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Field studies on environmental odors inducing annoyance as well as gastric and general health-related symptoms*

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Abstract The relationship between odor annoyance and health-related symptoms including gastric symptoms is still uncertain, particularly if intensity of odor exposure and specificity of symptoms is taken into account. Results from two field studies in two cities in Northrhine-Westfalia are, therefore, given to characterize the network of associations between environmental odor-exposure, annoyance, and gastric, general health-related symptoms. In the first study, the odor source was a plant manufacturing fertilizer for mushroom cultivation with particularly offensive odor emissions. The distance from the source was taken to characterize the degree of odor exposure, and odor effects were assessed through personal interviews using standardized questionnaires. 250 individuals were interviewed at close, medium or remote distance from the plant. Apart from an extremely high degree of annoyance, an exposure-related increase of somatic symptoms, especially gastric symptoms such as nausea, loss of appetite, disgust, vomiting and retching, was found. After control for annoyance, a significant degree of association between exposure and gastric as well as behavioral symptoms was still observed. In the 2nd study, the odor source was a pig rearing facility, and the degree of odor exposure was more directly assessed by measuring the frequency of odor-events by means of systematic field observations. Again, odor effects were assessed through personal interviews by means of standardized questionnaires in the vicinity of the source (n = 322). Results showed that the degree of odor-annoyance as well as the frequency of gastric symptoms increased significantly with increasing odor-exposure, although their prevalence was reduced relative to the 1st study, and was found to be exclusively mediated by annoyance. Environmental odors have, thus, been shown to be either directly associated with gastric symptoms as well as general health-related complaints under extreme conditions of exposure (1st study), or indirectly mediated through annoyance under moderate conditions of odor exposure (2nd study).

Introduction

Contrary to environmental noise, with a large and still increasing number of publications related to health and well-being, relatively little research-effort is available dealing with environmental odors at comparable depth and intensity. At least two main reasons may be given to explain this discrepancy: First, whereas sophisticated conventions for noise-measurement based on sound pressure-levels are available and used in dose-response studies, objective assessment of odorants in the environment has long been hampered by a lack of sufficiently valid and representative measurement techniques. Second, due to the pervasive nature of transportation in a mobile society, noise is an ubiquitous public health problem affecting large and still increasing segments of the population (Lercher, 1996); whereas odor-problem areas are essentially limited to the neighborhoods of localized point- and area sources.

Yet, although the overall impact of environmental odors may be smaller on a societal level, exposure to odor pollution from municipal, agricultural, and industrial sources nevertheless raises concern regarding possible short- and long-term consequences of such exposure

* Part of the findings presented here have already been reported elsewhere (Steinheider, Winneke, & Schlipköter, 1993; Winneke, Neuf, & Steinheider, 1996).

in terms of health and well-being for exposed individuals. Municipal odor sources mainly include sewage treatment plants and sanitary landfills. Agricultural sources include manure operations, animal rendering plants, livestock feed lots, poultry farms, as well as large-scale composting and other biomass operations. Industrial sources, on the other hand, are manifold and, among others, include pulp and paper mills, spray-painting operations in the automobile industry, tobacco and sugar factories, oil refineries and chemical plants. Field studies conducted in the vicinity of such sources and dealing with aspects of health and well-being in the exposed population have typically relied on the annoyance response as the main target or mediating variable.

Definitions of annoyance vary (Koelega, 1987). According to Lindvall and Radford (1973) annoyance describes a feeling of displeasure associated with agents or events believed to be detrimental to the individual or to groups of individuals; this definition emphasizes the attribution of potentially damaging qualities as being essential for triggering annoyance responses, i. e., the cognitive evaluation produces negative feeling. Other definitions emphasize the emotional component (anger) as being dominant (Craik, 1987; Russell & Pratt, 1980), and even three-component models of annoyance covering emotion, interference, and somatic aspects (Clark, 1984), or perceptual, socio-emotional and somatic aspects (Kastka, 1976) have been proposed.

Despite these rather divergent concepts it is interesting to note that rather similar, highly significant exposure-annoyance associations were found in field studies in the vicinity of quite different odor-emitting sources (Cavalini, Krdtel-Kemmerling, & Pulles, 1991; Miedema & Ham, 1988; Steinheider & Winneke, 1993; Winneke, Harkort, Ratzki, & Steinheider, 1990). This success was not possible until valid and representative methods of exposure assessment became available. Straightforward quantitative description of odorants in the environment is limited both by the sensitivity of the human nose, as well as by the fact that poorly defined odorant mixtures with likely component interactions typically escape analytical quantification (VDI 3881). Instead, sensory methods for odor exposure assessment are now being accepted as providing sufficiently reliable and valid information to characterize immission scenarios in the vicinity of odor-emitting sources (VDI 3940). Such sensory methods are basic to the exposure-annoyance studies mentioned above. They may either take the form of predicting immission-concentrations in the vicinity of the source by means of dispersion calculations based on olfactometric measurement of odor concentrations of the odorous emissions at the stack, taking meteorological conditions into account (VDI 3782), or by determining the frequency of odor events by systematic field inspections using trained and calibrated human observers at predetermined sampling points around the odor source following randomized statistical observation protocols (VDI 3940).

The question may be raised, if and to what extent odor annoyance relates to the known stimulus and response attributes of the sense of smell in such a manner, that annoyance might be predictable from such attributes. The basic stimulus attributes of odors are olfactory threshold and concentration, whereas main response attributes include perceived odor strength (intensity), odor quality and hedonic tone (pleasantness-unpleasantness). By convention, an odor threshold is that chemical concentration on a mass or volume basis which has a 0.5 probability of detection (VDI 3881). Thresholds for individual odorants vary widely over several orders of magnitude (Leonardos, Kendall, & Barnard, 1969; Hellman & Small, 1974) and, except for narrow classes of chemicals, as e. g., alcohols (Engen, 1986), no general structure-activity relations for odor thresholds, or for power functions relating odor concentrations to perceived odor intensity, have as yet been established (Plattig, 1995).

This is in essence also true for odor quality. So far, the most widely quoted classification system in this respect is that of the primary odors of Amoore (1970) comprising seven classes, namely ether-like, camphoric, musky, flowery, minty, pungent, and foul. The underlying assumption relating these qualities to seven basic shapes of odorant molecules, has not been found valid, however (Plattig, 1995). There is, furthermore, evidence to suggest that the most salient single dimension underlying odor quality is a hedonic dimension, since a wide variety of different odors could be shown to exhibit rank ordering on a pleasantness-un-

pleasantness dimension using the semantic differential as the scaling technique (Winneke & Kastka, 1975). Although one would predict odor hedonics to be a powerful predictor of odor annoyance, no convincing evidence has so far been presented in this respect: In one pertinent field study the degree of annoyance in the vicinity of different industrial sources, namely a brewery, a tarcoal refinery and a chocolate factory, was found to differ significantly, with the refinery exhibiting highest and the chocolate plant lowest degree of annoyance (Winneke & Kastka, 1987). Since, however, no measure of pleasantness-unpleasantness of odor was taken and since, furthermore, no valid marker of odor exposure was available, these results do not provide sufficient evidence for a decisive role of hedonic tone to influence source-specific annoyance. It may, thus, be concluded that, at the present state of knowledge, only odor concentrations measures or frequency of odor events, closely related to odor concentrations via threshold-crossings, can be used to predict odor annoyance-responses in exposed populations (Cavalini et al., 1991; Miedema & Ham, 1988; Steinheider & Winneke, 1993).

