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The relation between modeled odor exposure from livestock farming and odor annoyance among neighboring residents

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ABSTRACT

Purpose

Odor annoyance is an important environmental stressor for neighboring residents of livestock farms and may affect their quality of life and health. However, little is known about the relation between odor exposure due to livestock farming and odor annoyance. Even more, the relation between odor exposure and odor annoyance is rather complicated due to variable responses among individuals to comparable exposure levels and a large number of factors (such as age, gender, education) that may affect the relation. In this study, we (1) investigated the relation between modeled odor exposure and odor annoyance; (2) investigated whether other factors can affect this relation; and (3) compared our dose–response relation to a dose–response relation established in a previous study carried out in the Netherlands, more than 10 years ago, in order to investigate changes in odor perception and appreciation over time.

Methods

We used data from 582 respondents who participated in a questionnaire survey among neighboring residents of livestock farms in the south of the Netherlands. Odor annoyance was established by two close-ended questions in a questionnaire; odor exposure was estimated using the Stacks dispersion model.

Results

The results of our study indicate a statistically significant and positive relation between modeled odor exposure and reported odor annoyance from livestock farming (OR 1.92; 95 % CI 1.53–2.41). Furthermore, age, asthma, education and perceived air pollution in the environment are all related to odor annoyance, although they hardly affect the relation between estimated livestock odor exposure and reported odor annoyance. We also found relatively more odor annoyance reported among neighboring residents than in a previous study conducted in the Netherlands.

Conclusions

We found a strong relation between modeled odor exposure and odor annoyance. However, due to some uncertainties and small number of studies on this topic, further research and replication of results is recommended.

INTRODUCTION

Odor annoyance may modify behavior, mood and emotions among residents living near the livestock farms and as a result may affect their quality of life and health (Cavalini et al. 1991; Steinheider and Winneke 1993; Nimmermark 2004; Radon et al. 2004). Several studies found that exposure to offensive odors may cause irritations of eye, nose, and throat, headaches, nausea, stress, sleep disturbance and depressions (Schiffman 1998; Wing and Wolf 2000; Nimmermark 2004; Radon et al. 2004, 2007; Sucker et al. 2009; Claeson et al. 2013). Residents who live in the vicinity of a livestock farm report similar symptoms and health impairment, some even at odor levels below irritation thresholds (Schiffman 1998; Radon et al. 2007; O'Connor et al. 2010; Blanes-Vidal et al. 2012; Claeson et al. 2013). The relation between odor exposure and odor annoyance is complicated, because odor annoyance is a subjective concept which may result in variable responses from individuals exposed to comparable odor exposure levels (Van Thriel et al. 2008; Blanes-Vidal et al. 2012; Claeson et al. 2013; Greenberg et al. 2013). A little insight exists in the role and relative importance of factors such as age, gender, education, allergy, respiratory health, depression, smoking, alcohol use, or the personal attitude toward the odor or odor source (e.g., industry or livestock farm) (Schiffman 1998; Van Thriel et al. 2008; Claeson et al. 2013; Greenberg et al. 2013).

Odor exposure from livestock farming has been estimated previously through various methods with different degrees of spatial resolution: (1) the distance between animal houses and home addresses, (2) the number of livestock farms within a certain distance to the community, (3) odor compound concentration measurements at the community level (4) field inspections or (5) dispersion modeling (Wing and Wolf 2000; Radon et al. 2007; Bunton et al. 2007; Sucker et al. 2009; Blanes-Vidal et al. 2012). Although there is little insight on the relation between odor annoyance and modeled odor exposure, but by using a dispersion model, accumulated odor exposures from multiple sources can be estimated taking into account information on location, source strength, source characteristics and meteorological conditions (Erbrink 1994; Erbrink et al. 1998). This latter approach probably reflects annual cumulative odor exposure at a specific address best. Moreover, the current Dutch legislation on livestock odors uses a dispersion model to estimate livestock odor immissions in order to regulate odor emissions from livestock farms. On the other hand, there is an absence of studies that investigate the effectiveness of regulatory systems for odor annoyance based on odor dispersion modeling. Previous study by Bongers et al. (2001) has therefore been of great importance for the current Dutch policy and the ongoing social debate on livestock farming in the Netherlands. However, this study was carried out more than 10 years ago and had some limitations. For instance, this study used a different model [long term frequency distributions model (LTFD model)] to estimate odor exposure, in order to establish the dose–response relation, which is different from the dispersion models currently used for regulation. The researchers subsequently estimated a dose–response relation based on the Stacks dispersion model using a conversion factor (calculated specifically for this study) in order to adjust for differences in odor exposure

