyance^{8,18,27,29,33,34}. Annoyance is the feeling of displeasure associated with any agent believed to have an adverse effect¹⁸ and involves an individual's perceptions, emotions and attitudes towards the exposure²⁹. Involuntary psychological mechanisms mediated by perception and previous experience seem to be involved^{8,27,29,35,36}. In studies involving odour, the term *Proust phenomenon* is often encountered^{30,37,38}. This phenomenon occurs when a certain odour evokes a specific memory^{30,37,38}. According to previous studies, olfactory memory triggers are more evocative than other modality triggers resulting in more emotional and detailed memories³⁷. Olfactory memories might also last for longer³⁷, and might result in persistent health complaints like in the present study.

In the present study, the extensive and lengthy media coverage emphasizing the probability of toxic health effects from the pollution, as along with the lawsuit resulting in the maximum sentence for environmental crime in Norway, may have been of importance to the persistence of symptoms, even after clean-up. In previous studies, worries about a possible health risk have been shown to increase subjective health complaints in residents living close to hazardous waste sites³⁹. A study among residents exposed to malodorous emissions from a biofuel facility suggested that both symptoms and annoyance were mediated by perceived pollution and health risk perception, not by the pollution itself²⁹. Similarly, strong dose-response

associations between annoyance due to odour and non-specific symptoms, but only indirect associations between odorous exposures and non-specific symptoms, were found among residents experiencing malodorous air pollution from biodegradable wastes¹³.

The higher prevalence of PTSS in the high-odour score group when the malodorous pollution still was present could be attributable to the potential effect of the incident-related odour as a traumatic reminder^{11, 38}. The foul odour was continuously present in the industrial area for more than two years post-disaster, acting as a constant reminder of the actual incident as well as a cue to the possibility of another, similar accident.

Classical conditioning could also be of importance for the occurrence of symptoms when the malodorous pollution was still present. Several studies have proposed that classical conditioning is involved in the development of health complaints attributed to unpleasant odours^{11, 12, 40}. However, few have studied possible odour-related mechanisms in connection with PTSS and the development of PTSD. In one study among patients currently suffering from PTSD, it was found that these patients are better at recognizing odours, and that they more readily respond to unpleasant olfactory stimuli⁴¹. A single study among soldiers has put forward the hypothesis that odours play a significant role in the pathophysiology of PTSD¹². In classical conditioning, acquired fear is supposed to diminish as time pass by, but studies have suggested that fear conditioned to odours wanes very slowly⁴⁰, and there is even an inability to extinguish the conditioned fear response in soldiers who develop PTSD¹².

For employees in the industrial area and workers living nearby or frequently passing by the industrial area, visual cues could also be of importance for the development and persistence of PTSS. The burnt-out offices and large pieces of metal from the destroyed tanks strewn about the area, and later on, large bags containing solid pollutants are all items that might act as constant reminders of the accident. Even pictures of the accident site in different media such as newspapers, the Internet or television could act as visual cues. In an experimental study, offensive memories precipitated by olfactory triggers were more detailed, agitating and unpleasant than memories induced by auditory triggers, but not more haunting or emotional than visual triggers³⁸.

A major strength of the present study is the longitudinal design. By using this design, we were able to follow the participants over time, starting when the malodorous pollution was present, and up to three years after clean-up.

High response rates in all three surveys reduced the effect of a possible non-response bias. However, there was no available information about health complaints before the explosion accident among the participants, and there was no control group lacking accident experience.

Two validated instruments, The Subjective Health Complaints Inventory (SHC)¹⁴ and Impact of Event Scale-Revised (IES-R)¹⁵, were used to survey SHC and PTSS, respectively. Both instruments study health complaints, not diagnoses, which is of importance when examining assumedly healthy participants. Previous studies showed low agreement between report of symptoms when surveyed twice⁴², which introduces the risk of recall biases. To minimize such biases, the instruments we used enquired about SHC and PTSS during the previous 30 and 7 days, respectively. The IES-R is designed to be used repeatedly to assess progress or regress of PTSS. An obvious problem in this context, is the difficulty in relating present stress symptoms to the accident when the respondents are asked 5 ½ years post-disaster.

The odour score is a subjective measure established because there are no methods for objective measurement of odour. A subjective exposure measure like this introduces the risk of self-report bias. The score is even prone to recall biases since the participants in the first survey (autumn or winter 2008) were asked to list the months in the period from May 2007 through August 2008 during which they had perceived the specific odour. Participants who were more annoyed by the malodorous pollution might also have a tendency to report perceived odour during a longer period of months, thus yielding a higher odour score. Despite these limitations, an individual odour score is a better indicator of odour exposure than, for instance, distance to the odorous source, which previously has been shown to be prone to exposure misclassifications¹³.

SHC is very common, and even though participants in the high-odour score group had higher SHC scores than those in the low-odour score group, their scores are not high compared to the mean scores in a normal Norwegian population²³. The scores of the low-odour score group are even lower. This probably reflects a healthy worker effect⁴³, and is as expected in a study of the supposedly healthiest part of the population.

Conclusions

Perception of malodorous environmental air pollution was a determinant of both SHC and PTSS among gainfully employed adults after a chemical explosion. The effect of

the determinant lasted for at least three years after the malodorous pollution was removed. In terms of the development of PTSS, proximity to the explosion was also a significant determinant. A possible implication of the present study is that early clean-up is important to avoid persistent health effects after malodorous chemical spills.

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Conflicts of interest

No conflicts of interest were declared by any of the authors.