In addition to annoyance-responses, odor exposure has also been shown to be associated with the reporting of various somatic and psychosomatic symptoms. Among the most prominent such symptoms are vomiting, nausea, dizziness, headache, and irritation of eyes, throat and nose (e. g., Ames & Stratton, 1991; Deane & Sanders, 1978; National Academy of Sciences, 1979; Scarborough, Ames, Lipsitt, & Jackson, 1989). Individuals living near industrial odor sources express complaints about sleep disorders, headache, breathing problems, and nausea which are typically attributed to perceived odors (Winneke & Kastka, 1987). Additional symptoms reported are loss of appetite, dizziness, allergic reactions, cough, and wheezing (National Academy of Sciences, 1979).

Ames and Stratton (1991) studied the effects of 6 weeks of exposure to n-propyl-mercaptane, a highly odorous and volatile gas. No toxicologically mediated pesticide effects could be identified, but the frequency of health complaints was found elevated among those who reported smelling a strong odor. After controlling for age, sex and current cigarette smoking, these authors found significant exposure effects for headache, diarrhoea, running nose, sore throat, burning/itching eyes, fever, hay fever, and asthma attacks. Neutra, Lipscomb, Satin, and Shusterman (1991) studied the prevalence of symptoms (headache, irritation of throat and eyes, cold, sleep disorders) near hazardous waste sites. Exposure to chemicals was very low so that toxic effects could be excluded. A positive association between odor exposure zoning and the prevalence of symptoms was found, but symptom-reporting occurred primarily in those subjects who complained of odors or who expressed worry about environmental chemicals. Shusterman, Lipscomb, Neutra, and Satin (1991) reanalyzed three studies on hazardous waste sites and found associations between the incidence of headache, nausea, as well as eye- and throat-irritation, and self-reported frequency of odor perception. Perceived odor frequency and degree of self-reported environmental worry were found to exert both single and combined effects on symptom reporting.

Cavalini (1992) investigated annoyance and somatic symptoms near sugar beet and tobacco factories. Exposure was assessed by calculating average odor concentrations by means of dispersion models. No direct relationship between odor exposure and somatic complaints was found, but positive associations between odor annoyance and symptom reporting. It was concluded that somatic symptoms were not directly associated with odor exposure but were mediated by odor annoyance. It has, furthermore, been shown that even the suggestion of the presence of a malodor can increase complaints about headache, irritation of throat and eyes compared to a control group (Knasko, Gilbert, & Sabini, 1990), so that cognitive processes appear to be important factors for symptom reporting.

Two main conclusions may be drawn from these observations: (1) Both, general health-related complaints, as e. g., sleep disorders, headache, cough or throat irritation, as well as more odor-specific complaints related to gastrointestinal dysfunction, as e. g., nausea, vomiting and loss of appetite, have been found to be associated with exposure to environmental odorant mixtures. (2) Such symptom-reporting appears to be secondary to perceived odor exposure or to general environmental worry, rather than directly influenced by the expo-

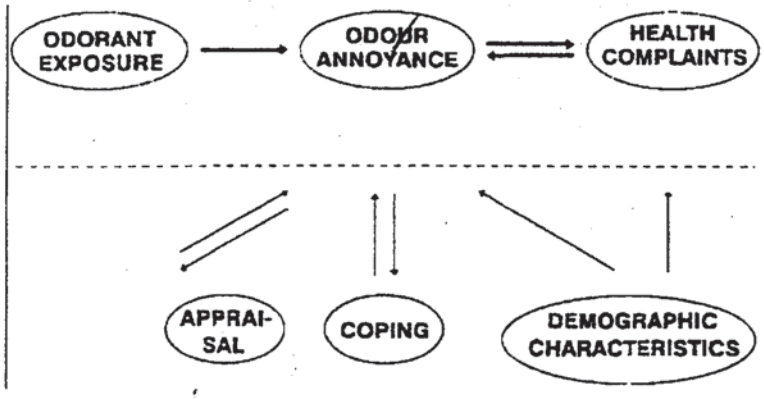

Figure 1 Schematic diagram relating odor exposure to symptom-reporting via annoyance as a mediating variable. Hyothetical influences of appraisal- and coping-processes as defined in transactional stress-modelling (Lazarus & Launier, 1978) as well as those of sociodemographic variables are indicated, as well (modified after Cavalini, 1992).

sure. These two conclusions are fundamental to the studies reported here.

The starting point of our investigations is a working model developed and largely confirmed by Cavalini (1992) in studies on odor annoyance and symptom reporting in the vicinity of sugarbeet and tobacco plants, using average odor concentrations in air as calculated from dispersion models as the exposure index (Figure 1). This model, which relates annoyance responses and symptom reporting to odor exposure as well as to concepts of appraisal and coping as conceptualized in the transactional stress model of Lazarus and coworkers (Lazarus & Folkman, 1984), will be used here as a framework for the development of the main hypotheses of our studies. The model assumes that, in addition to exposure, appraisal- and coping-processes as well as sociodemographic variables influence the relationship between exposure, annoyance and symptom-reporting, an assumption which has been substantiated in previous studies (Cavalini et al., 1991; Steinheider & Winneke, 1993).

Yet, the essential feature of the model for the purpose of our discussion is not the stress-theoretic element, which does not adequately reflect the transactional model with its stages of appraisal and feedback-loops of reappraisal, but rather the explicit assumption, that there is no direct link between odorant exposure and health complaints, but that the latter are assumed to be secondary to or mediated through annoyance. Reverse causality, namely of symptoms to influence annoyance, is also accepted as a possibility in the above model.

The question is, however, whether or not this principle holds equally for non-specific general and more odor-specific gastric complaints on the one hand, and, furthermore, for moderate versus more extreme scenarios of exposure on the other. Moderate exposure settings are those typically encountered in the vicinity of odor-emitting industrial sources (Cavalini et al., 1991; Steinheider & Winneke, 1993).

Aims of the study

Results from two studies are used to investigate the relationship between environmental odorant exposure and general health-related versus more odor-specific gastric symptom reporting as influenced by annoyance. The two study areas were characterized by moderate and high conditions of odorant-exposure, respectively. Moderate exposure, for the purpose of this discussion, is associated with average annoyance-responses not exceeding ratings of 6 on an 11-point graphic rating scale ranging from 0 (not at all annoying) to 10 (unbearably annoying), to be described below. The specific working hypothesis is that gastric symptom-reporting is indirectly related to odor-exposure through annoyance, i. e., mediated through annoyance, under moderate exposure conditions, but that direct links between exposure and gastric symptom-reporting will occur at high levels of exposure.