estimates between the underlying models (Noordegraaf and Bongers 2007). The study also used odor annoyance derived from a telephone survey, although the dose–response analysis did include some explanatory factors (like region (high-density versus low-density) or agrarian and non-agrarian), but not other explanatory factors like age and gender that could also affect the dose–response relation. We therefore aim to (1) investigate the relationship between reported odor annoyance and modeled odor exposure; (2) investigate whether other variables can affect this relation, in order to establish a model to estimate odor annoyance based on dispersion-modeled odor exposure; and finally (3) compared the results from our study to the dose–response relation of a previously carried out study in the Netherlands in order to investigate possible changes in odor annoyance complaints over a period of time.
We used annual cumulative odor exposure at respondents' home addresses. Odor exposure was modeled using the Stacks dispersion model (Erbrink 1994, 1995; Erbrink et al. 1998), while odor annoyance was quantified with data from a recent questionnaire survey among neighboring residents of livestock farms in the south of the Netherlands.

METHODS

Study setting

This study uses data from a larger case–control study, which was carried out in the eastern part of the province of Noord-Brabant and the northern part of Limburg in The Netherlands, a region with a relatively high density of livestock farms and farm animals. An extensive description of the study area and study population can be found in Smit et al. (2012, 2014). The case–control study was set up in order to investigate the respiratory health of residents living near livestock farms. Participants were selected based on the information derived from the electronic medical records (EMRs) of general practitioners (GPs) that operate in the study area. Cases were diagnosed with asthma and controls with lower back pain without radiation. Cases and controls were matched on general practice (GP).
We selected data of 786 respondents from the province of Noord-Brabant. For the current analysis, respondents have been excluded if there were no data available on reported odor annoyance (n = 120). Since the main focus of this study was on neighboring residents, respondents who have worked or lived on a farm (n = 84) have also been excluded from analysis. This leaves 582 respondents eligible for analysis.
This study was carried out according to the Dutch legislation on privacy and the Conduct for Medical research. The patient's privacy was ensured by keeping information from medical records and home addresses separated at all times, by using a trusted third party. Medical ethical approval or obtaining informed consent from individual participants was not required for this study according to Dutch legislation.

Outcome variables

Participants in the case–control study completed a questionnaire which included a question on odor annoyance and a question on major sources of odor annoyance. Odor annoyance was established by the following two close-ended questions from the questionnaire: (1) 'Do you experience odor annoyance in the living environment?', with response categories: 'no,' 'a little bit,' 'clearly' and 'strongly';

and (2) 'Which of the following sources is the major contributor to your experienced odor annoyance?', with response categories: 'road traffic,' 'industry,' 'spreading slurry and manure,' 'other livestock farming, namely …', 'sewerage' and last 'other odor sources, namely ….' We combined the answers to the two questions to form three separate dichotomous variables expressing odor annoyance yes/no (the outcome 'yes' represents the following response categories 'a little bit,' 'clearly' and 'strongly' from the first question. And the outcome 'no' follows from the respondents who filled-in 'no' from the first question) into (1) odor annoyance from livestock housings ('other livestock farming' from the second question), (2) odor annoyance from spreading slurry and manure ('spreading slurry and manure' from the second question) and (3) livestock farming in general (a combination of 'spreading slurry and manure' and 'other livestock farming' from the second question).

Odor exposure

Odor exposure at the respondents' home address was estimated using the Stacks dispersion model (Stacks+, DNV Kema, Arnhem, The Netherlands) and is expressed at the 98th percentile of hourly odor concentrations. This represents the level of odor exposure in European odor units per cubic meter (OU_E/m^3) that may be exceeded during 2 % of the time in a year (CEN 2003). Odor exposure can also be expressed in other percentiles of hourly odor concentrations; however, the 98th percentile is commonly used in the Dutch odor policy. An odor concentration of 1 OU_E/m^3 resembles the dilution at which 50 % of a selected test panel is able to detect the specific odor in the dilution-to-threshold method (EPA 2001; Noordegraaf and Bongers 2007).

The Stacks dispersion model uses detailed meteorological information, emission data and land use data for the specific locations (Erbrink 1994, 1995; Erbrink et al. 1998). The meteorological data consist of hourly values of diagnostic wind fields (wind direction and speed), global radiation, surface roughness (based on land use data; average values over 2 × 2 km (meaning all livestock odor sources within 2 km) for each home address, separately), temperature and cloud cover, combined with physically relevant parameters such as Monin–Obukhov length scale, friction velocity and boundary layer height, based on interpolation schemes from measurements at meteorological stations (either Amsterdam Airport or Eindhoven). In doing so, meteorological datasets are set up for every 20 × 20 km area, separately. For source parameters, the following parameters are used: source strength (odor emission factor based on farm type and farm animal type), stack height (6 m), height of animal housings (6 m) and vertical emission speed (4 m/s). Information on farm-specific odor emission factors for the selected study area was obtained from the provincial database of mandatory licenses for keeping farm animals (Web-BVB 4.0, Province of Noord-Brabant, 's-Hertogenbosch, The Netherlands). The dispersion model calculations are performed only on emissions from animal housings. Emissions due to spreading slurry and manure are not included in the dispersion calculations, because information on spreading locations and spreading days was not available.