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References

- 1) Tande RM, Norman T, Asheim TK, Midtbø M, Berg AL. Rapport om helseplager i Gulen og Masfjorden kommunar etter ulukka i Vest Tank sitt anlegg i Sløvåg 24.05.2007. [Report on subjective health complaints in Gulen and Masfjorden municipalities subsequent to the accident in the Vest Tank plant at Sløvåg 24 May 2007]. (In Norwegian)2008.
- 2) Folkehelseinstituttet. Miljømedisinsk vurdering av kjemikalieulykken ved Vest Tank 24.5.2007 i Gulen [Environmental medicine assessment of the chemical accident in Vest Tank 24 May 2007 in Gulen] (In Norwegian). Oslo: Nasjonalt folkehelseinstitutt 2008.
- 3) Tjalvin G, Hollund BE, Lygre SH, Moen BE, Bråtveit M (2015) Subjective Health Complaints Among Workers in the Aftermath of an Oil Tank Explosion. *Arch Environ Occup Health* **70**, 332–40. [Medline] [CrossRef]
- 4) ACGIH. Documentation of the TLVs and BEIs. 7 ed. Cincinnati, Ohio2011.
- 5) Guidotti TL (2010) Hydrogen sulfide: advances in understanding human toxicity. *Int J Toxicol* **29**, 569–81. [Medline] [CrossRef]
- 6) Tjalvin G, Lygre SH, Hollund BE, Moen BE, Bråtveit M (2015) Health complaints after a malodorous chemical explosion: a longitudinal study. *Occup Med (Lond)* **65**, 202–9. [Medline] [CrossRef]
- 7) Behbod B, Parker EM, Jones EA, Bayleyegn T, Guarisco J, Morrison M, McIntyre MG, Knight M, Eichold B, Yip F (2014) Community health assessment following mercaptan spill: Eight Mile, Mobile County, Alabama, September 2012. *J Public Health Manag Pract* **20**, 632–9. [Medline] [CrossRef]
- 8) Luginaah IN, Taylor SM, Elliott SJ, Eyles JD (2000) A longitudinal study of the health impacts of a petroleum refinery. *Soc Sci Med* **50**, 1155–66. [Medline] [CrossRef]
- 9) Ackermann-Liebrich UA, Braun C, Rapp RC (1992) Epidemiologic analysis of an environmental disaster: the Schweizerhalle experience. *Environ Res* **58**, 1–14. [Medline] [CrossRef]
- 10) Partti-Pellinen K, Marttila O, Vilkkä V, Jaakkola JJ, Jäppinen P, Haahela T (1996) The South Karelia Air Pollution Study: effects of low-level exposure to malodorous sulfur compounds on symptoms. *Arch Environ Health* **51**, 315–20. [Medline] [CrossRef]
- 11) Vermetten E, Bremner JD (2003) Olfaction as a traumatic reminder in posttraumatic stress disorder: case reports and review. *J Clin Psychiatry* **64**, 202–7. [Medline] [CrossRef]
- 12) Cortese BM, Leslie K, Uhde TW (2015) Differential odor sensitivity in PTSD: Implications for treatment and future research. *J Affect Disord* **179**, 23–30. [Medline] [CrossRef]
- 13) Blanes-Vidal V (2015) Air pollution from biodegradable wastes and non-specific health symptoms among residents: direct or annoyance-mediated associations? *Chemosphere* **120**, 371–7. [Medline] [CrossRef]
- 14) Eriksen HR, Ihlebaek C, Ursin H (1999) A scoring system for subjective health complaints (SHC). *Scand J Public Health* **27**, 63–72. [Medline] [CrossRef]
- 15) Weiss D. The impact of event scale—revised. Assessing psychological trauma and PTSD: A practitioner's handbook Second edition. 2. ed. New York: Guilford Press; 2004. p. 168–89.
- 16) Friedman M. PTSD and Related Disorders. Post-Traumatic Stress Disorder: John Wiley & Sons, Ltd; 2011. p. 1–34. [CrossRef]
- 17) American Psychiatric Association. Diagnostic and Statistical Manual of Mental Disorders 4 Text Revision ed. Washington, WA2000.
- 18) Axelsson G, Stockfelt L, Andersson E, Gidlof-Gunnarsson A, Sallsten G, Barregard L (2013) Annoyance and worry in a petrochemical industrial area—prevalence, time trends and risk indicators. *Int J Environ Res Public Health* **10**, 1418–38. [Medline] [CrossRef]
- 19) Breslau N (2009) The epidemiology of trauma, PTSD, and other posttrauma disorders. *Trauma Violence Abuse* **10**, 198–210. [Medline] [CrossRef]
- 20) Dirkzwager AJ, Grievink L, van der Velden PG, Yzermans CJ (2006) Risk factors for psychological and physical health problems after a man-made disaster. Prospective study. *Br J Psychiatry* **189**, 144–9. [Medline] [CrossRef]