Materials and methods

Study areas and odor sources

The first investigation took place in Nettetal in Northrhine-Westfalia in March/April 1992. The odor source was a plant for the production of fertilisers for mushroom cultivation; large

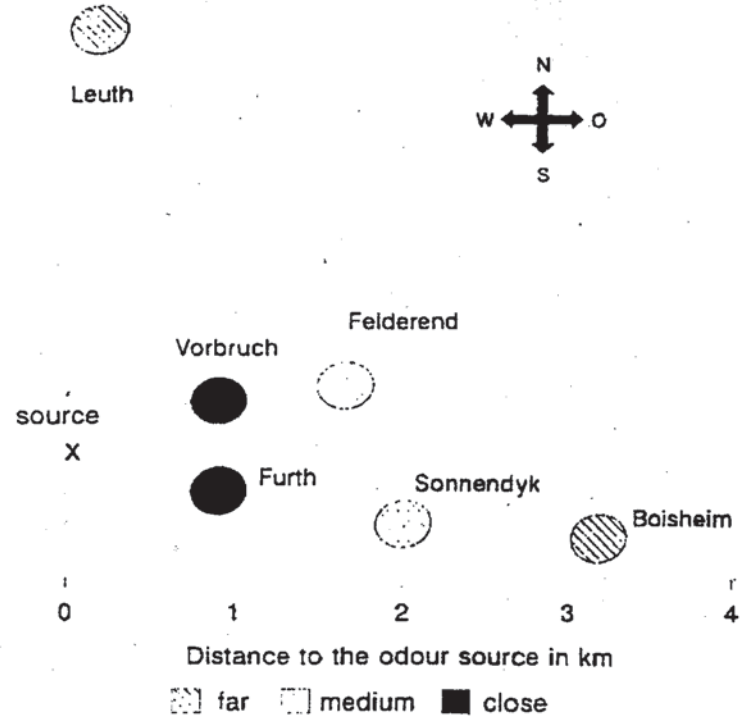

Figure 2 Schematic plan of the spatial orientation of the odor source and the study areas in Nettetal.

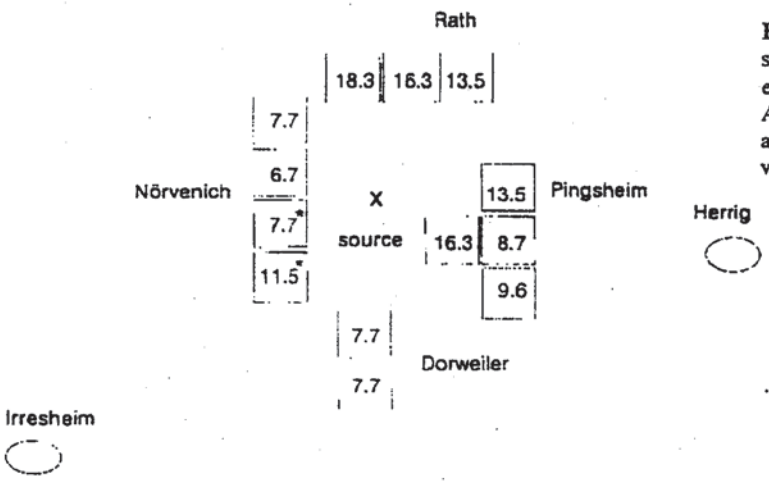

Figure 3 Spatial orientation of the study areas with odor frequency (area estimates) in the Nörvenich Study. Area estimates of odor frequencies are based on 78 independent observations each.

Wrong picture! Please insert the added figure.

quantities of manure from poultry- and horse-farming were mixed with straw and continuously watered to support fermentation. The emissions from this open air processing of fermenting manure caused substantial complaints in the neighbourhood. In order to study odor-annoyance and associated symptom reporting in the exposed population, four areas located north and east from the plant at close and intermediate distances, respectively, were chosen for the questionnaire-based study. In addition, two control areas without specific odor-exposure were chosen as well (Figure 2).

The second investigation took place in December 1993 near Nörvenich in Northrhine-Westfalia. In this case, the odor source was a large pig rearing facility which was situated in a rural area with predominant agricultural activities. Again, as before, both odor-annoyance and associated symptom-reporting were to be investigated in the vicinity of this source. Four communities around the plant were chosen for

a questionnaire-based study, namely Nörvenich at a distance of 1.4 km to the west, Rath at 1 km north, Pingsheim 1.1 km to the east, and Dorweiler, 800 m south of the source. The prevailing wind direction in this area is W/SW. Control areas were Herrig, 4 km east of the source, and Irresheim, 7 km south west of the source (Figure 3).

Assessment of exposure

In the first study in Nettetal, the distance from the odor source was taken as a surrogate measure of odor exposure, since neither odor concentrations nor odor frequencies were available for more direct exposure-assessment on this occasion. Two areas were chosen for two levels of exposure (Figure 1): Furth and Vorbruch as areas with presumably high exposure-levels at a close distance of between 400 and 800 m from the source, Felderend and Sonnendyk as areas with presumably moderate exposure at a greater distance of about 1600 m, and Leuth and Boisheim as control areas at a distance of 6 or 3.5 km, respectively. Data of one control area, Boisheim, had to be discarded later on, as this area, unexpectedly, turned out to be exposed to odor emissions from a cast-iron factory.

In the second study, odor frequency was measured by 17 trained non-resident observers by the Landesanstalt für Immissionsschutz (Essen) as a direct marker of odor exposure; for details of procedure see below. The members of the observation panel were screened for normal olfaction and reliable performance as follows: Odor thresholds were determined in order to select subjects with average odor sensitivity. For this purpose, the individual odor threshold for n-butanol (1 standard deviation around 69 $\mu g/m^3$), and the intraindividual variability of the odor threshold were determined (the difference between the highest and the lowest value of the individual odor threshold had to be lower than or equal to 0.6 on a log-scale). Furthermore, the observers had to correctly identify six odorous samples (gasoline, vanillin, onion, coffee, vinegar and camphor), and were excluded for more than one failure; another criterion for exclusion of observers was the number of false alarms during threshold testing (20% of blank stimuli falsely classified as odorous). From an initial sample of 33 applicants only 17 "survived" the selection process.

For the assessment of odor frequency as the exposure index according to VDI-Guideline 3940 (VDI = Verein Deutscher Ingenieure = Association of German Engineers, 1993), a grid of observation points (squares of 250 × 250 m; see Figure 3) was laid out within the study area, which were visited by these observers over a period of six months following a semi-random rotation plan. The duration of an observation at each point was 10 minutes, and the presence of odor as well as its duration and type (pig rearing/manure/agriculture/traffic/nature etc.) was recorded. The basic unit of measurement was the "odor hour" (Both, Otterbeck, & Prinz, 1993); whenever the summated duration of source specific odor events exceeded 10% (1 minute) of the observation time the respective observation was counted as an "odor hour." The ratio of odor hours to the total number of observations in per cent characterizes the degree of odor exposure in terms of odor-frequency at a given observation point.

During six months from July to December 1992 34 observation points were visited 26 times, i. e., once a week on average. Odor exposure was estimated by means of averaging odor frequencies from four adjacent observation points. Since the observation points were located close to each other, area-estimates of odor frequencies were used rather than point estimates as used in other previous studies (Steinheider & Winneke, 1993). Odor frequencies varied between 0% and 34.6% odor hours/year per observation point, or between 2.9% and 15.4% odor hours/year per area (250 × 250 m).

Questionnaire-based assessment of effects

In Nettetal, personal interviews based on standardized questionnaires, to be described below, were conducted by trained interviewers of a professional market research institute (AMR = Advanced Market Research, Düsseldorf). In each of the five study-areas 50 persons were interviewed, who had to be German speaking and above 18 years old to be included, so that the sample consisted of a total of 250 persons. The interviews in the Nörvenich study took place in December 1993. A total of 322 German-speaking subjects above 18 years of age were interviewed, namely 68 subjects in

Nörvenich, 76 in Rath, 80 in Pingsheim, 50 in Dorweiler and 30 or 73 in the control areas Herrig and Irresheim, respectively. Again, as in the first study, personal interviews were conducted by trained interviewers of the same professional market research institute as in the first study (AMR, Advanced Market Research). In order to reduce area-confounding due to interviewer bias, care was taken to assign at least two study areas to each interviewer in Nettetal and Nörvenich, respectively.