In order to investigate possible alterations in odor perception among neighboring residents over a period of time, we compared the results from our study to the dose–response relation derived from the Bongers study (Bongers et al. 2001). We therefore used LTFD-modeled odor exposure estimates for our study (provided by the

Province of Noord-Brabant). The LTFD model calculates yearly average odor exposures using meteorology and is a precursor of the currently used dispersion models (such as Stacks).

Explanatory variables

Information on not only personal characteristics like age, gender, educational level and residence (e.g., type of house), but also satisfaction with the current residence, satisfaction with the living environment, farm childhood, number of hours spent in or around home, and perceived environmental stressors in the living environment (e.g., noise or air pollution) has been collected through the questionnaire applied in the case–control study. Information on asthma was available through the case–control status.

Statistical analysis

Statistical analysis has been carried out using the SPSS statistical software package 20.0 (IBM SPSS, Armonk, New York, USA). Population characteristics have been explored using descriptive statistics. Natural logarithms of the 98th percentile odor exposure (P98 odor exposure in odor units/m^3) have been used to transform the positively skewed distribution of the odor exposure data. Because the P98 odor exposure contained null values, the value of 0.1 has been added to all values of P98 odor exposure before transformation. The odds ratios presented in the tables represent the odds of 1 unit increase on ln-scale.

Univariate logistic regression analyses have been performed investigating the crude relation between odor exposure levels and odor annoyance from livestock farming in general, odor annoyance from livestock housings, and odor annoyance from spreading slurry and manure. Furthermore, univariate analyses have been carried out to investigate the relation between odor annoyance and explanatory variables (independent variables) (results not shown). Correlations between outcome variables (dependent variables) and explanatory variables were analyzed using both Pearson's (interval variables) and Spearman's (categorical data) correlation coefficients to identify possible collinearity between independent variables (results not shown). In addition, we tested for effect modification by including an interaction term for asthma/lower back pain and for educational level.

In order to investigate the shape of the dose–response and potential nonlinear relation between odor annoyance and modeled odor exposure, we used a cubic spline to fit the observed data. The spline (see Fig. 1) is a flexible model which allows the results to vary nonlinearly with exposure in such a way that low-exposure estimates are less affected by high-exposure estimates (Greenland 1995). The spline has been carried out using SAS software (SAS Institute, Cary, NC, USA), and all figures were made using SigmaPlot (Systat Software, San Jose, CA, USA).

[FIG. 1]

Smoothed and linear logistic regression plots (with corresponding 95 % CI) representing the association between modeled odor exposure and reported odor annoyance from livestock farming (p-spline = 0.03, df-spline = 1.13, p value Chi-square goodness-of-fit test compared to linear model = 0.09). The association was additionally adjusted for case–control status

Furthermore, to establish the effect of the various explanatory variables on odor annoyance, we performed multiple logistic regression analysis with backward removal (likelihood ratio method). All explanatory variables (selected based on a priori knowledge and results from univariate analysis) were included in the first step and removed based on the likelihood ratio method in order to establish the multiple model that fits the observed data best. As this study is a secondary analyses on data with a case–control design in which asthma forms the basis of the case selection, the asthma/lower back pain variable was included in all analyses to take the study design into account.

We also compared the dose–response relation from a previous study, carried out in the Netherlands by Bongers et al. (2001) (for an area with a high density of livestock farms and non-agrarian) with the results from our study. We therefore established a crude dose–response relation for our study with odor annoyance from livestock farming as outcome variable and LTFD-modeled P98 odor exposure as input variable, and compared the regression line with the regression line from the study by Bongers et al. (2001).

Furthermore, we also explored the possible differences in predicted odor annoyance for the LTFD model and the Stacks dispersion model (see Fig. 3). We used the same odor annoyance data (odor annoyance from livestock farming in general) from our study, but odor exposure estimates determined by using two different exposure models, the LTFD and Stacks models. Because the P98 odor exposure outcome differs between the models (LTFD-P98 is expressed in odor units (ge/m^3), whereas Stacks-P98 is expressed as European odor units (OU_E/m^3)), we used a rough conversion factor for the LTFD-P98 odor exposure estimates (1 odor unit (ge/m^3) = 0.5 European odor units (OU_E/m^3)). Subsequently, we estimated for each model (both LTFD and Stacks models) a crude dose–response relation, with odor annoyance from livestock farming in general as the main outcome and modeled P98 odor exposure (C98 in the formula underneath) as input variable. The percentage of odor annoyance (H) among neighboring residents can be calculated using the following formula:

H=exp(β 0 +β 1 ·ln(C 98))1+exp(β 0 +β 1 ·ln(C 98))

Results

In Table 1, the population descriptives for the explanatory variables and outcome variables are shown.

