Environmental Research 111 (2011) 164–170

Contents lists available at ScienceDirect

Environmental Research

journal homepage: www.elsevier.com/locate/envres

Odour annoyance and physical symptoms among residents living near waste treatment centres ☆

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ARTICLE INFO

Article history:
Received 2 July 2010
Received in revised form
4 November 2010
Accepted 15 November 2010
Available online 4 December 2010

Keywords:
Odour annoyance
Odour perception
Self-reported physical symptoms
Resident
Waste treatment

ABSTRACT

Waste treatment processes produce odours and biological emissions to the environment, but their health effects are controversial. The aim of our study was to assess odour-associated self-reported physical symptoms among residents living near waste treatment centres. The study was conducted in the surroundings of five large-scale Finnish waste treatment centres with composting plants. In 2006, 1142 randomly selected residents living within 1.5, 3.0 and 5.0 km of these centres were interviewed by telephone. A questionnaire with 102 items asked about respondent's personal characteristics, odour exposure and symptoms during the preceding 12 months. Physical symptoms were analysed by distance to the waste treatment centre and by the respondent's perception and annoyance of waste treatment odour. The residents who were classified as "annoyed of the odour" reported following physical symptoms more than the others did: unusual shortness of breath (OR 1.5, 95% CI 1.0–2.2), eye irritation (1.5, 1.1–2.1), hoarseness/dry throat (1.5, 1.1–2.0), toothache (1.4, 1.0–2.1), unusual tiredness (1.5, 1.1–2.0), fever/shivering (1.7, 1.1–2.5), joint pain (1.5, 1.1–2.1) and muscular pain (1.5, 1.1–2.0). Moreover, the ORs for almost all other physical symptoms were elevated among the annoyed respondents. Reported odour annoyance near the waste treatment centres showed an association with many physical symptoms among residents living in the neighbouring areas.

1. Introduction

Waste treatment processes produce both chemical and biological emissions to the environment and may expose the residents of nearby neighbourhoods to some health problems. Chemical emissions from waste treatment processes are perceived as odour and can be occasional, repeated or continuous and vary strongly by intensity (Suffet et al., 2009). Because these odours arise largely from microbiological degradation processes (Romain et al., 2008; Witherspoon et al., 2004), we assume that they are mostly unpleasant by hedonic tone. The effects of odour emissions from waste treatment processes in residents' health are considered to be controversial (Dalton, 2003; Herr et al., 2003; Witherspoon et al., 2004).

The hedonic tone of odour is said to have a strong influence both on the association between exposure and annoyance and the association between exposure and symptoms (Sucker et al., 2008). More specifically, neutral and unpleasant odours, as compared with pleasant odours, appear to increase the occurrence of symptoms (Sucker et al., 2009). Under extreme exposure conditions odours can be associated with health-related symptoms (Steinheider et al., 1998), but at moderate odour exposure, symptom-reporting is mediated by annoyance among residents in areas nearby the source (Luginaah et al., 2002; Steinheider et al., 1998; Sucker et al., 2009). While the frequency of odour observations may be a suitable predictor for annoyance among residents in the case of unpleasant or neutral industrial odours (Both et al., 2004; Steinheider and Winneke, 1993; Sucker et al., 2008), both frequency and intensity have been reported affecting the annoyance of waste odours (Aatamila et al., 2010). However, in the case of industrial odours, the frequency was assessed by trained observers,

☆ Data acquisition for the selection of the study subjects was approved by the National Data Protection Agency of Finland. The procedure of the telephone survey was accepted by the Ethics Committee of National Public Health Institute (KTL) of Finland and it was executed according to Declaration of Helsinki. All study subjects with an available telephone number were sent an information letter concerning the coming study of residential environment, waste treatment and population health. Subsequently, the trained interviewers telephoned the subjects, inquired about their willingness to participate and scheduled, when appropriate, the time for the interview.

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0013-9351/$ - see front matter © 2010 Elsevier Inc. All rights reserved.
doi:10.1016/j.envres.2010.11.008

and in the case of waste odours, frequency and intensity were reported by the residents.

The role of odours in the causation of health effects is unclear. It has been suggested that it is the annoyance (and not the perception) of odour that leads to the symptoms (Cavalini, 1994; Steinheider et al., 1998). Odour characteristics may, in turn, be contributed to the genesis of odour annoyance and thus to symptoms. In addition to odour exposure, also non-olfactory factors such as person related factors, other environmental exposures, social-economic structure of the residential area and momentary situation (e.g. disturbance of leisure activities or sleeping) have been shown to influence the annoyance response (Sucker et al., 2001; van Thriel et al., 2008).

The potential pathophysiological mechanisms of symptoms possibly associated with odour or other air pollutants from waste treatment are insufficiently understood. Symptoms can be induced by exposure to volatile organic compounds or microbial emissions at levels that cause toxicological effects or sensory irritation in the eye, nose or throat (Schiffman, 1998; Schiffman and Williams, 2005). Typically, responses to biological aerosols and volatile compounds from such sources are inflammatory by their nature, as shown in connection with indoor mould growth (Hirvonen et al., 2005; Penttinen et al., 2005) and agricultural occupations (Kirkhorn and Garry, 2000). The nontoxicological mechanisms are supported by an observation that exposure to moderate or intense odours from industrial hog farming operations can affect the secretory immune system of residents (Avery et al., 2004). Another possible pathway is psychosocial reaction to the environmental stress (Luginaah et al., 2002; Shusterman, 1992) or environmental worry (Shusterman et al., 1991).