- 21) Frye RE, Schwartz BS, Doty RL (1990) Dose-related effects of cigarette smoking on olfactory function. *JAMA* **263**, 1233–6. [Medline] [CrossRef]
- 22) Greenberg MI, Curtis JA, Vearrier D (2013) The perception of odor is not a surrogate marker for chemical exposure: a review of factors influencing human odor perception. *Clin Toxicol (Phila)* **51**, 70–6. [Medline] [CrossRef]
- 23) Ihlebaek C, Eriksen HR, Ursin H (2002) Prevalence of subjective health complaints (SHC) in Norway. *Scand J Public Health* **30**, 20–9. [Medline] [CrossRef]
- 24) Javidi H, Yadollahie M (2012) Post-traumatic Stress Disorder. *Int J Occup Environ Med* **3**, 2–9. [Medline]
- 25) Kaloupek DG, Chard KM, Freed MC, Peterson AL, Riggs DS, Stein MB, Tuma F (2010) Common data elements for posttraumatic stress disorder research. *Arch Phys Med Rehabil* **91**, 1684–91. [Medline] [CrossRef]
- 26) Keane TM, Marshall AD, Taft CT (2006) Posttraumatic stress disorder: etiology, epidemiology, and treatment outcome. *Annu Rev Clin Psychol* **2**, 161–97. [Medline] [CrossRef]
- 27) Luginah IN, Taylor SM, Elliott SJ, Eyles JD (2002) Community reappraisal of the perceived health effects of a petroleum refinery. *Soc Sci Med* **55**, 47–61. [Medline] [CrossRef]
- 28) Skogstad M, Skorstad M, Lie A, Conradi HS, Heir T, Weisæth L (2013) Work-related post-traumatic stress disorder. *Occup Med (Lond)* **63**, 175–82. [Medline] [CrossRef]
- 29) Claeson AS, Lidén E, Nordin M, Nordin S (2013) The role of perceived pollution and health risk perception in annoyance and health symptoms: a population-based study of odorous air pollution. *Int Arch Occup Environ Health* **86**, 367–74. [Medline] [CrossRef]
- 30) Matsunaga M, Isowa T, Yamakawa K, Kawanishi Y, Tsuboi H, Kaneko H, Sadato N, Oshida A, Katayama A, Kashiwagi M, Ohira H (2011) Psychological and physiological responses to odor-evoked autobiographic memory. *Activitas Nervosa Superior Rediviva*. **53**, 114–20.
- 31) Patel RM, Pinto JM (2014) Olfaction: anatomy, physiology, and disease. *Clin Anat* **27**, 54–60. [Medline] [CrossRef]
- 32) Krusemark EA, Novak LR, Gitelman DR, Li W (2013) When the sense of smell meets emotion: anxiety-state-dependent olfactory processing and neural circuitry adaptation. *J Neurosci* **33**, 15324–32. [Medline] [CrossRef]
- 33) Steinheider B (1999) Environmental odours and somatic complaints. *Zentralblatt für Hygiene und Umweltmedizin = International journal of hygiene and environmental medicine*. **202**, 101–19.
- 34) Sucker K, Both R, Winneke G (2009) Review of adverse health effects of odours in field studies. *Water Sci Technol* **59**, 1281–9. [Medline] [CrossRef]
- 35) Shusterman D (2001) Odor-associated health complaints: competing explanatory models. *Chem Senses* **26**, 339–43. [Medline] [CrossRef]
- 36) Smeets MA, Dalton PH (2005) Evaluating the human response to chemicals: odor, irritation and non-sensory factors. *Environ Toxicol Pharmacol* **19**, 581–8. [Medline] [CrossRef]
- 37) Chu S, Downes JJ (2000) Odour-evoked autobiographical memories: psychological investigations of proustian phenomena. *Chem Senses* **25**, 111–6. [Medline] [CrossRef]
- 38) Toffolo MB, Smeets MA, van den Hout MA (2012) Proust revisited: odours as triggers of aversive memories. *Cogn Emotion* **26**, 83–92. [Medline] [CrossRef]
- 39) Shusterman D, Lipscomb J, Neutra R, Satin K (1991) Symptom prevalence and odor-worry interaction near hazardous waste sites. *Environ Health Perspect* **94**, 25–30. [Medline] [CrossRef]
- 40) Leer A, Smeets MA, Bulsing PJ, van den Hout MA (2011) Odors eliciting fear: a conditioning approach to Idiopathic Environmental Intolerances. *J Behav Ther Exp Psychiatry* **42**, 240–9. [Medline] [CrossRef]
- 41) Croy I, Schellong J, Joraschky P, Hummel T (2010) PTSD, but not childhood maltreatment, modifies responses to unpleasant odors. *Int J Psychophysiol* **75**, 326–31. [Medline] [CrossRef]
- 42) Duncan MA, Drociuk D, Belflower-Thomas A, Van Sickle D, Gibson JJ, Youngblood C, Daley WR (2011) Follow-up assessment of health consequences after a chlorine release from a train derailment—Graniteville, SC, 2005. *J Med Toxicol* **7**, 85–91. [Medline] [CrossRef]
- 43) Shah D (2009) Healthy worker effect phenomenon. *Indian J Occup Environ Med* **13**, 77–9. [Medline] [CrossRef]

Til innbyggjarane i Gulen og Masfjorden

Forespørsel om å delta i prosjektet "Oppfølging etter Vest Tank ulykka i Gulen kommune"

Helsedirektoratet ba i juli i år Helse Bergen om å utføra ei helseundersøking av innbyggjarane i Gulen og Masfjorden etter Vest Tank ulykka i Sløvåg den 24. mai 2007.

Dette er eit prosjekt som vert utført av helsepersonell og forskarar ved Yrkesmedisinsk avdeling, Haukeland universitetssjukehus og Universitetet i Bergen. Målsetjinga er å kartleggja eventuelle helseproblem som kan ha komme i samband med ulykka. Helseundersøkinga er planlagt gjennomført i perioden frå november 2008 til januar 2009. Ved oppfølgjande undersøkingar i 2010 og 2012 vil vi finne ut korleis ulykka på lenger sikt har verka inn på innbyggjarane si helse.

Gulen og Masfjorden kommunar har hjelpt oss med utsendinga av dette brevet, ved at vi fekk bruka adressene i folkeregisteret. Du blir spurt fordi du bur i det geografiske området vi har valt ut for undersøkinga.

Deltaking i undersøkinga vil innebere å fylle ut vedlagde spørjeskjema og deretter møta til undersøking hos lege. Spørjeskjemaet inneheld spørsmål om helsetilstanden din i tillegg til ulik bakgrunnsinformasjon som alder, bustad og arbeid. Vidare spør vi om tilhøve som gjeld forkomst av kroniske sjukdommar og symptom, vi spør også om vanskar som du har opplevd i samband med ulykka. Det er i tillegg spesielt viktig å få vite kor du oppheldt deg då ulykka skjedde, og om du har egne kommentarar i samband med denne.