Structure of the questionnaire

Annoyance and somatic symptoms were assessed by means of standardized questionnaires. In order to check for attribution tendencies, the questionnaires in Nettetal were presented in two versions: In version (A) a list of questions about the perceived frequency of symptoms was given first without any mentioning of environmental odors, and only afterwards subjects were given an opportunity to produce assumptions about the likely causation of these symptoms, namely stress, traffic noise, job-related worries, diseases, family quarrels or environmental odors. In version (B), on the other hand, the Ss were asked to scale the degree of odor-annoyance first, and were then given an opportunity to indicate the frequency of health-related symptoms presumably caused by environmental odors. The degree of odor annoyance was assessed by an 11-point graphic annoyance-scale, sometimes referred to as the "annoyance-thermometer" in noise-annoyance studies (Hangartner, 1983; Kastka & Noack, 1987). Good correspondence with the results of an annoyance scale consisting of 6 verbal categories with correlations exceeding r = 0.80 has been demonstrated (Steinheider & Winneke, 1993).

The questionnaire covered the following aspects:

1. *Odor annoyance:* Degree of disturbance "To what extent are you disturbed by environmental odors?" (11 point graphic scale; from "no disturbance at all" [stört überhaupt nicht] to "unbearably disturbed" [stört unerträglich]).
2. *Somatic symptoms:* This part was covered by 16 items on 7-point scales, from "never" [nie] to "always" [dauernd]. The wording was such that, based on studies by Rohrmann (1978), equal distance between categories was given. It should, furthermore, be mentioned that, according to Tränkle (1987), equal spacing of rating categories is no prerequisite for valid results. Gastric symptoms were the following: nausea, disgust, vomiting, retching and loss of appetite; general health complaints included sleep disorders, namely difficulties falling asleep, waking up during the night, difficulties falling asleep again after waking up, and not getting enough sleep, as well as other complaints like headache, breathing difficulties, cough, stomach disorders, and feeling miserable. In order to check for response tendencies and biases, the frequency of two control items, fever and asthma attacks, was assessed, which were not expected to be related to odor exposure.
3. *Demographic variables:* age, gender, level of education (type of schooling), occupation (four categories: housewife/retired/unemployed; blue collar worker; white collar worker; manager), length of residence and economic dependence on the odor source.
4. *Perceived health:* 5-point scale with values ranging from 0 = "very satisfied" [sehr zufrieden] to 4 = "not satisfied at all" [überhaupt nicht zufrieden].

Since only minor differences had been found between versions (A) and (B) of the questionnaire in the first study in Nettetal, only version A was given to the residents in Nörvenich, i. e., subjects had to scale the frequency of somatic symptoms without reference to environmental odors first, whereas odor annoyance and hypotheses about the likely causation of symptoms and complaints were covered later. The presented items were identical to those of questionnaire type A of the first study.

Data analysis

In the Nettetal study differences between areas in terms of the distribution of gender, age, length of residence, perceived health, level of education, profession and employment at the source, were tested by means of chi-square tests or by analysis of variance. In order to assess the influence of the odor exposure on outcome, namely annoyance and general health-related or gastric symptoms, means and standard errors were calculated for the three

distances to the odor source. The comparability of areas with equal distance to the odor source was tested by *t*-tests. Exposure-related hypotheses with annoyance, health symptoms and control variables as dependent variables and distance to the odor source (three levels: close, medium, far), and type of questionnaire (A versus B) as independent variables were tested by means of two-way analysis of variance. Post-hoc tests were done by means of the Ryan-Einot-Gabriel-Welsh Multiple Range Test (REGWQ). In order to clarify the relationship between odor exposure, annoyance and somatic symptoms, a further analysis of variance was calculated where annoyance was treated as a covariate.

In Nörvenich, linear regression analysis was used to test the significance of dose-response associations between measured odor frequency as the independent variable and annoyance and somatic symptoms as the dependent variables, respectively. Odor frequencies were transformed to log-values, since a log-linear relationship between odor exposure and odor annoyance and somatic complaints had been found to be in much better agreement with the data than a linear-linear relationship in previous studies (Steinheider & Winneke, 1993). In order to avoid zeros for the log scale, a constant of the value "1.0" was added. In order to investigate the influence of degree of annoyance on the frequency of somatic symptoms, a further regression analysis was done with odor exposure and annoyance as independent variables and somatic symptoms as dependent variables, respectively.

Results

Response rates

Nettetal: The response rate is given as the ratio of the number of subjects successfully interviewed (responders) to the total number of attempted interview contacts at each observation point. Non-responders are those who could not be interviewed, either owing to absence or to refusal. The response rates varied between 39% (medium distance) and 56% (close distance) and did not correlate with distance. The major reason for not responding was absence of the residents. The distribution of socio-demographic variables showed no significant differences between the five samples in terms of gender ($\chi^2 = 3.96$, df = 4, n. s.), age ($\chi^2 = 20.31$, df = 16, n. s.), education ($\chi^2 = 13.32$, df = 8, n.s.), profession ($\chi^2 = 30.16$, df = 20, $P < 0.10$), and length of residence ($\chi^2 = 20.73$, df = 12, $P < 0.10$). Perceived health was significantly lower in study areas at close and medium distance from the plant relative to the control area (F 4,245 = 11.38, $P < 0.0001$).

In the Nörvenich study, response rates varied between 27% (control area Irresheim) and 41% (control area Herrig) and did not correlate with odor frequencies. The major reason for not responding was absence of the residents. The distribution of socio-demographic variables exhibited no significant differences between the six samples in terms of gender ($\chi^2 = 9.50$, df = 5, $P < 0.10$), age ($\chi^2 = 29.88$, df = 20, $P < 0.08$), education ($\chi^2 = 10.79$, df = 10, n. s.), occupation ($\chi^2 = 19.39$, df = 15, n. s.), length of

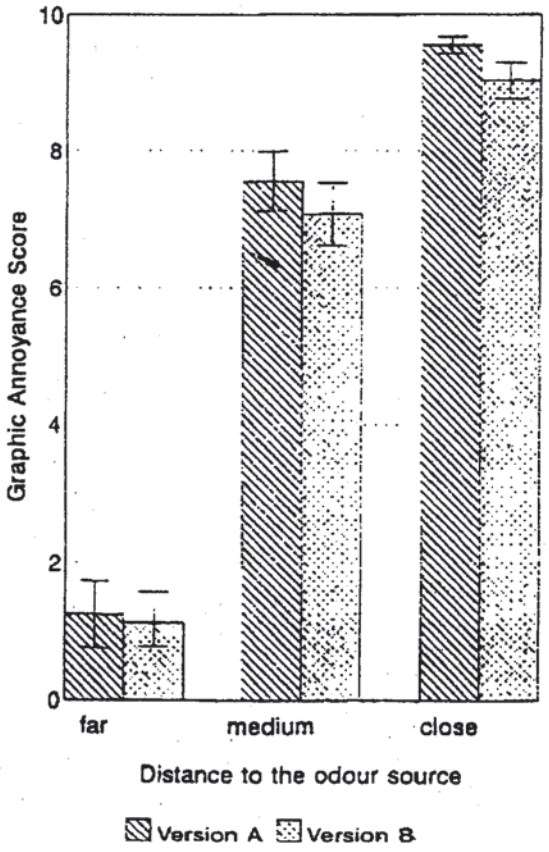

Figure 4 Annoyance-ratings for the varying distances to the odor source for questionnaire version A and B of the Nettetal Study. Means and standard errors are given.