Previous studies concerning various environmental odours have found associations between exposure to emissions from various odour sources and symptoms among residents. For example, increased reporting of headache, respiratory problems, eye, nose and throat symptoms, nausea, weakness and diarrhoea has been observed in the vicinity of two swine production facilities (Thu et al., 1997; Wing and Wolf, 2000). Nausea, frequent diarrhoea and excessive tiredness have been associated with exposure to annoying odour and microorganisms from a composting site, and nausea and impaired coordination with exposure to annoying odour (Herr et al., 2009). Bronchitis, waking up due to coughing, coughing when getting up or during the day, shortness of breath at rest and after exertion, smarting eyes, excessive tiredness and shivering were associated with exposure to microorganism concentrations of up to $>10^5$ CFU m^{-3} near composting site (Herr et al., 2003). In the same study, odour annoyance was associated with eye, joint and muscular symptoms, but not with respiratory tract symptoms. Headache, nausea, eye and throat irritation had a positive relationship with both frequency of odour perception and degree of environmental worry among residents near hazardous waste sites (Shusterman et al., 1991).

As part of the development of modern waste treatment policies and practises, more information about the possible associations between waste odours and human health is needed. The aim of this study was to investigate the associations between distance, odour perception and annoyance, and self-reported physical symptoms among residents living near large-scale waste treatment centres with composting plants. This is to our knowledge the first study on this subject that has been carried out in the cold climate.

2. Materials and methods

2.1. Selection of waste treatment centres and study subjects

For this study, we selected the five Finnish waste treatment centres that were both landfilling municipal waste and composting annually at least 5000 tons of biowaste or sewage sludge. These centres were situated near five cities: centre A was located in Espoo, B in Jyväskylä, C in Lahti, D in Oulu and E in Turku. The composting technique for centre D was drum composting and other centres used tunnel composting. Centre A handles the largest amount of waste in Finland, approximately 0.6 million tons/year, which is approximately 3–5 fold the amount of the other centres. All residential buildings situated at the distance zones of <1.5, 1.5– <3.0 and 3.0– <5.0 km from the borders of each centre, were identified using a geographic information system (ArcGIS9). All households in detached and row houses with at least one permanent resident (native language Finnish, aged 25–64 years) were randomly sampled by centre and zone at the National Population Register Centre. Consequently, again by random sampling, one resident meeting these eligibility criteria was selected from each household. Data acquisition was approved by the National Data Protection Agency. The details on the selection of five waste treatment centres and the study subjects have been described in our previous paper (Aatamila et al., 2010).

2.2. Telephone interviews

Telephone interviews were conducted by the computer-assisted telephone survey unit of the Finnish Institute of Occupational Health during May and June 2006. All study subjects with an available telephone number ($N=1496$) were sent an information letter concerning the coming study of residential environment, waste treatment and population health. The trained interviewers telephoned the subjects, inquired about their willingness to participate and scheduled, when appropriate, the time for the interview. The total number of completed interviews was 1142 with average duration of 21 min. The overall response rate was 76.3%, varying between 71.6% and 81.2% by the centre. The procedure of the telephone survey was accepted by the Ethics Committee of National Public Health Institute, Finland (KTL) (currently the National Institute for Health and Welfare).

2.3. Questionnaire

Our semi-structured questionnaire consisted of 102 items and was developed primarily based on a previous telephone survey on health among working-aged people (“Work and Health in Finland 2006”), conducted at the Finnish Institute of Occupational Health (Perkiö-Mäkelä et al., 2006). Further questions related to environmental exposures were added based on earlier environmental studies conducted at the Department of Environmental Health, National Institute for Health and Welfare, Finland. Overall, using the questionnaire, we obtained information about the respondent’s background, socioeconomic status (SES), life style and housing. Thirty-four questions asked about the respondent’s general health status and physical symptoms during the preceding 12 months (e.g. respiratory tract and gastrointestinal symptoms, eye/nose/throat irritation, headache, fever, tiredness, dizziness, joint/muscular pain) and three during the respondent’s entire life (allergic rhinitis, eczema, asthma). Furthermore, the respondent’s odour sensitivity was defined by asking: “Do strong odours or fragrances trouble you? The response options were: (1) very much, (2) quite a lot, (3) somewhat, (4) not at all”. Subsequently, we asked about perception of odour from the waste treatment centre as follows: “Have you noticed any odour from the waste treatment centre in your residential area? (1) no, (2) yes”. Odour reporting respondents were further queried “Does the odour annoy you? (1) very much, (2) quite a lot, (3) somewhat, (4) not at all”. Responses (1) and (2) were further categorised as “annoyed of the odour” and others as “not annoyed”.