Undersøkinga er planlagt slik:

- Utfylling av eit spørjeskjema
- Klinisk undersøking av luftvegane utført av lege
- Undersøking av tårefilm i auga (vi lyser i auga ei kort stund)
- Spirometri (lungefunksjonsundersøking)
- Urinprøve (måling eggekvitestoff)
- Blodprøvar – blodprøvane blir tatt for å analysera blodbilde (blodprosent, antall kvite og raude blodceller, blodplater), lever- og nyre funksjon, immunglobuliner, komplementfaktorar, kvikksølv, nikkel, kopar og sink. I tillegg blir det tatt ein prøve for å analysera genuttrykk som blir kalla P53. P53 kan indikere tidlege tekn på kreftutvikling.

Vi ber også om å ta ti milliliter ekstra blod av deg som kan lagrast for eventuelle nye testar i framtida. I dag er det ikkje bestemt kva analysar som skal takast av denne prøven. Dersom det kjem meir informasjon om den eksponeringa innbyggjarane har vore utsett for

ved eksplosjonsulykka i Gulen, kan det bli aktuelt med andre analyser som vi ikkje kan planleggja i dag. Det er også mogleg at det kan koma nye analysar i framtida som kan vera til nytte for deg og innbyggjarane i Gulen.

Dersom vi finn tekn til sjukdom hos deg, vil du få informasjon om dette, og råd om korleis du vil bli følgd opp vidare. Analysen for genuttrykk er slik at vi ikkje kan seie noko sikkert om kva som er normalt for kvar enkelt person, berre for ulike grupper. Dersom innbyggjarane i Gulen/Masfjorden skulla ha verdiar som er unormale, vil vi sørge for grundig informasjon om dette og følgje dette opp vidare.

Det utfylte skjemaet er konfidensielt, og data frå dette blir tatt imot, ordna og analysert av personar med teieplikt. Alle utfylte skjema vil bli lagra i låst skap. Personidentifiserbare datafiler vil berre vere tilgjengelege for dei som er ansvarlege for undersøkinga. Andre enn desse vil ikkje på noko tidspunkt ha tilgang til utfylte spørjeskjema eller få vita kven som har deltatt i undersøkinga.

Hovudresultata frå undersøkinga vil bli gitt i eigne rapportar slik at innbyggjarane også kan få rask informasjon. Vi vil også publisere resultata i vitskaplege tidsskrift. Resultata vil bli presentert på ein slik måte at det ikkje er mogeleg å identifisere den enkelte deltakar eller den enkelte arbeidsplass. Prosjektet vil bli avslutta ved utgangen av 2018 og datamaterialet vil bli anonymisert og blodprøvene makulert.

Før prosjektet blir avslutta kan du bli kontakta med spørsmål om å delta i tilleggsundersøkingar og/ eller innhenting av opplysningar frå aktuelle registre. I så tilfelle vil du få ny forespørsel og vi vil innhente nytt samtykke.

Det er friviljug å delta i denne undersøkinga, og du kan trekkja deg når som helst. Opplysningane dine vil då bli sletta. Prosjektet er klarert av Regional komité for medisinsk forskningsetikk Vest-Norge og godkjent av Personvernombudet for forskning, Norsk samfunnsvitenskapelig datatjeneste.

Dersom du samtykkjer i å delta i denne undersøkinga, ber vi om at du leverer utfylt spørjeskjema hos oss når du møter til helseundersøking.

Dato og tid:

Stad:

Ta med urinprøve til helseundersøkinga.

Dersom tida ikkje passar, være vennleg å ringa xx xx xx xx, så kan vi avtale ny tid.

Dersom du har noko du vil spørja om, ta kontakt med oss. På førehand tusen takk for hjelpa!

Bergen, oktober 2008

Tor B. Aasen
prosjektansvarleg/lege

Björg Eli Hollund
prosjektleder/yrkeshygienikar dr. philos.

SAMTYKKE

Eg har lest informasjonsbrevet om undersøkelsen ”**Oppfølging etter Vest Tank ulykka i Gulen kommune**” som starter hausten 2008, og seier meg villig til å delta i undersøkinga:

Namn: _____

Dato: _____

Vær vennleg å ta med spørjeskjema og samtykkearket til helseundersøkinga.

HELSEUNDERSØKELSE ETTER SLØVÅG-ULYKKEN

Spørreskjema til voksne i Gulen og Masfjorden kommuner.



KONFIDENSIELT

1. Navn: _____

2. Fødselsnummer:

3. Adresse: _____

4. Hvor lenge har du hatt nåværende adresse? Antall år: _____

5. Hvor langt er det fra boligen din til kaien på Sløvåg? Antall km: _____

6. Hvor var du da eksplosjonen i Sløvåg skjedde (24.mai 2007):

Antall km fra Sløvåg: _____

7. Arbeidet du i en av bedriftene i Sløvåg industriområde da eksplosjonen skjedde?

Ja Nei

Hvis ja, hvilken bedrift? _____

Hvor lenge har du arbeidet i Sløvåg? Antall år: _____

8. Deltok du i brannslukningen etter eksplosjonen i Sløvåg? Ja Nei

9. Deltok du i opprydningen av avfall fra eksplosjonen? Ja Nei

10. Har du merket lukt fra Sløvåg etter ulykken? Ja Nei

Hvis ja, når? (sett gjerne flere kryss)

2007: mai jun jul aug sep okt nov des

2008: jan feb mar apr mai jun jul aug

11. Hvor har du merket lukt? hjemme på jobb

12. Kan du kort beskrive hvordan du opplevde eksplosjonsulykken, om du for eksempel opplevde helseplager i forbindelse med denne

Skriv kort her. Er det for liten plass, kan du bruke baksiden av skjemaet også.