Table 1 Results from analyses of variance for annoyance-ratings and reported frequency of somatic and behavioral complaints as the dependent variables, and distance from the odor source (A), type of questionnaire (B) and the interaction between both (A × B) as independent variables in Nettetal (N = 250).

Variable	Distance from the odor source (A) df	F	Type of questionnaire (B) df	F	Interaction A × B df	F	r^2 in %
Odor annoyance	2,244	186.88[a]	1,244	1.31	2,244	0.12	60.64
Gastric symptoms							
Disgust	2,244	63.57[a]	1,244	0.07	2,244	0.12	34.34
Loss of appetite	2,244	57.99[a]	1,244	0.15	2,244	0.45	32.47
Vomiting	2,244	42.04[a]	1,244	0.26	2,244	0.01	25.69
Nausea	2,244	38.72[a]	1,244	0.27	2,244	0.01	24.16
Retching	2,244	32.86[a]	1,244	0.04	2,244	0.04	21.26
General health complaints							
Difficulties to fall asleep	2,244	25.69[a]	1,244	3.16	2,244	1.00	19.19
Waking up during the night	2,244	26.21[a]	1,244	2.35	2,244	0.01	18.38
Difficulties to fall asleep after waking up	2,244	16.80[a]	1,243	4.84[d]	2,243	0.75	14.43
Not getting enough sleep	2,244	21.38[a]	1,244	1.05	2,244	1.48	15.97
Headache	2,243	17.38[a]	1,243	1.40	2,243	0.96	13.38
Cough	2,244	9.36[a]	1,244	2.70	2,244	2.02	9.83
Stomach disorders	2,244	12.73[a]	1,244	6.04[d]	2,244	3.30[d]	14.15
Breathing difficulties	2,244	22.24[a]	1,244	0.61	2,244	0.38	15.98
Feeling miserable	2,244	22.62[a]	1,244	0.24	2,244	0.60	16.01
Control variables							
Fever	2,244	2.46	1,244	3.80	2,244	2.58	5.88
Asthma attacks	2,244	1.05	1,244	1.92	2,244	1.70	3.16

[a] $P < 0.0001$, [b] $P < 0.001$, [c] $P < 0.01$, [d] $P < 0.05$

Table 2 Results from linear regression analyses of annoyance-ratings and reported frequency of somatic and behavioral complaints as the dependent, and odor frequency as the independent variable in Nörvenich (N = 322).

Variable	β	SE	t	r^2 in %
Odor annoyance	2.901	0.361	8.037[a]	16.70
Gastric symptoms				
Disgust	0.583	0.146	3.989[a]	4.50
Loss of appetite	0.665	0.162	4.101[a]	4.80
Vomiting	0.298	0.101	2.964[c]	2.40
Nausea	0.511	0.138	3.703[a]	3.90
Retching	0.361	0.113	3.207[b]	2.80
General health complaints				
Difficulties to fall asleep	0.323	0.165	1.962	0.90
Waking up during the night	0.615	0.212	2.904[c]	2.30
Difficulties to fall asleep after waking up	0.805	0.186	4.327[a]	5.30
Not getting enough sleep	0.337	0.221	1.524	0.40
Headache	0.403	0.197	2.043[d]	1.00
Cough	0.368	0.171	2.155[d]	1.10
Stomach disorders	0.479	0.172	2.793[c]	2.10
Breathing difficulties	0.350	0.135	2.587[c]	1.70
Feeling miserable	0.205	0.145	1.413	0.30
Control variables	-0.012		-0,152	-0.30
Fever	~~0.0296~~	0.078	~~0.291~~	~~0.29~~
Asthma attacks	~~0.1887~~	~~0.0917~~	~~2.057[d]~~	~~1.02~~
	0.215	0.092	2.366[d]	1.50

[a] $P < 0.0001$, [b] $P < 0.001$, [c] $P < 0.01$, [d] $P < 0.05$

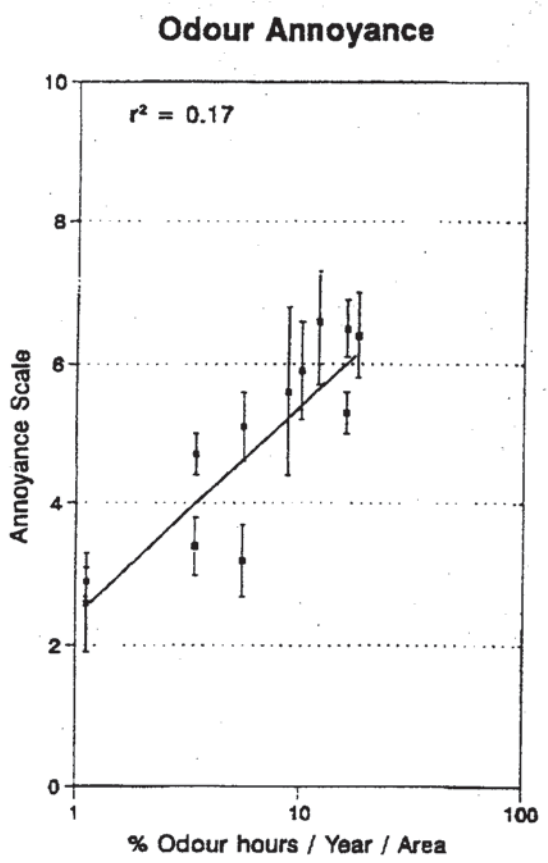

Figure 5 Relationship between annoyance and odor frequency (odor hours/year/area) in the vicinity of a pig-rearing facility in the Nörvenich Study. Means, standard errors and the regression equation with explained variance (r^2) are given.

residence (χ^2 = 22.44, df = 15, $P < 0.10$), and occupation in agriculture (χ^2 = 9.94, df = 5, $P < 0.08$).

Odor exposure and annoyance

Nettetal: There were no significant differences in terms of annoyance between areas close to the source (Furth and Vorbruch, $t_{(98)} = -0.13$, n. s.) as well as between the areas at medium distance from the odor source (Sonnendyk & Felderend, $t_{(98)} = 1.74$, $P < 0.10$); therefore, the results from these areas were pooled. Table 1 summarises the results of the analysis of variance for annoyance and symptom-reporting. The r^2-value describes percent variance accounted for by the relevant factor. With increasing proximity to the odor source, the degree of annoyance increases significantly. Close to the odor source, the mean degree of annoyance approaches 10 (Figure 4). Post-hoc-testing revealed significant differences between each level of exposure. There were no significant differences between the two versions of the questionnaire and no interactions. The distance from the odor source explains about 61% of the variance of the annoyance response.