2.4. Statistical analyses

Characteristics of the respondents were categorised by distance zone, odour perception and odour annoyance. Analyses were done with SAS 9.1. (SAS Institute Inc., 2004). Odds ratios (OR) and 95% confidence intervals (CI) for self-reported physical symptoms were obtained by distance zone, odour perception and annoyance using logistic regression models. In these models we categorised symptom reporting in two classes: no (“no” and “do not know”) and yes. Model 1 was adjusted for sex, age, education, SES and smoking, and model 2 also for odour sensitivity. The adjusting for odour sensitivity was based on testing the correlation between odour sensitivity and odour annoyance (Spearman correlation coefficient 0.2), which showed that those questions were not measuring the similar trait. We also considered the possibility that odour sensitivity is a modifier for odour annoyance. Therefore, we performed stratified analysis by odour sensitivity. The original four classes of odour sensitivity were, for this analysis, further categorised in two classes: “sensitive” (“very much” or “quite a lot”) and “not sensitive” (“somewhat” or “not at all”).

3. Results

Table 1 shows the characteristics of the respondents by distance from the waste treatment centre, by odour perception and by odour

Table 1
Characteristics of respondents living near five waste treatment centres by distance, odour perception and odour annoyance in Finland, 2006.

Characteristic	All		Distance zone						Odour perception				Odour annoyance			
			(*N*=1142)						(*N*=1126)				(*N*=1126)			
			3.0–5.0 km		1.5–3.0 km		< 1.5 km		No		Yes		No		Yes	
	n	*%*	*n*	*%*	*n*	*%*	*n*	*%*	*n*	*%*	*n*	*%*	*n*	*%*	*n*	*%*
Sex																
Male	**570**	*50*	107	*49*	127	*50*	336	*50*	195	*47*	371	*52*	453	*51*	113	*48*
Female	**572**	*50*	110	*51*	126	*50*	336	*50*	217	*53*	343	*48*	439	*49*	121	*52*
Age																
25–34 years	**198**	*17*	30	*14*	46	*18*	122	*18*	91	*22*	104	*15*	161	*18*	34	*15*
35–44 years	**264**	*23*	51	*24*	52	*21*	161	*24*	88	*21*	172	*24*	191	*21*	69	*29*
45–54 years	**336**	*29*	70	*32*	77	*30*	189	*28*	103	*25*	229	*32*	254	*28*	78	*33*
55–64 years	**344**	*30*	66	*30*	78	*31*	200	*30*	130	*32*	209	*29*	286	*32*	53	*23*
Education																
Lower secondary or less	**181**	*16*	33	*15*	39	*15*	109	*16*	56	*14*	122	*17*	148	*17*	30	*13*
Upper secondary	**354**	*31*	61	*28*	81	*32*	212	*32*	128	*31*	220	*31*	267	*30*	81	*35*
Lower tertiary	**276**	*24*	52	*24*	57	*23*	167	*25*	95	*23*	177	*25*	216	*24*	56	*24*
Higher tertiary	**331**	*29*	71	*33*	76	*30*	184	*27*	133	*32*	195	*27*	261	*29*	67	*29*
Socioeconomic status																
Entrepreneur	**112**	*10*	22	*10*	26	*10*	64	*10*	42	*10*	69	*10*	93	*10*	18	*8*
Upper-level employee	**323**	*28*	77	*35*	71	*28*	175	*26*	122	*30*	197	*28*	253	*28*	66	*28*
Lower-level employee	**332**	*29*	55	*25*	75	*30*	202	*30*	124	*30*	202	*28*	248	*28*	78	*33*
Manual worker	**213**	*19*	31	*14*	45	*18*	137	*20*	65	*16*	146	*20*	162	*18*	49	*21*
Student, pensioner and other	**162**	14	32	*15*	36	*14*	94	*14*	59	*14*	100	*14*	136	*15*	23	*10*
Smoking																
Never smoked	**580**	*51*	111	*51*	125	*49*	344	*51*	220	*53*	350	*49*	464	*52*	106	*45*
Ex-smoker	**302**	*26*	58	*27*	67	*26*	177	*26*	105	*25*	194	*27*	226	*25*	73	*31*
Smoker	**260**	*23*	48	*22*	61	*24*	151	*22*	87	*21*	170	*24*	202	*23*	55	*24*
Odour sensitivity (missing 1)																
Very much	**111**	*10*	19	*9*	32	*13*	60	*9*	32	*8*	76	*11*	61	*7*	47	*20*
Quite a lot	**242**	*21*	44	*20*	51	*20*	147	*22*	81	*20*	157	*22*	170	*19*	68	*29*
Somewhat	**481**	*42*	89	*41*	105	*42*	287	*43*	171	*42*	304	*43*	385	*43*	90	*38*
Not at all	**307**	*27*	65	*30*	65	*26*	177	*26*	128	*31*	176	*25*	275	*31*	29	*12*
Biowaste container in kitchen (missing 1)																
No	**379**	*33*	84	*39*	108	*43*	187	*28*	133	*32*	239	*33*	274	*31*	98	*42*
Yes	**762**	*67*	132	*61*	145	*57*	485	*72*	278	*68*	475	*67*	617	*69*	136	*58*
Moisture damage at home (missing 18)																
No	**1085**	*97*	210	*98*	240	*96*	635	*96*	395	*97*	675	*96*	852	*97*	218	*95*
Yes	**39**	*3*	4	*2*	11	*4*	24	*4*	12	*3*	26	*4*	26	*3*	12	*5*
Living in residential area near																
Centre A	**114**	*10*	39	*18*	51	*20*	24	*4*	22	*5*	92	*13*	70	*8*	44	*19*
Centre B	**332**	*29*	45	*21*	47	*19*	240	*36*	165	*40*	163	*23*	293	*33*	35	*15*
Centre C	**146**	*13*	43	*20*	44	*17*	59	*9*	58	*14*	87	*12*	126	*14*	19	*8*
Centre D	**298**	*26*	45	*21*	43	*17*	210	*31*	75	*18*	219	*31*	206	*23*	88	*38*
Centre E	**252**	*22*	45	*21*	68	*27*	139	*21*	92	*22*	153	*21*	197	*22*	48	*21*
All	**1142**	***100***	**217**	***100***	**253**	***100***	**672**	***100***	**412**	***100***	**714**	***100***	**892**	***100***	**234**	***100***