Her kommer noen generelle spørsmål:

13. Hvor mange år har du gått på skole/studert etter grunnskolen (9-årig skole)?

Antall år: _____

14. Er du:

I arbeid Sykemeldt eller under attføring Uføretrygdet

Alderspensjonist Student/skoleelev

15. Hvis du er i inntektsgivende arbeid:

a) Hvilket yrke har du? (Skriv for eksempel bonde, anestesisykepleier, snekker e.l.):

b) Beskriv virksomheten på arbeidsstedet ditt (skriv for eksempel jordbruk, sykehus, snekkeravdeling på skipsverft eller lignende) _____

c) Navn på bedriften: _____

16. Plager i dag

Har du hatt noen av disse symptomene i dag?

Gradér symptomene på en skala fra 0 til 4, der 0 er ingen symptomer og 4 er mye symptomer:

	Ingen 0	1	2	3	Mye 4
Tett nese	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Rennende nese	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Irritert nese, nysing	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Sår hals	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

17. Andre plager fra luftveiene

Hoster eller harker du vanligvis om morgenen? Ja Nei

Hoster du omtrent daglig? Ja Nei

Hvis ja, hoster du så mye som 4-6 ganger om dagen, mer enn fire dager i uka? Ja Nei

Hoster du både natt og dag? Ja Nei

Hoster du så mye som dette mer enn tre måneder i året? Ja Nei

Har du vanligvis oppspytt og slim når du hoster eller harker? Ja Nei

Hvis ja,

...har du oppspytt mer enn 4-6 ganger om dagen, fire dager eller mer i uka? Ja Nei

...har du hoste med oppspytt daglig i tre måneder eller mere i året? Ja Nei

Blir du tungpusten når du går med vanlig fart på flat mark? Ja Nei

Blir du tungpusten når du går sammen med jevnaldrende på flat mark? Ja Nei

Blir du mer tungpusten enn jevnaldrende når du går i motbakker? Ja Nei

Har du hatt anfall med pipelyder i brystet? Ja Nei

Hvis ja, hvor lenge har du hatt dette? År Måneder

18. Helseproblemer siste 30 døgn

Nedenfor nevnes noen vanlige helseplager. Vi vil be deg om å vurdere hvert enkelt problem/symptom og oppgi i hvilken grad du har vært plaget av dette i løpet av de siste tretti døgn.

Eksempel:

Hvis du føler at du har vært en del plaget med forkjølelse/influensa siste måned, fylles dette ut på følgende måte:

Nedenfor nevnes noen alminnelige helseproblemer	0=ikke plaget 1=litt plaget 2=en del plaget 3=alvorlig plaget
1. Forkjølelse, influensa	2

Nedenfor nevnes noen alminnelige helseproblemer	0=ikke plaget 1=litt plaget 2=en del plaget 3=alvorlig plaget
1. Forkjølelse, influensa	
2. Hoste, bronkitt	
3. Astma	
4. Hodepine	
5. Nakkesmerter	
6. Smerter øverst i ryggen	
7. Smerter i korsrygg	
8. Smerter i armer	
9. Smerter i skuldre	
10. Migrene	
11. Hjertebank, ekstraslag	
12. Brystsmerter	
13. Pustevansker	
14. Smerter i føttene ved anstrengelser	
15. Sure oppstøt, "halsbrann"	
16. Sug eller svie i magen	
17. Magekatarr, magesår	
18. Mageknip	
19. "Luftplager"	
20. Løs avføring, diaré	
21. Forstoppelse	
22. Eksem	
23. Allergi	
24. Hetetokter	
25. Søvnproblemer	
26. Tretthet	
27. Svimmelhet	
28. Angst	
29. Nedtrykthet, depresjon	
30. Neseblod	

Får du noen av disse plagene (punkt 1-30 over) når du kjenner lukt av parfyme, stekeos, eksos eller lignende? Ja Nei

19. Har du eller har du hatt følgende sykdommer? Kryss av.

			Hvis ja, årstall for første gang du fikk sykdommen
Allergisk snue (høysnue)	<input type="checkbox"/> Ja	<input type="checkbox"/> Nei	_____
Astma	<input type="checkbox"/> Ja	<input type="checkbox"/> Nei	_____
Bronkitt	<input type="checkbox"/> Ja	<input type="checkbox"/> Nei	_____
Tuberkulose	<input type="checkbox"/> Ja	<input type="checkbox"/> Nei	_____
Eksem	<input type="checkbox"/> Ja	<input type="checkbox"/> Nei	_____
Hjertesykdom (infarkt, hjertekrampe)	<input type="checkbox"/> Ja	<input type="checkbox"/> Nei	_____
Hjerneslag	<input type="checkbox"/> Ja	<input type="checkbox"/> Nei	_____
Sukkersyke	<input type="checkbox"/> Ja	<input type="checkbox"/> Nei	_____
Nyresykdom	<input type="checkbox"/> Ja	<input type="checkbox"/> Nei	_____
Leversykdom	<input type="checkbox"/> Ja	<input type="checkbox"/> Nei	_____
Kreft	<input type="checkbox"/> Ja	<input type="checkbox"/> Nei	_____

Annet, evt hva? _____

20. Røking

Hvor mange år har du røkt totalt i ditt liv: _____ år

Røker du daglig nå? Ja Nei
Hvis ja, skriv antall sigaretter daglig: _____

Har du røykt tidligere og sluttet? Ja Nei
Hvis ja, skriv årstall da du sluttet å røke: _____

21. Alkoholbruk

Omtrent hvor ofte drikker du noen form for alkohol?