Nörvenich Study: The results from linear regression analyses are summarized in Table 2. Figure 5 depicts the relationship between odor load and annoyance. The degree of annoyance increases with increasing odor frequency; this relationship is approximately linear with log-transformed odor load. Odor exposure ex-

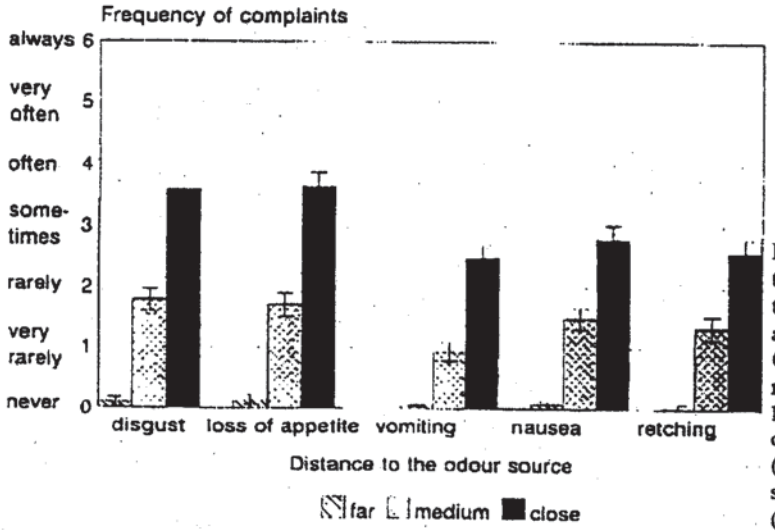

Figure 6 Nettetal: Frequency of gastric complaints for the three distances from the odor source. Means and standard errors are given. The German equivalents of the different rating categories are as follows: Dauernd (always) – sehr oft (very often) – oft (often) – manchmal (sometimes) – selten (rarely) – sehr selten (very rarely) – niemals (never).

plains about 17% of the variance of the annoyance response.

Gastric symptoms

Nettetal: Figure 6 depicts the frequency of gastric symptoms for the three study-areas at varying distance from the odor source. Frequency of gastric symptoms, namely "disgust," "loss of appetite," "vomiting," "nausea," and "retching," increases with increasing proximity to the source. In the areas closest to the source, the mean frequency of "disgust" and "loss of appetite" is between categories "often" and "sometimes". Similarly graded response-frequencies occur for "vomiting," "nausea," and "retching." Response frequencies in control areas for these symptoms are almost zero. The overall effect of distance from the odor source on the frequency of gastric symptoms is significant, and the post-hoc test reveals significant differences between the three distance categories. Again, there are no significant differences between versions A and B of the questionnaire and no significant interaction either. It may,

Table 3 Results from analyses of covariance for perceived frequency of somatic symptom-reporting as the dependent variable, and distance from the odor source as independent variable after treating annoyance as a covariate in Nettetal (N = 250)

Variable	Distance from the odor source (A) df	F	Type of questionnaire (B) df	F
Gastric symptoms				
Disgust	2,246	15.48[a]	1,246	16.35[a]
Loss of appetite	2,246	15.77[a]	1,246	13.74[a]
Vomiting	2,246	14.52[a]	1,246	8.48[c]
Nausea	2,246	7.06[b]	1,246	14.56[a]
Retching	2,246	6.23[c]	1,246	12.20[b]
General health complaints				
Difficulties to fall asleep	2,246	7.92[a]	1,246	6.07[d]
Waking up during the night	2,246	10.56[a]	1,246	2.51
Difficulties to fall asleep after waking up	2,246	4.46[a]	1,246	3.93[d]
Not getting enough sleep	2,246	3.77[d]	2,246	6.29[d]
Headache	2,246	1.58	1,246	16.19[a]
Cough	2,246	1.73	1,246	2.39
Stomach disorders	2,246	0.72	1,246	6.27[d]
Breathing difficulties	2,246	3.50[d]	1,246	8.08[c]
Feeling miserable	2,246	4.87[c]	1,246	7.27[c]

[a] $P < 0.0001$, [b] $P < 0.001$, [c] $P < 0.01$, [d] $P < 0.05$

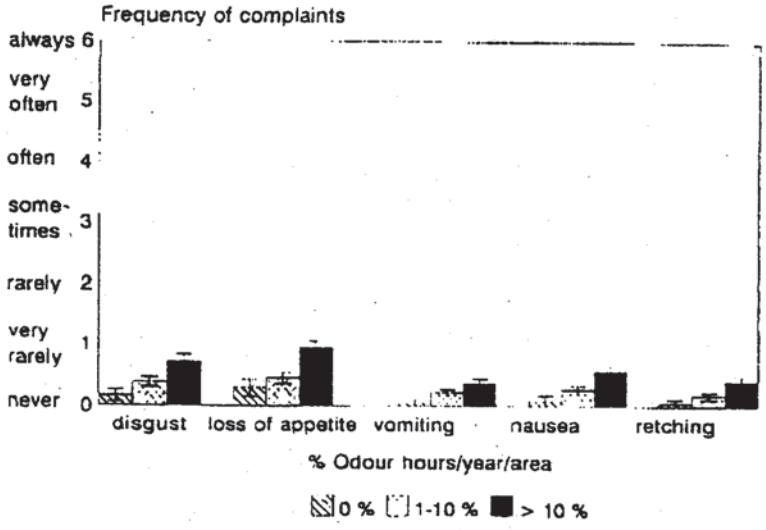

Figure 7 Nörvenich: Frequency of gastric complaints for three exposure levels. Means and standard errors are given. For the German equivalents of the different response categories see legend to Figure 6.

Table 4 Results from linear regression analyses for perceived frequency of somatic symptom-reporting as the dependent variable and odor frequency or odor-annoyance as the independent variables in Nörvenich (N = 322).

Variable	Log odor frequency β	SE	t	Odor annoyance β	SE	t
Gastric symptoms						
Disgust	0.213	0.157	1.467	0.121	0.022	5.149[a]
Loss of appetite	0.177	0.162	1.092	0.190	0.023	8.122[a]
Vomiting	0.141	0.111	1.271	0.054	0.016	3.405[b]
Nausea	0.195	0.149	1.315	0.111	0.021	5.235[a]
Retching	0.090	0.121	0.741	0.094	0.017	5.482[a]
General health complaints						
Difficulties to fall asleep	0.185	0.181	1.023	0.063	0.026	2.469[d]
Waking up during the night	0.326	0.230	1.415	0.124	0.033	3.775[b]
Difficulties to fall asleep after waking up	0.650	0.203	3.203[b]	0.077	0.029	2.668[b]
Not getting enough sleep	0.111	0.243	0.456	0.094	0.035	2.724[c]
Headache	0.166	0.218	0.760	0.087	0.031	2.799[c]
Cough	0.063	0.188	0.334	0.098	0.027	3.686[b]
Stomach disorders	0.179	0.184	0.970	0.122	0.026	4.673[a]
Breathing difficulties	0.088	0.146	0.602	0.099	0.021	4.764[a]
Feeling miserable	0.020	0.159	0.124	0.076	0.023	3.344[b]

[a] $P < 0.0001$, [b] $P < 0.001$, [c] $P < 0.01$, [d] $P < 0.05$

thus, be concluded that embedding these gastric items in the context of environmental odors or not does not affect the frequency of symptom-reporting. The distance from the odor source accounts for 21% ("retching") up to 34% ("disgust") of the variance of the gastric symptoms.

Nörvenich Study: In order to be able to roughly compare these results with those of the Nettetal study, odor frequencies were grouped into three categories, as follows: Control areas with no odor exposure, odor frequencies ranging between 1 and 10% and odor frequencies between 11 and 20%. Figure 7 depicts the frequencies of "disgust," "loss of appetite," "vomiting," "nausea," and "retching" for the three exposure levels. Regression analysis confirmed that symptom-reporting increases significantly with increasing odor load ($0.05 > P < 0.01$), but, in absolute terms, the effect-size is much smaller than in the Nettetal study. Odor exposure explains only between 2 (vomiting) and 3% (disgust and loss of appetite) of the outcome-variance for these symptoms.

