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Original Article

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

Gro TJALVIN[1, 2]*, Nils MAGERØY[2], Magne BRÅTVEIT[1], Stein Håkon Låstad LYGRE[2], Bjørg Eli HOLLUND[2] and Bente Elisabeth MOEN[3]

[1]Department of Global Public Health and Primary Care, Faculty of Medicine and Dentistry, University of Bergen, Norway
[2]Department of Occupational Medicine, Haukeland University Hospital, Norway
[3]Centre for International Health, Faculty of Medicine and Dentistry, University of Bergen, Norway

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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 2007[1)]. 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 by[2)]. 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 explosion[1)]. The accident and the malodorous pollution received

*To whom correspondence should be addressed.
E-mail: gro.tjalvin@uib.no

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 controls[3]. 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 area[6]. However, these workers still reported significantly more subjective neurological complaints compared to controls[6]. 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 reminder[11]. 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 environmental 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 misclassifications[13], an individual odour

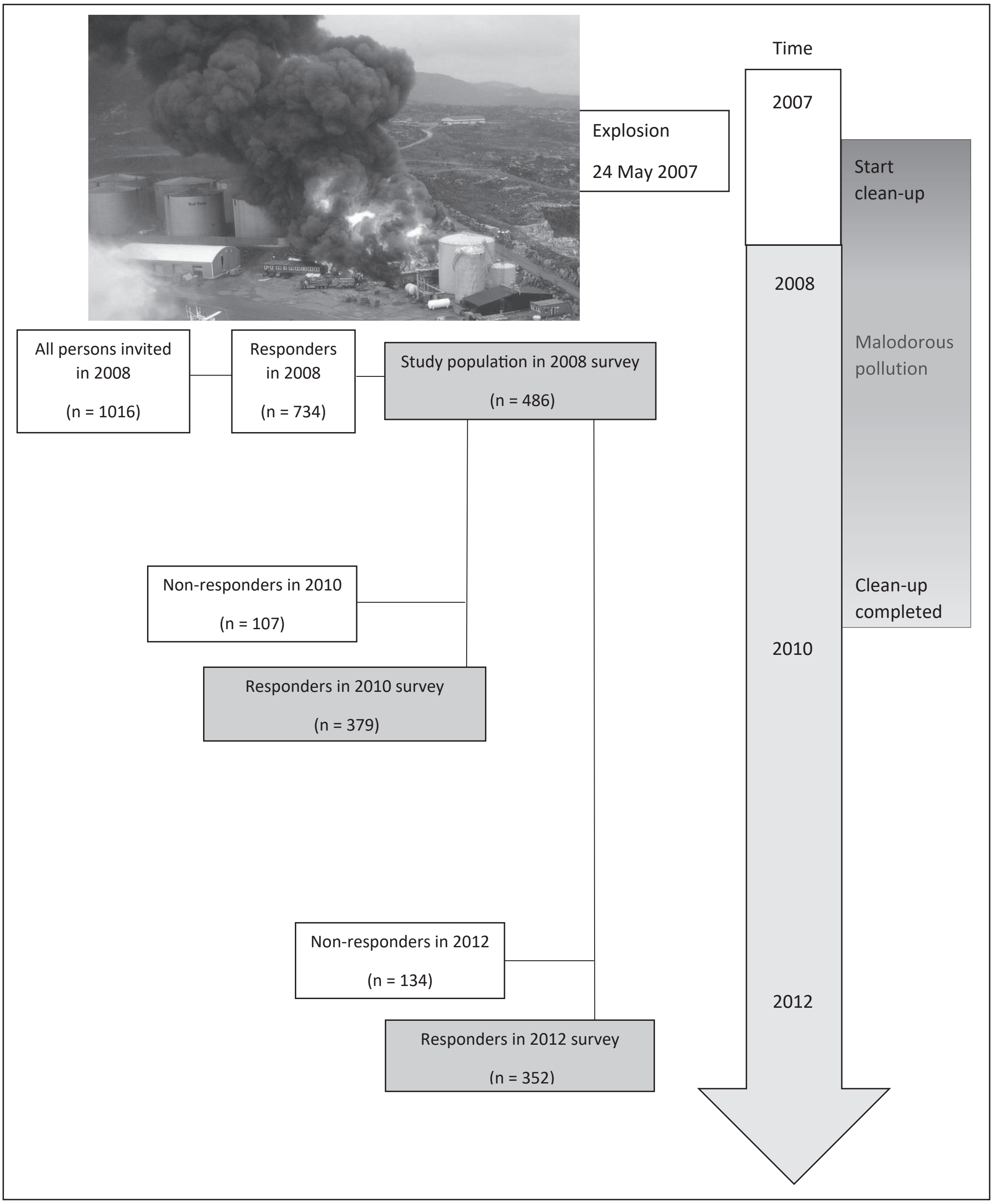

Fig. 1. The present study is a part of a comprehensive study started in 2008 after a chemical explosion in May 2007. The study population (shaded grey), comprised all adults (18–67) from the main cohort who were gainfully employed in 2008. These participants were surveyed when the malodorous pollution 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