N, total number of respondents; *n*, number of respondents; %, proportion of respondents.

annoyance. 50% of the all respondents were males and 60% were 45–64 years old. The number of respondents varied between 114 and 332 by waste treatment centre. In the innermost zone, we had a smaller proportion of respondents with higher tertiary education and upper-level employees, and a bigger proportion of manual workers than in the outermost zone. The youngest age group reported odour less than others and the oldest age group was less annoyed with the odour. The most sensitive respondents reported odour annoyance more than others and the respondents with a biowaste container in their kitchen reported less odour annoyance. In addition, differences were found for centre by odour perception and by odour annoyance. More specifically, proportions of respondents reporting odour and odour annoyance were highest near centre A and lowest near centre B.

The occurrence of physical symptoms was first studied by distance zones and the outermost zone was used as the reference area. We observed elevated, statistically significant ORs for some physical symptoms, such as nose irritation/stuffy nose, hoarseness/dry throat and fever/shivering in the innermost zone and joint pain in the intermediate zone when adjusted for age, sex, education, SES, smoking and odour sensitivity (Table 2). However, distance zones were not consistently associated with these physical symptoms.

The associations between odour perception or annoyance and physical symptoms are shown in Table 3. The associations between odour perception and physical symptoms were the strongest for hoarseness/dry throat, headache and diarrhoea when adjusted for age, sex, education, SES, smoking and odour sensitivity. The majority of the ORs for physical symptoms were elevated although not statistically significant.

The residents classified as ‘‘annoyed of the odour’’ tended to report physical symptoms more than the residents who were ‘‘not annoyed’’. After adjustment for age, sex, education, SES, smoking and odour sensitivity, the elevated ORs were seen for unusual shortness of breath (OR 1.5, 95% CI 1.0–2.2), eye irritation

Table 2
Odds ratios (OR) and 95% confidence intervals (CI) for self-reported physical symptoms during preceding 12 months by distance zone (N=1142).