General health-related symptoms

In Nettetal, the frequencies of general health complaints, e. g., headache, breathing difficulties, cough, stomach, and sleep disorders are significantly higher near the odor source and decrease with increasing distance from the source. The variance explained by distance for these symptoms varies between 10 (cough) and 19% (difficulties to fall asleep; see Table 1). For only two of these variables (stomach disorders; difficulties to fall asleep after waking up) a significant influence of the questionnaire-type was shown (Table 1).

In Nörvenich, with increasing odor load, the likelihood of complaining about stomach disorders, breathing difficulties, headache, cough and some of the sleep disorder-items was significantly increased ($0.05 > P < 0.01$; see table 2). Subjects exposed to higher odor frequencies are more likely to complain about waking up at night ($P < 0.05$), or of having problems to fall asleep again ($P < 0.001$) compared to individuals exposed to lower odor-frequencies.

Odor annoyance as a mediator for symptom-reporting

Nettetal: The results of the analysis of covariance with annoyance as a covariate are summarized in Table 3. As for gastric symptoms, both odor-exposure (i. e., distance from the source) and odor context (i. e., type of questionnaire), still influence symptom reporting significantly even after adjustment for odor-annoyance. With the exception of headache, cough and stomach disorders, this is also true for more general health complaints, although in a less pronounced manner ($0.05 > P < 0.001$). It thus follows that both gastric symptoms as well as general health-related symptoms bear

direct links with odor exposure here, but are additionally mediated through odor annoyance.

In Nörvenich, however, regression analysis revealed no significant direct links between odor exposure and gastric or general health complaints after adjustment for annoyance, with the exception of "difficulties to fall asleep after waking up" ($P < 0.001$). The results are summarized in Table 4. On the other hand, gastric symptoms as well as general health symptoms are significantly associated with annoyance after adjustment for exposure ($0.05 > P < 0.0001$). It thus follows that, for this exposure scenario, perception of environmental odors and subsequent odor annoyance is both a necessary and sufficient condition of symptom-reporting. In conclusion, whereas in Nettetal gastric and general health-related symptoms exhibit direct as well as annoyance-mediated (indirect) associations with odor-exposure, this is not true for the more moderate exposure-condition in Nörvenich; here symptom-reporting is only mediated by annoyance.

Discussion

The feeling of nausea precedes vomiting and can easily be acquired by way of classical conditioning. Vomiting in the context of food intake is a protective physiological mechanism, by which the stomach is cleared from rotten food or otherwise dangerous items, particularly decaying proteins and carbohydrates. The sensory input is mediated through receptors in the throat and its central control is located in the emetic center in the medulla oblongata close to the Nucleus and tractus solitarius. Rotten food is typically – although not always – associated with offensive odorants which, among others, may take the form of sulphur-containing inorganic compounds, such as hydrogen sulphide ("rotten egg"-odor), or sulphur-containing organics, such as dimethyl-disulphide or, even worse, some alcohols like the mercaptanes, the smell of which strongly reminds of "rotten cabbage" and is a prominent constituent of emissions from pulp-and-paper mills. These compounds, typically characterized by odor-thresholds in the lower ppb-range, have the potential to induce nausea at elevated concentrations, and may thus be interpreted as serving a warning-function to prevent the intake of toxic material. It should, however, be pointed out that this cannot be considered to be a general principle (Plattig, 1995): Some highly toxic chemicals, as e. g., carbon monoxide, do not smell at all.

Volatile chemicals from agricultural operations, such as pig-rearing, represent complex mixtures of, among others, sulphur containing compounds including hydrogen sulphide, methanethiol, carbon disulphide, dimethyl sulphide, dimethyl-di- and trisulphide, all of which are highly odorous (Odam, Page, Townsend, & Wilkins, 1986); some of these are certainly involved in the experience of "rotten" smell. We have shown here that both gastric symptoms as well as more general health-related complaints exhibit dose-response characteristics relative to exposure to odorant-mixtures associated with agricultural operations, such as the mixing of manure from poultry- and horse-farming to produce mushroom-fertilizer in Nettetal (study 1) and pig-rearing operations in Nörvenich (study 2). Disgust, loss of appetite, vomiting, nausea, and retching were taken to represent a syndrome of gastric disturbance differentially associated with odor-annoyance in both these studies. Despite similarities in terms of outcome both studies differed sufficiently in several methodological aspects to warrant comparative discussion of results.

In the Nettetal study a strong association between environmental odors and annoyance as well as symptom-reporting was confirmed. In the absence of more direct measures of exposure, distance from the odor source had been taken as a surrogate measure of exposure. Compared to previous studies near industrial odor sources, a higher degree of odor annoyance with mean values close to the maximum of 10 (unbearably annoying) was observed here, suggestive of particularly offensive odors. In former investigations, odor annoyance was never found to exceed mean values of 6 on an 11-point annoyance-scale (Steinheider & Winneke, 1993; Winneke et al., 1990). The distance from the odor source accounted for 60% of the outcome variance. A direct comparison with previous studies near industrial sources, in which outcome variance was never found to exceed 11% (Steinheider & Winneke, 1993) or 13% (Cavalini et al., 1991), is questionable, because the distance measure is not quantitative-

ly comparable to the exposure measures used in these studies, namely measured odor frequency or calculated odor concentration, respectively.

In accordance with other studies near odor emitting sources (Neutra et al., 1991; Scarborough et al., 1989), the occurrence of pronounced somatic complaints was found to be associated with odor-exposure. Apart from annoyance responses, odor exposure was also found to be associated with the occurrence of gastric symptoms, e. g., nausea, vomiting, disgust, retching, and loss of appetite, and the distance from the odor source as a surrogate measure of exposure accounted for up to 34% of the effect variance. Other odor-associated complaints were more non-specific health-related symptoms (e. g., headache, cough, stomach disorders).

In observational studies such as this, the question may be asked whether or not symptoms are merely attributed to rather than induced by assumed causative factors, as is true for much of the symptom-reporting in the context of the so called "environmental syndromes" (Wessely, 1997). This is unlikely to be the case here: When comparing the two types of questionnaires, the frequency of gastric symptoms remained largely unaffected by whether or not they were put into the context of environmental odors. If anything, reported symptom frequencies were higher rather than smaller, if the odor context was presented after the symptom list relative to the reversed sequence. This outcome is not compatible with an attribution hypothesis. It is, however, consistent with the observations of Cavalini (1992) who concluded that general health complaints are not influenced by the context in which they are reported.

Interestingly enough, in this rather extreme exposure scenario and confirmed by analysis of covariance, odor annoyance as a covariate did not markedly reduce the degree of association between distance from the odor source and symptom reporting, so that, at least in the case of particularly offensive odors, odor exposure apparently may induce somatic, especially gastric symptoms directly. This is at variance with other studies presumably conducted under more moderate conditions of odor-exposure, in which symptom reporting was found to be secondary to the perception of odors, odor annoyance or environmental worry (Cavalini, 1992; Neutra et al., 1991; Shusterman et al., 1991).