[Table 1]

There are relatively more women (63.4 %) than men (36.6 %) included in this study. The average age of the respondents was 51 years and the respondents lived approximately 18 years in their current residence. Approximately 25 % of the study population grew up on a farm. Furthermore, almost 30 % of the study population reported odor annoyance from livestock farming, but only a minority (6 %) identified livestock housings as the major source, and the remaining respondents (22.2 %) reported odor annoyance from spreading slurry and manure as the major source of odor. The 98th percentile odor exposure for respondents ranged from 0 to 40.2 OU_E/m^3 with 4.2 OU_E/m^3 as average.

In order to investigate the relation between modeled odor exposure and reported odor annoyance, we used univariate logistic regression analysis. These analyses showed a statistically significant positive association between livestock stable odor exposure and reporting of odor annoyance from livestock housings (OR 2.19; 95 % CI 1.49–

3.23), odor annoyance from spreading slurry and manure (OR 1.60; 95 % CI 1.27–2.01), and livestock farming in general (OR 1.92; 95 % CI 1.53–2.41) (see Table 2).

[TABLE 2]

We tested for interaction between case/control status and odor exposure and for interaction between educational level and odor exposure; however, no interaction effect was found (p = 0.66 and p = 0.50, respectively). We also fitted a spline to the data in order to examine the potential nonlinearity of the relation between odor exposure and odor annoyance. Although the spline was significant (p = 0.03) indicating that the relation between odor annoyance and modeled odor exposure is nonlinear, we compared the function of the spline to the function of the logistic regression model (see Fig. 1) and concluded that the differences are relatively small and that the relation can be analyzed using logistic regression.

In order to investigate whether odor annoyance and/or the relation between odor exposure and odor annoyance is affected by other variables, we also performed multivariate logistic regression analysis. All potential explanatory variables were included in the backward regression procedure, since no strong correlations were found between variables included in the model (correlation matrix not shown). Resulting multiple regression models are presented in Table 2. Besides odor exposure, age (OR 1.03; 95 % CI 1.01–1.04), asthma (OR 1.49; 95 % CI 0.98–2.29), education level ($OR_{high\ vs.\ low}$ 3.06; 95 % CI 1.79–5.23) and reporting of air pollution in the environment (OR 1.71; 95 % CI 0.99–2.93) were related to odor annoyance. Modeled odor exposure, however, remained a strong predictor (OR 1.88; 95 % CI 1.48–2.38) of reported odor annoyance, and the odds of odor annoyance due to odor exposure hardly changed after including other explanatory variables in the model as well. Figure 2 demonstrates the influence of asthma and education, each separately, on odor annoyance. The results show that, at a given level of odor exposure, especially asthmatics with a high education are more likely to report odor annoyance than control subjects with a low education level.

[FIG. 2]

Linear logistic regression plots representing the association between modeled odor exposure and reported odor annoyance from livestock farming, stratified by presence or absence of asthma and level of education. The figure represents the additive multiple linear logistic regression model from Table 2 (model 1b). No interaction at the logistic scale are observed (p values for interactions between odor exposure and asthma or education >0.05)

We also examined predicted odor annoyance from livestock farming for LTFD-modeled odor exposure estimates for our study and compared the results with the dose–response relation established by Bongers et al. (2001) because this may indicate changes in reported odor annoyance within a time period of approximately 10 years. We found that our current study predicts relatively more odor annoyance among neighboring residents of livestock farms at the same odor exposure levels (results not shown). These differences in dose–response may be due to differences between odor exposure estimates caused by using two different models. Figure 3 shows predicted odor annoyance in relation to estimated P98 odor exposure levels for two different odor exposure-estimating models. The figure shows that especially in the higher-exposure categories, the LTFD model seems to predict relatively more odor annoyance compared to the Stacks dispersion model. However, most respondents will be exposed to lower estimated odor exposure levels and using a dose–response relation based on the LTFD model may underestimate odor annoyance among those respondents, compared to odor exposure estimates based on the Stacks model.