Self-reported physical symptoms	Distance zone										
	3.0– < 5.0 km	1.5–3.0 km	< 1.5 km	Model 1[a]				Model 2[b]			
	(N=217)	(N=253)	(N=672)	1.5–3.0 km		< 1.5 km		1.5–3.0 km		< 1.5 km	
	n	n	n	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Maxillary sinusitis/bronchitis/pneumonia	40	39	115	0.8	0.5–1.3	0.9	0.6–1.3	0.8	0.5–1.3	0.9	0.6–1.3
Respiratory infection	145	175	458	1.1	0.8–1.7	1.0	0.7–1.5	1.1	0.7–1.7	1.0	0.7–1.4
Cough/phlegm	137	175 (1)[c]	466 (1)[c]	1.4	0.9–2.0	**1.3**	1.0–1.9	1.3	0.9–2.0	**1.3**	1.0–1.8
Unusual shortness of breath	23 (1)[c]	39 (1)[c]	101	1.6	0.9–2.8	1.5	0.9–2.4	1.5	0.8–2.6	1.5	0.9–2.4
Wheezing	22	38	97 (1)[c]	1.6	0.9–2.8	1.5	0.9–2.4	1.5	0.8–2.6	1.4	0.9–2.4
Pain/pressing feeling/tightness of the chest	28	42 (1)[c]	107	1.4	0.8–2.3	1.3	0.8–2.0	1.3	0.8–2.2	1.3	0.8–2.0
Eye irritation	95	122	319	1.3	0.9–1.8	1.2	0.9–1.7	1.2	0.8–1.8	1.2	0.9–1.6
Non-allergic rhinitis (≥ month)	34	24	104	**0.5**	0.3–1.0	0.9	0.6–1.4	**0.5**	0.3–0.9	0.9	0.6–1.4
Nose irritation/stuffy nose	143	178	500	1.2	0.8–1.8	**1.5**	1.1–2.1	1.2	0.8–1.8	**1.5**	1.1–2.1
Hoarseness/dry throat	102	118	369	1.0	0.7–1.4	**1.4**	1.0–1.8	0.9	0.6–1.3	**1.3**	1.0–1.8
Sore throat	118 (1)[c]	138 (2)[c]	349	1.0	0.7–1.5	0.9	0.6–1.2	1.0	0.7–1.5	0.9	0.6–1.2
Headache	148	178 (1)[c]	473	1.1	0.8–1.7	1.1	0.8–1.6	1.1	0.7–1.7	1.1	0.8–1.5
Toothache	38	44 (1)[c]	131	1.0	0.6–1.6	1.1	0.7–1.7	1.0	0.6–1.6	1.1	0.7–1.6
Unusual tiredness	72 (2)[c]	83 (1)[c]	234 (1)[c]	1.0	0.7–1.5	1.1	0.8–1.5	0.9	0.6–1.4	1.1	0.8–1.5
Dizziness	49	58 (1)[c]	165	1.0	0.7–1.6	1.1	0.8–1.7	1.0	0.6–1.5	1.1	0.8–1.7
Fever/shivering	23	38 (1)[c]	112	1.5	0.9–2.7	**1.7**	1.1–2.8	1.5	0.9–2.6	**1.7**	1.0–2.8
Nausea/vomiting	34	48 (1)[c]	132 (1)[c]	1.3	0.8–2.1	1.3	0.8–2.0	1.2	0.7–2.0	1.3	0.8–2.0
Diarrhoea	60	74 (1)[c]	208	1.1	0.7–1.6	1.2	0.8–1.6	1.1	0.7–1.6	1.1	0.8–1.6
Joint pain	80	123 (1)[c]	255 (2)[c]	**1.7**	1.1–2.5	1.1	0.8–1.5	**1.6**	1.1–2.4	1.0	0.7–1.5
Muscular pain	96	115 (1)[c]	306	1.1	0.7–1.6	1.1	0.8–1.4	1.1	0.7–1.5	1.0	0.8–1.4
Asthma (diagnosed by physician)[d]	17	29	67	1.5	0.8–2.8	1.3	0.7–2.2	1.4	0.7–2.6	1.3	0.7–2.2
Allergic rhinitis[d]	90	101	295	0.9	0.6–1.3	1.1	0.8–1.5	0.9	0.6–1.3	1.0	0.8–1.4
Itching eczema[d]	56	64	193	1.0	0.6–1.5	1.2	0.8–1.7	1.0	0.6–1.5	1.2	0.8–1.7

N, total number of respondents; n, number of respondents.

[a] Adjusted for age, sex, education, SES and smoking.
[b] Adjusted for age, sex, education, SES, smoking and odour sensitivity.
[c] Number of missing answers.
[d] During lifetime.

(1.5, 1.1–2.1), hoarseness/dry throat (1.5, 1.1–2.0), toothache (1.4, 1.0–2.1), unusual tiredness (1.5, 1.1–2.0), fever/shivering (1.7, 1.1–2.5), joint pain (1.5, 1.1–2.1) and muscular pain (1.5, 1.1–2.0). Almost all other ORs were elevated although they did not reach statistical significance (Table 3). There were only small differences between models 1 and 2 when adjusting for odour sensitivity. In the stratified analyses, the odour sensitive respondents reported elevated ORs for unusual shortness of breath, headache, toothache, unusual tiredness, fever/shivering, diarrhoea, joint pain and muscular pain, and the non-sensitive respondents reported elevated ORs for eye irritation, hoarseness/dry throat, sore throat, unusual tiredness, joint pain, muscular pain and allergic rhinitis by odour annoyance (Table 4). However, no systematic difference between ORs of these two groups was shown.

We found no association between having biowaste container in kitchen (n=762) and reporting physical symptoms. Instead, moisture damage at home (n=39) was associated with some physical symptoms and the highest ORs were observed for asthma (OR 4.2, 95% CI 2.0–8.9), unusual shortness of breath (4.1, 2.0–8.4) and joint pain (3.0, 1.5–6.1). We tested our models adjusting for waste treatment centre, having biowaste container in kitchen and moisture damage at home, which attenuated some of the ORs slightly, but not more than 0.1 units (data not shown).

4. Discussion

Several self-reported physical symptoms were associated with odour annoyance. These included unusual shortness of breath, eye irritation, hoarseness/dry throat, toothache, unusual tiredness, fever/shivering, joint pain and muscular pain. The associations between physical symptoms and odour perception were weak at most. We observed no consistent change in the reporting of physical symptoms by the distance from waste treatment centre. Although odour sensitivity of an individual seems to be associated with physical symptoms, it accounts for only part of the symptoms.

The strengths of this study include the random sampling of respondents and the fairly good response rate (> 70%), which reduce the potential for biased selection of the most annoyed residents and subsequent overestimation of the physical symptoms. In addition, there were only minor differences in the characteristics of respondents across distance zones suggesting that the sampling was unbiased. To reduce reporting bias, no mention on odour was made when introducing the survey to the respondent and the questions about physical symptoms preceded the odour related questions. Assessment of odour was based on retrospective self-reports. Due to the cross-sectional design, however, the reverse causality cannot be ruled out. That is, reported odour perception and especially odour annoyance may be affected by perceived symptoms.