The Nörvenich investigation partly confirmed the observations of the Nettetal study, namely that odor-exposure was not only found to be associated with annoyance responses but also with somatic, particularly gastric symptoms. Contrary to the first study, however, the degree of odor-exposure was measured by means of systematic field observations yielding odor frequency as the exposure index. Thus, in this study, odor exposure explained about 17% of the outcome variance of the annoyance reaction. This is much lower than the 60% value of the first study using the distance measure as an indirect exposure index, but higher than in former investigations based on the frequency measure of odor-load, in which the percent of outcome variance explained by exposure to industrial odors never exceeded 11% (Steinheider & Winneke, 1993). Similar exposure-response associations have been reported in the vicinity of sugar beet and tobacco factories with exposure indices derived from dispersion calculations based on olfactometric source measurements (Cavalini et al., 1991).

The relationship between odor exposure and odor annoyance appears to be rather specific in Nörvenich: When comparing aggregate instead of individual measures of odor annoyance with odor-exposure both, exposure and outcome, were highly correlated $r = 0.76$, $P < 0.01$, $n = 10$), whereas odor annoyance did not exhibit significant correlations with background agricultural odors ($r = 0.26$, $P > 0.20$, $n = 10$). This implies that those living in the vicinity of the pig rearing facility are able to discriminate between source-specific odors and agricultural background odors.

Perceived symptom frequencies were much lower compared to the former study and, on average, hardly exceeded the category "rarely": Gastric symptoms, e. g., disgust, loss of appetite, nausea, vomiting and retching, were significantly associated with odor exposure, but the exposure-measure explained only about 2–3% of the outcome variance; whereas in the former study the respective values varied between 21 and 34%. An explanation of this discrepancy is not straightforward: One likely possibility relates to the less offensive character of odors as evidenced in the lower annoyance-ratings relative to those in the first study.

Besides gastric symptoms, more non-specific health complaints were associated with odor exposure as well. Among these symptoms are sleep disorders, headache, stomach disorders, and breathing difficulties, but the explained variance never exceeded 19% in Nettetal or 1% in Nörvenich.

Contrary to the study in Nettetal, no direct relationship between odor exposure and health complaints was found in the Nörvenich study. Here, symptom-reporting was clearly secondary to or mediated through annoyance. Whereas in the Nettetal study, the relationship between the distance to the odor source and the frequencies of somatic symptoms remained unchanged when introducing annoyance as a covariate, this was not found to be true in Nörvenich. After adding odor annoyance to the regression model, only one correlation remained significant (behaviour related complaints). The identification of annoyance as a determinant for or mediator of symptom-reporting is in line with observations from other investigations (Cavalini, 1992). More systematic efforts are still necessary, however, to integrate findings from odor-induced alterations of psychological and bodily processes into more comprehensive stress models such as those used to discuss and explain long-term health effects of exposure to environmental noise (Lercher, 1996).

Conclusion

We have shown here that exposure to offensive environmental odors from different agricultural operations does not only induce annoyance reactions in a dose-dependent manner, but is also associated with general health-related and more odor-specific complaints, especially gastric symptoms like nausea, vomiting, disgust and loss of appetite. At moderate conditions of odor-exposure such symptom-reporting is clearly secondary to or mediated by annoyance. Under conditions of more extreme odor-exposure, however, direct links between exposure and gastric as well as general health-related symptoms have been demonstrated in addition to indirect or secondary linking via annoyance. Such symptom-reporting exhibits pronounced dose-response characteristics, as well. The meaning of these observations in terms of environmental stress and potential long-term health-outcome still remains to be elucidated, however.

Acknowledgments

We wish to thank the city of Nettetal, especially mayor Peter Ottmann, for the opportunity to realize the first investigation, but also the coworkers from the Landesumweltamt Nordrhein-Westfalen who were instrumental in the field inspections for the exposure assessment of the second study.

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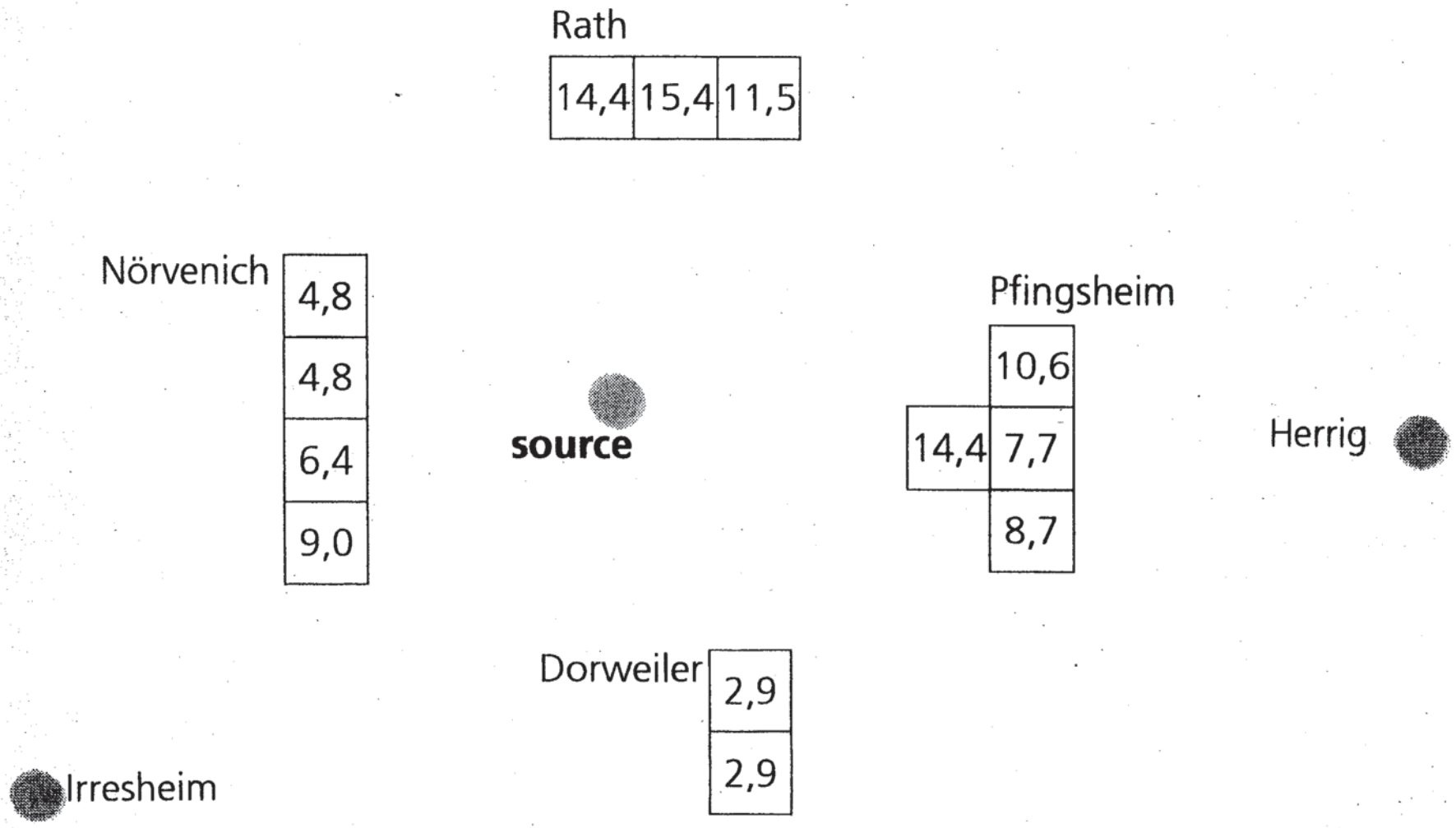
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