[FIG. 3]
Linear logistic regression plots representing the association between reported odor annoyance from livestock farming and modeled odor exposure calculated using the LTFD model and the Stacks model. The figure represents the differences between the two models. The LTFD model was used in the study by Bongers et al. (2001). LTFD model: odor annoyance from livestock farming = −2.83 + 0.99 × (lnP98 (LTFD-modeled P98)) + 0.25 × (asthma/lower back pain). Stacks model: odor annoyance from livestock farming = −1.77 + 0.65 × (lnP98 (Stacks-modeled P98)) + 0.29 × (asthma/lower back pain). Output parameter of the LTFD model regression function is expressed in odor units, (ge/m^3), is in a different unit than the output parameter in the second regression function, the European odor unit (OU_E/m^3). We therefore converted the results from the first regression function as follows: 1 odor unit (ge/m^3) = 0.5 European odor units (OU_E/m^3)

DISCUSSION

We conducted this study in order to investigate the relation between odor annoyance and modeled odor exposure, and the effect of other explanatory factors on this relation (such as age, gender and education). We showed that odor exposure is positively associated with reporting of odor annoyance and that other explanatory factors such as age and education can affect odor annoyance, although these factors hardly affect the relation between odor annoyance and modeled odor exposure. We also found that in our current study, relatively more odor annoyance is reported compared to a similar study conducted 10 years earlier in the Netherlands.

There are hardly any studies that investigated odor exposure at the individual level in association with reporting of odor annoyance. The fact that we could use spatially explicit estimated odor exposure from livestock farms for each individual in the study population, is one of the strengths of this study. In addition, to our knowledge, our study is the first study which does not only investigate the relation between odor annoyance and dispersion-modeled odor exposure, but also include other explanatory variables that may influence the relation between reported odor annoyance and modeled odor exposure.

The results from univariate analysis indicated a strong and statistically significant relation between modeled odor exposure and reported odor annoyance from livestock farming in general, livestock housings and spreading slurry and manure. In the multiple analysis, the study also gives evidence of influence from other factors, such as age, education and occurrence of air pollution in the living environment on odor annoyance, although we found no evidence of effect modification or confounding. We showed that particularly higher educated respondents report more often odor annoyance than respondents with a lower education level. Furthermore, older respondents reported slightly more odor annoyance compared to younger participants. These results were in accordance with the results reported in some previous investigations (Radon et al. 2004; Van Thriel et al. 2008; Claeson et al.

2013; Greenberg et al. 2013). However, the multiple regression analysis showed that the contribution of some of these factors on odor annoyance is relatively small, compared to modeled odor exposure. This study is the first to identify that modeled exposure levels are one of the major drivers of odor annoyance.

The current Dutch legislation on odors from livestock farming urges the use of a dispersion model to estimate the odor emissions from livestock farms into the environment. However, there is very little insight on the relation between odor annoyance and modeled odor exposure using a dispersion model. In the Netherlands, one previous study investigated the relation between reported odor annoyance and estimated odor exposure levels (Bongers et al. 2001). However, this study used a precursor of the current dispersion models and the study was carried out more than 10 years before our study. Furthermore, since the outbreak of Q-fever in the Netherlands (2007–2009), there has been an ongoing debate within the Dutch community about livestock farming in general and the potential health effects. This may also have influenced the perception and appreciation of livestock odors among neighboring residents of livestock farms. Therefore, we also aimed to investigate whether odor perception has changed over the period of time elapsed since the study conducted by Bongers et al. (2001). In order to investigate changes in odor perception among neighboring residents, we compared our results to those from the study carried out by Bongers using LTFD-modeled odor exposure estimates for our study. We found relatively more reported odor annoyance in our study compared to results from Bongers et al. (2001). These results indicate that little has changed in the perception and appreciation of livestock odors among neighboring residents of farms in areas with a high density of livestock farms, despite the fact that in general livestock odor emission levels in the Netherlands have declined (based on provincial reports on livestock emissions) in the last years. We also investigated the differences in estimated odor annoyance given certain odor exposure levels between the LTFD model and Stacks dispersion model. We roughly compared predicted odor annoyance using LTFD-modeled odor exposure and Stacks-modeled odor exposure using the same input data for odor annoyance from our study but different odor exposure estimates since these were calculated using different models (see Fig. 3). The figure demonstrates that in the lower exposure categories the Stacks dispersion model estimates more odor annoyance compared to odor exposure estimates using the LTFD model. This indicates that LTFD-modeled dose–response relations are different from dispersion-modeled dose response relations due to the differences in the underlying model. However, caution is needed in interpreting these results because we used a conversion factor (1 odor unit (ge/m^3) = 0.5 European odor units (OU_E/m^3)) for the LTFD-modeled odor exposure estimates to be able to plot dose–response relation into one figure. These findings do corroborate the numerous odor complaints from neighboring residents to local authorities. The outbreak of Q-fever and the ongoing debate on potential health effects of exposure to livestock emissions will likely be of some influence on the perception of livestock odors by neighboring residents. However, we were unable to investigate the reasons for reporting of odor annoyance into more detail, due to a lack of information.