Generally, the symptoms did not show dose–response pattern by vicinity of waste treatment centre. This might be due to considerable differences between the studied waste treatment centres (Aatamila et al., 2010). This means that at least in the case of different waste treatment centres, the vicinity alone is not a sufficient predictor for physical symptoms, and that the personal experience of odour is likely to be a more important exposure measure. This is supported by studies near hazardous waste sites, where many of the symptoms were excessive primary in those who complained of odour (Neutra et al., 1991). In general, however, to

Table 3
Odds ratios (OR) and 95% confidence intervals (CI) for self-reported physical symptoms during preceding 12 months by odour perception and annoyance ($N=1126$).

Self-reported physical symptoms	Odour perception						Odour annoyance					
	No ($N=412$)	Yes ($N=714$)	Model 1[a]		Model 2[b]		No ($N=892$)	Yes ($N=234$)	Model 1[a]		Model 2[b]	
	n	*n*	OR	95% CI	OR	95% CI	*n*	*n*	OR	95% CI	OR	95% CI
Maxillary sinusitis/bronchitis/pneumonia	71	117	1.0	0.7–1.3	0.9	0.7–1.3	142	46	1.2	0.8–1.8	1.1	0.7–1.6
Respiratory infection	278	487	1.1	0.8–1.4	1.1	0.8–1.4	593	172	1.3	0.9–1.8	1.2	0.9–1.7
Cough/phlegm	275	488 (2)[c]	1.1	0.8–1.4	1.1	0.8–1.4	598 (1)[c]	165 (1)[c]	1.1	0.8–1.5	1.1	0.8–1.5
Unusual shortness of breath	57	101 (1)[c]	1.0	0.7–1.5	0.9	0.7–1.4	108	50 (1)[c]	**2.0**	1.3–2.9	**1.5**	1.0–2.2
Wheezing	48	108 (1)[c]	1.3	0.9–1.9	1.2	0.8–1.7	112 (1)[c]	44	**1.5**	1.0–2.3	1.1	0.7–1.7
Pain/pressing feeling/tightness of the chest	59	115 (1)[c]	1.1	0.8–1.6	1.1	0.8–1.6	128	46 (1)[c]	**1.4**	1.0–2.1	1.2	0.8–1.9
Eye irritation	190	339	1.1	0.9–1.4	1.0	0.8–1.3	394	135	**1.8**	1.3–2.4	**1.5**	1.1–2.1
Non-allergic rhinitis (≥ month)	58	102	1.1	0.8–1.6	1.1	0.8–1.6	130	30	0.9	0.6–1.4	0.9	0.6–1.4
Nose irritation/stuffy nose	285	521	**1.3**	1.0–1.7	1.2	0.9–1.6	624	182	**1.5**	1.1–2.1	1.3	0.9–1.9
Hoarseness/dry throat	196	383	**1.4**	1.1–1.7	**1.3**	1.0–1.7	432	147	**1.8**	1.3–2.4	**1.5**	1.1–2.0
Sore throat	220	375 (2)[c]	1.0	0.8–1.4	1.0	0.8–1.3	454	141 (2)[c]	**1.4**	1.0–1.9	1.3	0.9–1.8
Headache	275	509 (1)[c]	**1.4**	1.1–1.9	**1.4**	1.0–1.8	607	177 (1)[c]	1.3	0.9–1.9	1.2	0.8–1.7
Toothache	72	134 (1)[c]	1.1	0.8–1.6	1.1	0.8–1.5	151	55 (1)[c]	**1.5**	1.0–2.2	**1.4**	1.0–2.1
Unusual tiredness	142 (1)[c]	240 (1)[c]	1.0	0.7–1.3	0.9	0.7–1.2	278 (1)[c]	104 (1)[c]	**1.8**	1.3–2.4	**1.5**	1.1–2.0
Dizziness	89	177 (1)[c]	1.2	0.9–1.7	1.1	0.8–1.6	196	70 (1)[c]	**1.6**	1.1–2.2	1.3	0.9–1.8
Fever/shivering	51	120 (1)[c]	**1.4**	1.0–2.0	1.3	0.9–1.9	120	51 (1)[c]	**1.9**	1.3–2.8	**1.7**	1.1–2.5
Nausea/vomiting	75 (1)[c]	133 (1)[c]	1.1	0.8–1.6	1.1	0.8–1.6	164 (1)[c]	44 (1)[c]	1.0	0.7–1.5	0.9	0.6–1.4
Diarrhoea	110	228 (1)[c]	**1.3**	1.0–1.7	**1.3**	1.0–1.7	257	81 (1)[c]	1.3	0.9–1.7	1.2	0.9–1.7
Joint pain	157	293 (3)[c]	1.1	0.8–1.4	1.0	0.8–1.4	337 (2)[c]	113 (1)[c]	**1.7**	1.2–2.2	**1.5**	1.1–2.1
Muscular pain	172	337 (1)[c]	1.2	0.9–1.5	1.2	0.9–1.5	380	129 (1)[c]	**1.6**	1.2–2.2	**1.5**	1.1–2.0
Asthma (diagnosed by physician)[d]	41	71	1.0	0.7–1.5	0.9	0.6–1.4	87	25	1.1	0.7–1.8	0.8	0.5–1.3
Allergic rhinitis[d]	168	309	1.2	0.9–1.5	1.1	0.9–1.4	363	114	**1.3**	1.0–1.8	1.1	0.8–1.5
Itching eczema[d]	109	196	1.1	0.8–1.5	1.1	0.8–1.5	234	71	1.2	0.9-1.6	1.1	0.8–1.5