- Ikke i løpet av det siste året
- Sjeldnere enn en gang i måneden
- Omtrent en gang i måneden
- 2 - 3 ganger i måneden
- Omtrent en gang i uken
- 2 - 4 ganger i uken
- Hver dag eller nesten hver dag

Omtrent hvor mange ganger i året drikker du minst så mye alkohol at det tilsvarer 5 halvflasker øl, eller en helflaske rød- eller hvitvin, eller en halv flaske hetvin eller en kvart flaske brennevin (dvs. ca. 60 gram etanol)?

- Ingen ganger
- 1 - 4 ganger i året
- 5 - 10 ganger i året
- Omtrent en gang i måneden
- 2 - 3 ganger i måneden
- Omtrent 1 gang i uken
- 2 - 4 ganger i uken
- Hver dag eller nesten hver dag

22. Vanskeligheter etter eksplosjonsulykken i Gulen 24.mai 2007

Her finner du en liste over vanskeligheter som personer kan oppleve etter belastende livshendelser. Vennligst les hvert ledd og angi med et kryss i hvilken grad disse vanskelighetene har plaget deg i løpet av de siste 7 dager når det gjelder eksplosjonsulykken i Gulen 24.mai 2007.

	Hvor mye har eksplosjonsulykken stresset eller plaget deg i løpet av de siste 7 dager?	Ingen grad 0	Liten grad 1	Viss grad 2	Ganske mye 3	Ekstremt mye 4
1	Enhver påminnelse har vekket følelser om det som skjedde					
2	Jeg har hatt vanskeligheter med å sove uavbrutt natten igjennom					
3	Andre ting har stadig fått meg til å tenke på det					
4	Jeg har følt meg irritabel og sint					
5	Jeg har unngått å bli opprørt når jeg tenkte på eller blitt minnet om hendelsen					
6	Jeg tenkt på hendelsen også når jeg ikke har villet det					
7	Jeg har følt det som uvirkelig eller som om det ikke har skjedd					
8	Jeg har holdt meg unna alt som kunne minne meg om hendelsen					
9	Bilder fra hendelsen har dukket opp i hodet mitt					
10	Jeg har vært skvetten og lettskremt					
11	Jeg har forsøkt å ikke tenke på det som skjedde					
12	Jeg har vært klar over at jeg fortsatt har mange følelser rundt dette, men jeg ikke sluppet dem til					
13	Mine følelser rundt hendelsen har på en måte vært numne (bedøvet)					
14	Jeg har tatt meg i å handle eller føle på samme måte som da jeg opplevde hendelsen					
15	Jeg har hatt vansker med å sovne					
16	Jeg har hatt bølger av sterke følelser om hendelsen					
17	Jeg har forsøkt å viske hendelsen ut av hukommelsen					
18	Jeg har hatt vansker med å konsentrere meg					
19	Påminnelser om hendelsen har gitt meg fysiske reaksjoner, som svetting, pustevansker, kvalme eller hjertebank					
20	Jeg har hatt drømmer om hendelsen					
21	Jeg har følt meg vaksom, som om noe kunne komme til å skje					
22	Jeg har forsøkt å ikke snakke om hendelsen					

23. Vi vil gjerne vite om du har følt deg sliten, svak eller i mangel av overskudd den siste måneden.

Vennligst besvar ALLE spørsmålene ved å krysse av for det svaret du synes passer best for deg. Vi ønsker at du besvarer alle spørsmålene selv om du ikke har hatt slike problemer.

Vi spør om hvordan du har følt deg i det siste og ikke om hvordan du følte deg for lenge siden. Hvis du har følt deg sliten lenge, ber vi om at du sammenlikner deg med hvordan du følte deg sist du var bra. (Ett kryss per linje)

Har du problemer med at du føler deg sliten?

Mindre enn vanlig Ikke mer enn vanlig Mer enn vanlig Mye mer enn vanlig

Trenger du mer hvile?

Mindre enn vanlig Ikke mer enn vanlig Mer enn vanlig Mye mer enn vanlig

Føler du deg søvngig eller døsigg?

Mindre enn vanlig Ikke mer enn vanlig Mer enn vanlig Mye mer enn vanlig

Har du problemer med å komme i gang med ting?

Mindre enn vanlig Ikke mer enn vanlig Mer enn vanlig Mye mer enn vanlig

Mangler du overskudd?

Mindre enn vanlig Ikke mer enn vanlig Mer enn vanlig Mye mer enn vanlig

Har du redusert styrke i musklene dine?

Mindre enn vanlig Ikke mer enn vanlig Mer enn vanlig Mye mer enn vanlig

Føler du deg svak?

Mindre enn vanlig Ikke mer enn vanlig Mer enn vanlig Mye mer enn vanlig

Har du vansker med å konsentrere deg?

Mindre enn vanlig Ikke mer enn vanlig Mer enn vanlig Mye mer enn vanlig

Forsnakker du deg i samtaler?

Mindre enn vanlig Ikke mer enn vanlig Mer enn vanlig Mye mer enn vanlig

Er det vanskeligere å finne det rette ordet?

Mindre enn vanlig Ikke mer enn vanlig Mer enn vanlig Mye mer enn vanlig

Hvordan er hukommelsen din?

Mindre enn vanlig Ikke mer enn vanlig Mer enn vanlig Mye mer enn vanlig

Hvis du føler deg sliten for tiden, omtrent hvor lenge har det vart? (Ett eller ingen kryss)

Mindre enn en uke Mindre enn tre måneder Mellom tre og seks måneder
 Seks måneder eller mer

Hvis du føler deg sliten for tiden, omtrent hvor mye av tiden kjenner du det?