There are, however, also uncertainties in our study. The data we used to investigate odor annoyance among neighboring residents were not collected for the purpose of our study. This is reflected especially by the two questions on odor annoyance in the questionnaire. The second question identifies only the major underlying source of odor annoyance. Respondents were only allowed to fill out one answer. This could have resulted in underreporting of odor annoyance from livestock in general and livestock housings in particular, as it is likely that people are more prone to report odor of spreading slurry and manure as a major source than odor from livestock housings. In addition, other sources of odor could be a major source as well. Therefore, we also introduced odor annoyance from spreading slurry and manure as outcome variable in order to investigate odor annoyance from livestock farming thoroughly. It should be noted that modeled odor exposure is established for livestock housings, which is not necessarily a good proxy for odor exposure from spreading slurry and manure as it may be spread on cultivated land further away from livestock housings. However, we had no detailed information on spreading days and specific spreading locations. Nonetheless, we found a statistically significant relation between modeled odor exposure and reporting of odor annoyance from spreading slurry and manure. This may be explained by the high density of livestock farms in the study area or the fact that we cannot disentangle the different sources of annoyance. However, these results indicate clearly that an explicit distinction should be made by including spreading slurry and manure separately from livestock housings.

As mentioned above, the presented data stem from a secondary analysis from a case–control study investigating respiratory health in relation to livestock farming. This might compromise the generalization to the general population. However, as no significant interaction for case/control status and exposure in relation to odor annoyance was observed, no major differences for the general population in an area with a high density of livestock farms are expected.

Finally, misclassification in odor exposure estimates may be present in our analysis. It is known that choice of the model input parameters, like dimension of animal housings and emission parameters (output temperature, vertical or horizontal ventilation outlet, emission height), may result in different odor concentration levels up to a factor 5. In addition, information on source location and source characteristics (type of farm, stack height, height of animal housings, vertical emission speed and size of emission opening) may not be completely up to date, and the dispersion model does not take into account the inherent variation in odor emission from livestock farms due to weather conditions and farm management (e.g., animal feeding, manure management, animal growth or presence of animal diseases) (Erbrink 1994, 1995; Erbrink et al. 1998). Despite these variable conditions, we believe that estimated odor exposure levels will reflect ambient odor exposures from livestock housings relatively well, and compared to the LTFD model, the usage of a more refined and detailed dispersion model in odor regulation is an improvement (Erbrink et al. 1998). However, we also feel that for mandatory regulation of odor emissions, both the regulatory dispersion model and the databases should be kept updated to the latest technology and knowledge. On the other hand, this manuscript and previous studies also demonstrate that odor annoyance is a complex concept and is caused and affected by more than just odor exposure estimates. This is demonstrated by the log-likelihood values from the models presented in Table 2; the model with all other explanatory variables does add to the model fit; however, the change in model fit is relatively small compared to the model with only odor exposure.

In conclusion, the results of this study indicate a strong relation between modeled odor exposure and odor annoyance from livestock farming. Other explanatory factors like age, education and occurrence of air pollution in the environment are also independently associated with odor annoyance, but we did not find evidence of confounding or effect modification by these factors. These results could have implications for odor policy making, since current Dutch legislation was not underpinned by empirical evidence but that should have been. Furthermore, we compared the results from our study with those from an earlier study carried out in the Netherlands and found relatively more odor annoyance among neighboring residents for our study at the same odor exposure level. However, our study also had some uncertainties, and therefore, the results from this study should be replicated in a larger study, which is specifically designed to elicit the association between livestock-associated odor exposure and odor annoyance from livestock housings.

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Compliance with Ethical Standards

Conflict of interest

The authors declare that they have no conflict of interest.