N, total number of respondents; *n*, number of respondents

[a] Adjusted for age, sex, education, SES and smoking.
[b] Adjusted for age, sex, education, SES, smoking and odour sensitivity.
[c] Number of missing answers.
[d] During lifetime.

improve the exposure assessment (e.g. odour dispersion modelling, or grid measurements with trained observers), it might be important to consider the effects of some other environmental factors, such as noise, dust, living conditions, wind direction, roads, electric power lines or forests. More information about the types and magnitudes of emissions, for example on treatment capacities, treatment processes and environmental controls would be important to provide.

In addition, our results for the higher occurrence of the symptoms of eye and throat are, in the context of odour annoyance, supported by a previous study near hazardous waste sites where frequent odour was associated with irritation or soreness of eye and throat (Shusterman et al., 1991). One explanation for the throat symptoms might be that avoiding unpleasant odours often leads into breathing through mouth rather than nose (Dalton, 2003). Similar eye and throat symptoms are also associated with emissions from other types of organic sources. Eye symptoms have been observed near large-scale swine production facilities (Thu et al., 1997; Wing and Wolf, 2000) and in association with odour annoyance near composting sites (Herr et al., 2003). In our study unusual tiredness was associated with annoying odour whereas in a previous study of composting sites, excessive tiredness was connected with exposure to elevated microorganism concentrations and annoying odour from a composting site, but not with exposure to annoying odour solely (Herr et al., 2009, 2003). We observed associations between unusual shortness of breath, fever/shivering and odour annoyance. Shivering and shortness of breath at rest and after exertion have been previously associated with elevated microorganism levels near a composting site (Herr et al., 2003). Our results for the connections between odour annoyance and joint and muscular pain are supported by the above-mentioned study, which found joint troubles and muscular symptoms in residents with odour annoyance in a residential area near composting site (Herr et al., 2003). The symptom profile in our study resembles those observed in association with building dampness and mould (WHO, 2009) and occupational exposure of waste treatment (Bunger et al., 2000; Gelberg, 1997; Ivens et al., 1999; Krajewski et al., 2004).

As for occupationally exposed subjects, similar physical symptoms as in our study have been observed among waste workers: diseases of the airways and skin among compost workers (Bunger et al., 2000), and dermatologic, neurologic and respiratory symptoms and sore throat symptom among employees working at landfill (Gelberg, 1997). Furthermore, joint and muscle pain was reported by 43% of the workers at a large sewage treatment plant (Krajewski et al., 2004). Moreover, a linear exposure–response relationship between microbial exposure and nausea as well as diarrhoea has been shown among workers in the waste collection industry (Ivens et al., 1999). It should be noted, however, that the exposure levels to both microbial particles and odorous chemicals are orders of magnitude higher in the occupational settings (Ivens et al., 1999; Poulsen et al., 1995) than in the nearby residential areas (Herr et al., 2003; Kaarakainen et al., 2008). Although the source of exposure is the same for both the workers and the residents, different levels of exposure as a consequence of distance suggest that the mechanisms are not necessarily the same. Another difference is that there are probably not many highly sensitive individuals working at landfill because they either cannot work at all or leave work quickly due to acute reactions to occupational exposures. Consequently, in occupational settings higher exposure levels overestimate the occurrence of physical symptoms whereas the absence of most sensitive individuals does the opposite.

Table 4
Odds ratios (OR) and 95% confidence intervals (CI) for self-reported physical symptoms during preceding 12 months by odour annoyance stratified by respondents odour sensitivity.