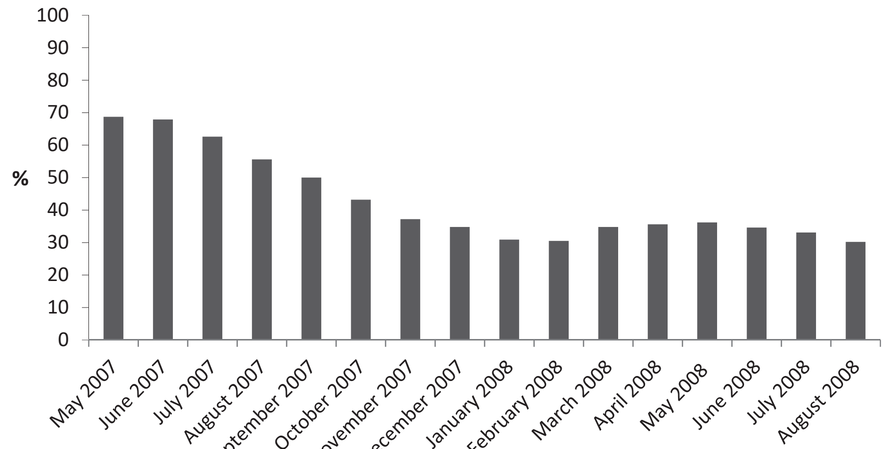

Fig. 2. Percentage of participants (n=486) who reported the characteristic odour at some time each month between May 2007 and August 2008.

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 days[14]. 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 event[15]. 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 (kilometres). 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 missing[14] 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 expolosion, 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 (%)				9 (2)	1 (1)	8 (4)	12 (3)	3 (2)	9 (5)
Total SHC score[c], mean (median) min-max	11.47 (10) 0–46	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			*p* for interaction
				MD[b] (95% CI)	SMD[c]	*p*	
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				
p	<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				
p	<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				
p	<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).

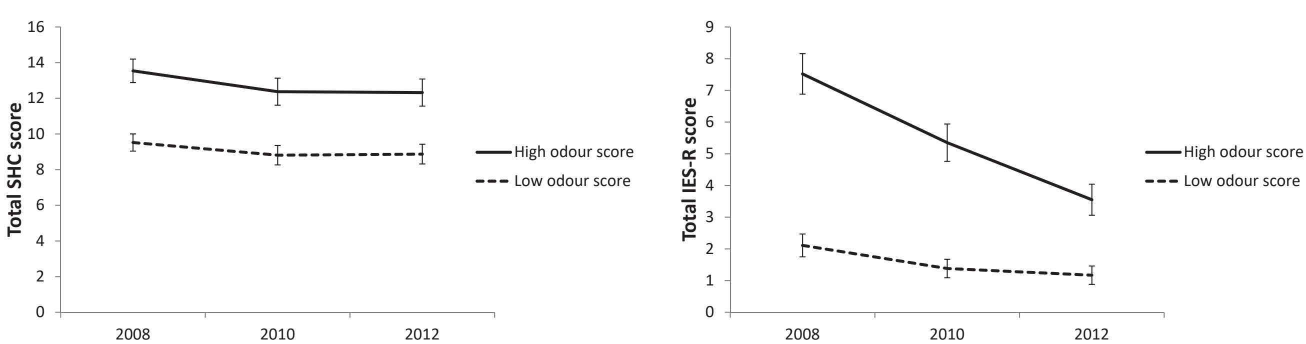

Fig. 3. Total mean scores with standard errors of the mean of The Subjective Health Complaints Inventory (SHC) and Impact of Event Scale Revised (IES-R) among participants in the high and low odour score groups, respectively, when the pollution was present in the area (2008), as well as 1 and 3 years 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 present 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 hyper-arousal, 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 mill[10)], and in the aftermath of a fire in an agrochemical storage house[9)]. 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 spill[7)]. 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 study[27)].

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 time[28)].

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 environment[31)]. Odours elicit emotions in humans depending on how the stimulus is processed by the brain[8)]. An olfactory stimulus can activate amygdala directly through neural communication[30)] even without involving initial processing by the olfactory cortex[32)].

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 effect[18)] and involves an individual's perceptions, emotions and attitudes towards the exposure[29)]. 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 memories[37)]. Olfactory memories might also last for longer[37)], 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 sites[39)]. 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 itself[29)]. 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 wastes[13].

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 stimuli[41]. A single study among soldiers has put forward the hypothesis that odours play a significant role in the pathophysiology of PTSD[12]. In classical conditioning, acquired fear is supposed to diminish as time pass by, but studies have suggested that fear conditioned to odours wanes very slowly[40], and there is even an inability to extinguish the conditioned fear response in soldiers who develop PTSD[12].

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 triggers[38].

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 twice[42], 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 misclassifications[13].

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 population[23]. The scores of the low-odour score group are even lower. This probably reflects a healthy worker effect[43], 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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