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TABLES AND FIGURES

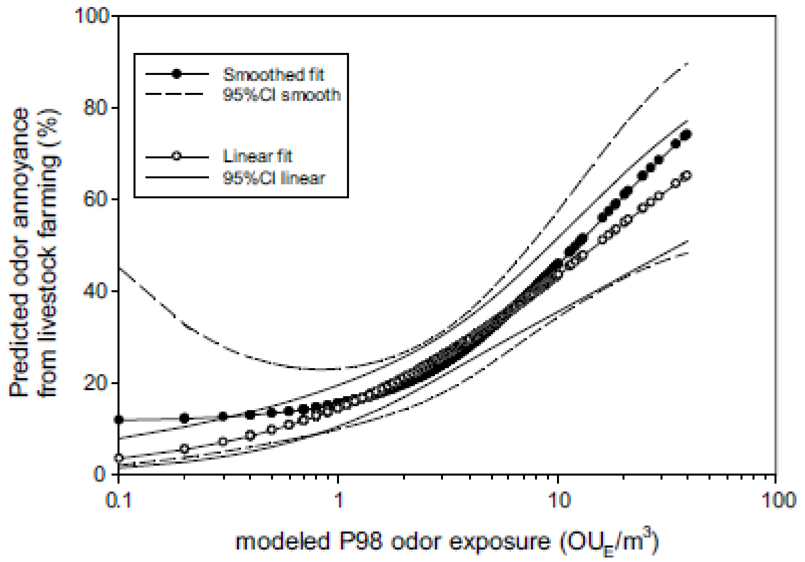

Fig. 1 Smoothed and linear logistic regression plots (with corresponding 95 % CI) representing the association between modeled odor exposure and reported odor annoyance from livestock farming (p-spline = 0.03, df-spline = 1.13, p value Chi-square goodness-of-fit test compared to linear model = 0.09). The association was additionally adjusted for case–control status

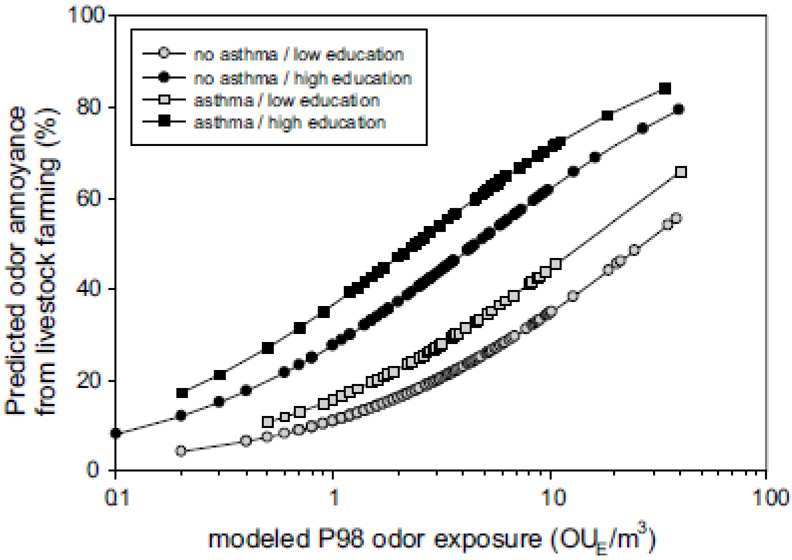

Fig. 2 Linear logistic regression plots representing the association between modeled odor exposure and reported odor annoyance from livestock farming, stratified by presence or absence of asthma and level of education. The figure represents the additive multiple linear logistic regression model from Table 2 (model 1b). No interaction at the logistic scale are observed (*p* values for interactions between odor exposure and asthma or education >0.05)

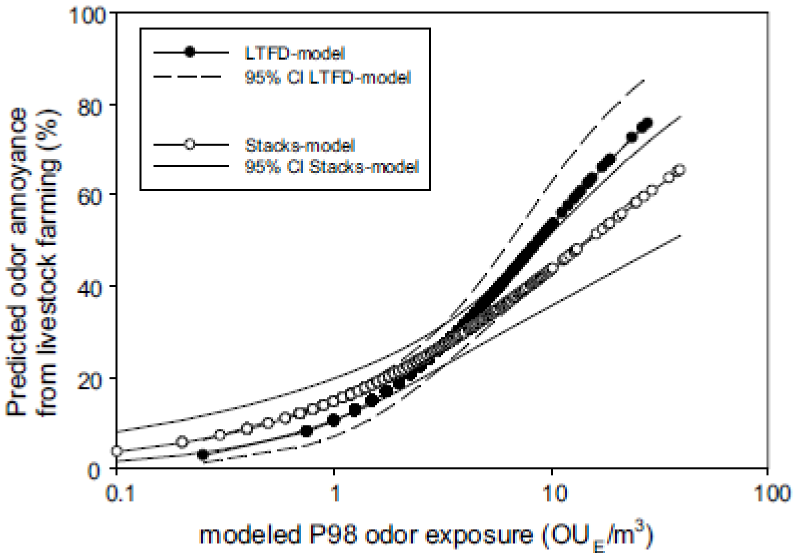

Fig. 3 Linear logistic regression plots representing the association between reported odor annoyance from livestock farming and modeled odor exposure calculated using the LTFD model and the Stacks model. The figure represents the differences between the two models. The LTFD model was used in the study by Bongers et al. (2001). LTFD model: odor annoyance from livestock farming = −2.83 + 0.99 × (lnP98 (LTFD-modeled P98)) + 0.25 × (asthma/lower back pain). Stacks model: odor annoyance from livestock farming = −1.77 + 0.65 × (lnP98 (Stacks-modeled P98)) + 0.29 × (asthma/lower back pain). Output parameter of the LTFD model regression function is expressed in odor units, (ge/m^3), is in a different unit than the output parameter in the second regression function, the European odor unit (OU_E/m^3). We therefore converted the results from the first regression function as follows: 1 odor unit (ge/m^3) = 0.5 European odor units (OU_E/m^3)