Self-reported physical symptoms	Odour sensitive respondents				Non-sensitive respondents			
	Odour annoyance				Odour annoyance			
	No (N=231)	Yes (N=115)	Model 1[a]		No (N=660)	Yes (N=119)	Model 1[a]	
	n	*n*	OR	95% CI	*n*	*n*	OR	95% CI
Maxillary sinusitis/bronchitis/pneumonia	39	29	1.6	0.9–2.8	103	17	0.8	0.5–1.4
Respiratory infection	154	84	1.2	0.7–2.1	439	88	1.3	0.8–2.1
Cough/phlegm	163	78	0.8	0.5–1.3	435(1)[b]	87(1)[b]	1.4	0.9–2.3
Unusual shortness of breath	47	34	**1.7**	1.0–2.8	61	16(1)[b]	1.6	0.8–2.9
Wheezing	45	31	1.4	0.8–2.4	67(1)[b]	13	1.1	0.6–2.1
Pain/pressing feeling/tightness of the chest	42	29	1.5	0.9–2.6	86	17(1)[b]	1.1	0.6–1.9
Eye irritation	138	71	1.2	0.7–1.9	255	64	**1.9**	1.3–2.9
Non-allergic rhinitis (≥ month)	33	13	0.8	0.4–1.6	97	17	1.0	0.6–1.8
Nose irritation/stuffy nose	179	94	1.3	0.7–2.4	444	88	1.4	0.9–2.2
Hoarseness/dry throat	140	77	1.3	0.8–2.1	291	70	**1.8**	1.2–2.7
Sore throat	126	69(1)[b]	1.2	0.7–1.9	328	72(1)[b]	**1.5**	1.0–2.2
Headache	167	94	**2.0**	1.1–3.6	439	83(1)[b]	1.0	0.6–1.6
Toothache	38	29	**1.7**	1.0–3.0	112	26(1)[b]	1.3	0.8–2.1
Unusual tiredness	98	62	**1.7**	1.1–2.7	180(1)[b]	42(1)[b]	**1.5**	1.0–2.3
Dizziness	81	42	1.2	0.7–1.9	114	28(1)[b]	1.5	0.9–2.5
Fever/shivering	41	32	**1.8**	1.0–3.2	78	19(1)[b]	1.6	0.9–2.7
Nausea/vomiting	54(1)[b]	24	0.9	0.5–1.5	110	20(1)[b]	1.1	0.6–1.9
Diarrhoea	59	44	**1.7**	1.1–2.9	198	37(1)[b]	1.0	0.7–1.6
Joint pain	102(1)[b]	60	**1.6**	1.0–2.6	234(1)[b]	53(1)[b]	**1.6**	1.0–2.4
Muscular pain	108	66	**1.5**	1.0–2.5	272	63(1)[b]	**1.6**	1.1–2.4
Asthma (diagnosed by physician)[c]	38	18	0.9	0.5–1.8	49	7	0.8	0.3–1.9
Allergic rhinitis[c]	123	58	0.8	0.5–1.3	239	56	**1.5**	1.0–2.2
Itching eczema[c]	71	42	1.3	0.8–2.1	163	29	0.9	0.6–1.4

N, total number of respondents; *n*, number of respondents

[a] Adjusted for age, sex, education, SES and smoking.
[b] Number of missing answers.
[c] During lifetime.

The physical symptoms represented here resemble the symptom profile observed in residents living in moisture damaged houses (WHO, 2009). We also observed an association between moisture damage at home and physical symptoms, based on 39 exposed subjects. However, including moisture damage in the model did not markedly change the ORs, which means that moisture damage does not explain the results of the present study. Conversely, in a German study mould and dampness in homes were not associated with airway symptoms among residents nearby a composting site (Herr et al., 2003), but also in this case the number of respondents with dampness problems was very small. This does not exclude the possibility that moisture damage might explain the physical symptoms in the case of a single study subject or other person living near waste treatment centre.

According to our previous measurements on microbial emissions (Kaarakainen, unpublished data) background concentrations are reached by the distance of 200 m from the source. In two other studies, the bioaerosol levels were increased at about 500 m of the composting plant (Recer et al., 2001) and near background concentrations within 550 m of the composting plant (Herr et al., 2003). Given that, in our present study, only three residents lived closer than 200 m from the border of the waste treatment centre and all subjects more than 600 m from the composting plant, it is unlikely that the microbial exposure plays an important role in the development of the observed symptoms. Perceiving odour denotes exposure to chemical compounds, but on the other hand, many odorants associated with organic decomposition can be smelled in extremely small concentrations, smaller than concentrations known to be harmful (Dalton, 2003; Rosenkranz and Cunningham, 2003; STM, 2009). Due to these facts and the finding that the associations between odour perception and physical symptoms were weak, it is likely that the concentrations of chemical compounds in residential areas in our study were too small to cause symptoms by immunotoxicological mechanisms or sensory irritation.

Our study showed that the physical symptoms were more clearly associated with odour annoyance than with odour perception. Several other studies have ended up with similar conclusions. Three former studies discovered that in moderate odour conditions, health effects are mediated by annoyance (Luginaah et al., 2002; Steinheider et al., 1998; Sucker et al., 2009). It can be concluded that the physical symptoms are mainly associated with odour annoyance, not with odour perception.

Partially similar symptoms as in our study have also been found in a questionnaire study on patients who attributed their unexplained physical symptoms to environmental factors (Herr et al., 2009). These patients had no indication of a current relevant environmental exposure; still they reported more symptoms than residents with exposure to annoying odours and biological emissions from waste treatment. This emphasises the importance of psychosocial reactions, in parallel with possible pathophysiological mechanisms, when considering associations between environmental exposure and perceived symptoms.

To conclude, reported odour annoyance near waste treatment centres was associated with physical symptoms among residents living in the neighbouring areas. The associations between reported odour annoyance and physical symptoms were consistent although not strong.

Acknowledgments

The study was supported by the Finnish Ministry of Social Affairs and Health, Marjaleena Aatamila was supported by the Juho Vainio Foundation and Pia K. Verkasalo was supported by the Academy of Finland (Grant number 206950). The assistance of the interviewers and the residents who participated in the study is appreciated.

The roles of funding sources

The funding sources had no involvement with the study design, collection, analysis or interpretation of data, writing of the report or with the decision to submit the paper for publication.

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