(Ett eller ingen kryss)

25 % av tiden 50 % av tiden 75 % av tiden Hele tiden

24. Vi ønsker svar på spørsmål angående boligen din:

Bor du i et hus hvor det er heldekkende tepper i stuen? Ja Nei

Er det katt eller hund i boligen din? Ja Nei

Har det vært fuktproblemer i bygningen der du bor? Ja Nei

25. Forekommer allergiske sykdommer i din familie? Ja Nei
(astma, høysnue, eksem)

26. Om din generelle helse

	Veldig god	God	Dårlig	Veldig dårlig
a) Hvor god er helsen din?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

	Bedre	Samme	Verre	Mye verre
b) Hvor god er helsen din nå, sammenlignet med for fem år siden?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

	Godt	Som for andre	Ikke godt	Dårlig
c) Hva tenker du om livet ditt generelt?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

	Bedre	Samme	Verre	Mye verre
d) Hva tenker du om livet ditt nå, sammenlignet med for fem år siden?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Takk for at du tok deg tid til å fylle ut skjemaet!

HELSEUNDERSØKELSE ETTER SLOVÅG-ULYKKEN

Spørreskjema til voksne i Gulen og Masfjorden kommuner

2012



KONFIDENSIELT

Vennligst fyll ut skjemaet så fullstendig som mulig og ta det med til helseundersøkelsen.

1. Navn _____

Eventuelt nytt navn dersom du har endret navn etter november 2008

2. Fødselsnummer

3. Telefonnummer

4. Har du flyttet til ny adresse etter november 2008: Ja Nei

Hvis ja, hvor _____

Dato for flytting _____

Hvor mange km er det fra din **nye** bolig til kaien i Sløvåg industriområde?

Antall km (luftlinje) _____

5. Det luktet vondt etter ulykken ved Vest Tank. Har du merket denne lukten den siste måneden?

Ja Nei

Hvis ja, hvor: Hjemme På jobb

6. Hva er din høyeste fullførte utdanning?

- Grunnskole (7 eller 9 år)
- Videregående/gymnas/yrkesskole
- Høyskole/ Universitet

7. Er du nå

- I arbeid
- Student/skoleelev
- Sykemeldt eller arbeidsavklaringspenger
- Uføretrygdet
- Alderspensjonist
- Annet, beskriv hva _____

8. Har du vært sykemeldt/hatt legemeldt sykefravær i perioden fra ulykken skjedde og frem til i dag?

Ja Nei

Hvis ja, ble du sykemeldt pga sykdom/helseplager du selv relaterer til ulykken?

Ja Nei

9. Hvis du er i inntektsgivende arbeid:

a) Hvilket yrke har du nå? (f.eks. bonde, anestesisykepleier, snekker e.l.)

b) Beskriv virksomheten på arbeidsstedet ditt (f.eks. jordbruk, sykehus, snekkeravdeling på skipsverft e.l.)

c) Navn på bedriften _____

d) Begynte du i denne bedriften etter undersøkelsen i november 2008?

Ja Nei

Hvis ja, oppgi dato for oppstart _____

e) Ligger bedriften du arbeider ved nå i Sløvåg industriområde? Ja Nei

10. Har du hatt noen av disse symptomene **i dag**?

Grader symptomene på en skala fra 0 til 4, der 0 er ingen symptomer og 4 er mye symptomer:

	Ingen symptomer				Mye symptomer
	0	1	2	3	4
Tett nese	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Rennende nese	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Irritert nese, nysing	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Sår hals	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Kløende, brennende eller irriterte øyne	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Såre, tørre øyne	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

11. Andre plager fra luftveiene

- a) Hoster eller harker du vanligvis om morgenen? Ja Nei
- b) Hoster du omtrent daglig? Ja Nei
- Hvis ja:**
Hoster du så mye som 4-6 ganger om dagen, mer enn fire dager i uka? Ja Nei
Hoster du både natt og dag? Ja Nei
Hoster du så mye som dette mer enn tre måneder i året? Ja Nei
- c) Har du vanligvis oppspytt og slim når du hoster eller harker? Ja Nei
- Hvis ja:**
Har du oppspytt mer enn 4-6 ganger om dagen, fire dager eller mer i uka? Ja Nei
Har du hoste med oppspytt daglig i tre måneder eller mer i året? Ja Nei
- d) Blir du tungpusten når du går med vanlig fart på flat mark? Ja Nei
- e) Blir du tungpusten når du går sammen med jevnaldrende på flat mark? Ja Nei
- f) Blir du mer tungpusten enn jevnaldrende når du går i motbakker? Ja Nei
- g) Har du hatt anfall med pipelyder i brystet? Ja Nei
- Hvis ja:**
Hvor lenge har du hatt dette? Antall år
- h) Har du noen gang i løpet av **de siste 12 månedene** våknet opp med følelse av å være tung i pusten? Ja Nei
- i) Har du noen gang i løpet av **de siste 12 månedene** hatt anfall av tungpustethet om dagen når du har vært i ro? Ja Nei
- j) Har du noen gang i løpet av **de siste 12 månedene** hatt anfall av tungpustethet etter en anstrengelse? Ja Nei
- k) Har du noen gang i løpet av **de siste 12 månedene** blitt vekket av et anfall med tungpustethet? Ja Nei
- l) Har du noen gang i løpet av **de siste 12 månedene** hatt pipelyder i brystet? Ja Nei
- Hvis ja:**
Har du vært tung i pusten i forbindelse med at du hadde pipelyder i brystet? Ja Nei

12. Helseproblemer siste 30 døgn

Nedenfor nevnes noen vanlige helseplager. Vi vil be deg om å vurdere hvert enkelt problem/symptom og oppgi i hvilken grad du har vært plaget av dette i løpet av **de siste 30 døgn**.