Table 1 Population descriptives for explanatory variables and outcome variables in the analysis ($n = 582$)

	Mean	SD
P98 odor exposure (OU_E/m^3)	4.2	4.9
Age (years)	51	13
	N	%
Sex		
Men	213	36.6
Women	369	63.4
Educational level[a]		
Low	198	34.0
Middle	229	39.3
High	132	22.7
Missing	23	4.0
Asthma		
No (controls)	402	69.1
Yes (cases)	180	30.9
Number of years in current home		
0–4 years	94	16.2
5–9 years	96	16.5
10–14 years	65	11.2
15–24 years	158	27.2
25 + years	155	26.6
Missing	14	2.4
Number of hours spent per day in or around home		
<8 h	40	6.9
8–15 h	293	50.3
16–19 h	147	25.3
20–24 h	94	16.2
Missing	8	1.4
Occurrence of noise in the living environment		
No	421	72.5
Yes	160	27.5
Missing	1	0.0
Occurrence of air pollution in the living environment		
No	499	85.9
Yes	82	14.1
Missing	1	0.0
Farm childhood		
No	425	73.0
Yes	153	26.3
Missing	4	0.7
	N	%
Outcome variables		
Odor annoyance from livestock farming		
No	415	71.3
Yes	167	28.7
Odor annoyance from livestock housings		
No	544	93.5
Yes	38	6.5

Table 1 continued

	Mean	SD
Odor annoyance from spreading manure and slurry		
No	453	77.8
Yes	129	22.2

[a] Educational level: low, lower secondary school or less; medium, intermediate vocational education or upper secondary school; high, upper vocational education or university

Table 2 Univariate and multiple logistic regression analyses between reported odor annoyance from livestock farming and modeled P98 odor exposure ($n = 582$)

	Beta (β)	SE	OR	95 % CI	−2LL
Univariate logistic regression: odor annoyance from livestock farming					
Constant (β_0)	−1.77	0.2			
lnP98 odor exposure	0.65	0.1	1.92	1.53–2.41	
Asthma/lower back pain	0.29	0.2	1.34	0.91–1.99	
Univariate model fit					658.9
Multiple logistic regression: odor annoyance from livestock farming					
Constant (β_0)	−3.61	0.6			
lnP98 odor exposure	0.63	0.1	1.88	1.48–2.38	
Asthma/lower back pain	0.41	0.2	1.49	0.98–2.29	
Age	0.03	0.01	1.03	1.01–1.04	
Educational level					
Medium versus low	0.47	0.3	1.59	0.96–2.63	
High versus low	1.12	0.3	3.06	1.79–5.23	
Occurrence of air pollution in the living environment	0.54	0.3	1.71	0.99–2.93	
Multiple model fit					581.8
Univariate logistic regression: odor annoyance from livestock housings					
Constant (β0)	−3.57	0.4			
lnP98 odor exposure	0.79	0.2	2.19	1.49–3.23	
Asthma/lower back pain	−0.45	0.4	0.64	0.29–1.39	
Univariate model fit					263.2
Multiple logistic regression: odor annoyance from livestock housings					
Constant (β_0)	−4.09	0.5			
lnP98 odor exposure	0.72	0.2	2.04	1.39–3.01	
Asthma/lower back pain	−0.53	0.4	0.59	0.26–1.32	
Education					
Medium versus low	0.29	0.5	1.34	0.55–3.23	
High versus low	1.01	0.5	2.73	1.11–6.74	
Occurrence of air pollution in the living environment	1.19	0.4	3.29	1.55–6.97	
Multiple model fit					246.7
Univariate logistic regression: odor annoyance from spreading slurry and manure					
Constant (β_0)	−1.96	0.2			
lnP98 odor exposure	0.47	0.1	1.60	1.27–2.01	
Asthma/lower back pain	0.48	0.2	1.61	1.07–2.44	
Univariate model fit					593.5
Multiple logistic regression: odor annoyance from spreading slurry and manure					
Constant (β_0)	−3.71	0.6			
lnP98 odor exposure	0.49	0.1	1.63	1.28–2.08	
Asthma/lower back pain	0.56	0.2	1.76	1.13–2.73	
Age	0.03	0.01	1.03	1.01–1.05	
Education					
Medium versus low	0.41	0.3	1.51	0.89–2.57	
High versus low	0.91	0.3	2.47	1.41–4.32	
Multiple model fit					534.3