Eksempel:

Hvis du føler at du har vært en del plaget med forkjølelse/influenza siste måned, fylles dette ut på følgende måte:

Nedenfor nevnes noen alminnelige helseproblemer	0=ikke plaget 1=litt plaget 2=en del plaget 3=alvorlig plaget
1. Forkjølelse, influensa	2

Nedenfor nevnes noen alminnelige helseproblemer	0=ikke plaget 1=litt plaget 2=en del plaget 3=alvorlig plaget
1. Forkjølelse, influensa	
2. Hoste, bronkitt	
3. Astma	
4. Hodepine	
5. Nakkesmerter	
6. Smerter øverst i ryggen	
7. Smerter i korsrygg	
8. Smerter i armer	
9. Smerter i skuldre	
10. Migrene	
11. Hjertebank, ekstraslag	
12. Brystsmerter	
13. Pustevansker	
14. Smerter i føttene ved anstrengelser	
15. Sure oppstøt, "halsbrann"	
16. Sug eller svie i magen	
17. Magekatarr, magesår	
18. Mageknip	
19. "Luftplager"	
20. Løs avføring, diaré	
21. Forstoppelse	
22. Eksem	
23. Allergi	
24. Hetetokter	
25. Søvnproblemer	
26. Tretthet	
27. Svimmelhet	
28. Angst	
29. Nedtrykthet, depresjon	
30. Neseblod	

b) Får du noen av disse plagene (punkt 1-30 over) når du kjenner lukt av parfyme, stekeos, eksos eller lignende? Ja Nei

13. Har du, eller har du hatt følgende sykdommer?

Hvis ja, er det bekreftet av lege?

Allergisk snue (høysnue)	<input type="checkbox"/> Ja	<input type="checkbox"/> Ja	<input type="checkbox"/> Nei
Astma	<input type="checkbox"/> Ja	<input type="checkbox"/> Ja	<input type="checkbox"/> Nei
Kronisk obstruktiv lungesykdom (KOLS)	<input type="checkbox"/> Ja	<input type="checkbox"/> Ja	<input type="checkbox"/> Nei
Eksem	<input type="checkbox"/> Ja	<input type="checkbox"/> Ja	<input type="checkbox"/> Nei
Hjertesykdom (infarkt, hjertekrampe)	<input type="checkbox"/> Ja		
Hjerneslag	<input type="checkbox"/> Ja		
Sukkersyke	<input type="checkbox"/> Ja		
Nyresykdom	<input type="checkbox"/> Ja		
Leversykdom	<input type="checkbox"/> Ja		
Kreft	<input type="checkbox"/> Ja		

Annet, beskriv hva: _____

14. Røyking

a) Hvor mange år har du røykt totalt i ditt liv _____ år

b) Røyker du daglig nå? Ja Nei

Hvis ja, skriv antall sigaretter daglig _____

c) Har du røykt tidligere og sluttet? Ja Nei

Skriv årstall da du sluttet å røyke _____

Skriv antall sigaretter du pleide å røyke daglig (ca) _____

15. Vanskeligheter du har **NÅ** etter eksplosjonsulykken i Gulen 24.mai 2007

Her finner du en liste over vanskeligheter som personer kan oppleve etter belastende livshendelser. Vennligst les hvert ledd og angi med et kryss i hvilken grad disse vanskelighetene har plaget deg i løpet av de siste 7 dager når det gjelder eksplosjonsulykken i Gulen.

Hvor mye har eksplosjonsulykken stresset eller plaget deg i løpet av de siste 7 dager?	Ingen grad	Liten grad	Viss grad	Ganske mye	Ekstremt mye
1 Enhver påminnelse har vekket følelser om det som skjedde	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2 Jeg har hatt vanskeligheter med å sove uavbrutt natten igjennom	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3 Andre ting har stadig fått meg til å tenke på det	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4 Jeg har følt meg irritabel og sint	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
5 Jeg har unngått å bli opprørt når jeg tenkte på eller har blitt minnet om hendelsen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6 Jeg har tenkt på hendelsen også når jeg ikke har villet det	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7 Jeg har følt det som uvirkelig eller som om det ikke har skjedd	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8 Jeg har holdt meg unna alt som kunne minne meg om hendelsen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
9 Bilder fra hendelsen har dukket opp i hodet mitt	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10 Jeg har vært skvetten og lettskremt	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
11 Jeg har forsøkt å ikke tenke på det som skjedde	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
12 Jeg har vært klar over at jeg fortsatt har mange følelser rundt dette, men jeg har ikke sluppet dem til	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
13 Mine følelser rundt hendelsen har på en måte vært numne (bedøvet)	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
14 Jeg har tatt meg i å handle eller føle på samme måte som da jeg opplevde hendelsen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
15 Jeg har hatt vansker med å sovne	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
16 Jeg har hatt bølger av sterke følelser om hendelsen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
17 Jeg har forsøkt å viske hendelsen ut av hukommelsen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
18 Jeg har hatt vansker med å konsentrere meg	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
19 Påminnelser om hendelsen har gitt meg fysiske reaksjoner, som svetting, pustevansker, kvalme eller hjertebank	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
20 Jeg har hatt drømmer om hendelsen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
21 Jeg har følt meg vaksom, som om noe kunne komme til å skje	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
22 Jeg har forsøkt å ikke snakke om hendelsen	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

16. Har du hatt andre opplevelser i forbindelse med Sløvågulykken som du har lyst til å skrive om?

Skriv her, fortsett eventuelt på eget ark

17. Om din generelle helse

Hvor god er helsen din?

Veldig god God Dårlig Veldig dårlig

Hvordan er helsen din sammenlignet med for fem år siden?

Bedre Samme Verre Mye verre

Hva tenker du om livet ditt generelt?

Godt Som for andre Ikke godt Dårlig

Hva tenker du om livet ditt nå, sammenlignet med for fem år siden?

Bedre Samme Verre Mye verre

Takk for at du tok deg tid til å fylle ut skjemaet!