HHS Public Access

Author manuscript

Pediatrics. Author manuscript; available in PMC 2015 July 28.

Published in final edited form as:

Pediatrics. 2006 July ; 118(1): e66–e75. doi:10.1542/peds.2005-2812.

Asthma Symptoms Among Adolescents Who Attend Public Schools That Are Located Near Confined Swine Feeding Operations

Maria C. Mirabelli, PhD[a], **Steve Wing, PhD**[a], **Stephen W. Marshall, PhD**[a,b,c], and **Timothy C. Wilcosky, PhD**[a,d]

[a]Department of Epidemiology, School of Public Health, University of North Carolina, Chapel Hill, North Carolina

[b]University of North Carolina Injury Prevention Research Center, University of North Carolina, Chapel Hill, North Carolina

[c]Department of Orthopedics, School of Medicine, University of North Carolina, Chapel Hill, North Carolina

[d]Environmental Health and Epidemiology Program, RTI International, Research Triangle Park, North Carolina

Abstract

OBJECTIVES—Little is known about the health effects of living in close proximity to industrial swine operations. We assessed the relationship between estimated exposure to airborne effluent from confined swine feeding operations and asthma symptoms among adolescents who were aged 12 to 14 years.

METHODS—During the 1999–2000 school year, 58 169 adolescents in North Carolina answered questions about their respiratory symptoms, allergies, medications, socioeconomic status, and household environments. To estimate the extent to which these students may have been exposed during the school day to air pollution from confined swine feeding operations, we used publicly available data about schools (n = 265) and swine operations (n = 2343) to generate estimates of exposure for each public school. Prevalence ratios and 95% confidence intervals for wheezing within the past year were estimated using random-intercepts binary regression models, adjusting for potential confounders, including age, race, socioeconomic status, smoking, school exposures, and household exposures.

RESULTS—The prevalence of wheezing during the past year was slightly higher at schools that were estimated to be exposed to airborne effluent from confined swine feeding operations. For students who reported allergies, the prevalence of wheezing within the past year was 5% higher at schools that were located within 3 miles of an operation relative to those beyond 3 miles and 24%

Address correspondence to Maria Mirabelli, PhD, Centre for Research in Environmental Epidemiology, Municipal Institute of Medical Research, c/Doctor Aiguader, 80, Barcelona 08003, Spain. mmirabelli@imim.es.

The authors have indicated they have no financial relationships relevant to this article to disclose.

higher at schools in which livestock odor was noticeable indoors twice per month or more relative to those with no odor.

CONCLUSIONS—Estimated exposure to airborne pollution from confined swine feeding operations is associated with adolescents' wheezing symptoms.

Keywords

asthma; environmental health; epidemiology; school age children; school health

During the past 2 decades, the process of raising swine and other livestock has grown into a major industry in the United States. Production has shifted from smaller, family-owned farms to larger, industrialized confined animal feeding operations (CAFOs). Animals in North Carolina's industrialized operations are raised in confinement buildings, housing hundreds to thousands of hogs per operation. Residues of food additives, bedding, dried waste, and animal dander are vented from confinement buildings, and animal waste from the confinement houses is flushed into on-site cesspools, where it begins to decompose and aerosolize anaerobically before being sprayed onto nearby land. There are concerns about the health impacts of exposure to particulate matter, antibiotic residues, volatile organic compounds, and bioaerosols that are present in air that is downwind from confinement buildings, waste lagoons, and spray fields.[1–4]

In occupational settings, adverse respiratory symptoms and changes in bronchial responsiveness and lung function have been observed among confinement building workers.[5–12] Studies that have compared swine CAFO neighbors with other rural residents showed that neighbors reported more frequent respiratory symptoms and mucosal membrane irritation.[13] This literature about health impacts of residential exposures that arise from CAFOs focuses on adults[2,13–15] and may describe inadequately the potential respiratory health effects among children, who may experience notably different physical, educational, and social impacts from such exposures. We designed this research to assess the relationship between self-reported wheezing symptoms among adolescents who were aged 12 to 14 years and estimated exposure to airborne effluent from swine CAFOs.

METHODS

This study combined data about adolescents' respiratory health symptoms, data from a survey of school environments, and location data about swine CAFOs and public schools in North Carolina. Random-intercepts binary regression models were used to estimate prevalence ratios (PRs) that assessed the association between airborne swine pollutants and the prevalence of wheezing symptoms.

North Carolina School Asthma Survey Data

During the 1999–2000 school year, the North Carolina Department of Health and Human Services conducted a statewide respiratory health surveillance project to assess the prevalence of respiratory symptoms among middle school–aged children.[16] Approximately 67% (128 568 of 192 248) of all eligible students participated in the survey, which included core wheezing questions from the International Study of Asthma and Allergies in Childhood

questionnaire, a standardized and validated instrument that combines a traditional written questionnaire with a series of video scenes that show children with asthma symptoms.[17–20] To complete the video-based survey questions, students viewed a sequence of video vignettes that showed adolescents experiencing asthma-related symptoms; each scene was followed by time to complete a written survey question, allowing each student to indicate whether he or she had experienced symptoms like those illustrated in the scene.[19,20] We analyzed the prevalence of any wheezing symptoms within the past year ("current wheezing"), as determined by responses to questions about wheezing at rest, waking at night as a result of wheezing, exercise-induced wheezing, and severe wheezing attacks. The definition of current wheezing used here is consistent with that applied in previous analyses of the North Carolina School Asthma Survey (NCSAS) data.[16,21–23]

To evaluate whether the estimated exposure had an impact other asthma-related outcomes, we assessed "severe wheezing" using responses to survey questions about waking at night as a result of wheezing and having a severe wheezing attack during the past year; considered the severe wheezing symptoms to be frequent when they occurred at least once per month ("frequent severe wheezing"); and evaluated physician-diagnosed asthma, medical care, and behavioral consequences of asthma-related symptoms.

Each adolescent also answered questions about age, race, Hispanic ethnicity, allergies, socioeconomic status, cigarette smoking history, and home environment. We included age as a continuous variable (centered at 13) and categorized all other variables: race (black/white); Hispanic ethnicity (yes/no); allergies to cat, dog, dust, grass, or pollen (yes/no); ever smoked cigarettes (yes/no); number of other smokers in household (0, 1, 2, or ≥3); and use of a gas stove at home (<1 time per month vs ≥1 times per month). Socioeconomic status was assessed using responses to a question about payment for lunch at school, with lower economic status designated by receiving free or reduced-price lunch at school compared with paying full price for lunch or bringing lunch to school.

School Environment Data

During the 2003–2004 school year, we mailed 4 copies of a survey to principals of 337 public schools and asked each to distribute the surveys to current school employees. More than 800 anonymous survey respondents, employed in 265 (79%) of the targeted schools, answered questions about their observations of the environmental conditions in and around the school buildings. The survey responses indicated whether there was visible evidence of the presence of cockroaches, rodents, or mold and noticeable odors from indoor (eg, mold) and outdoor (eg, nearby industries) sources of airborne pollutants. Responses were used to create school-level indicator variables for the presence of indoor respiratory irritants and sources of outdoor air pollution from agriculture and industries that are located near the school. Because of concerns about response bias resulting from social and political conflict surrounding industrial swine production in North Carolina, we asked survey respondents to answer a question about livestock odor generically rather than about odor specifically arising from swine operations. When we received >1 survey from a single school, schools were categorized as positive for a given survey question when any respondent reported the given condition.

Swine CAFO Exposure Estimates

Estimates of exposure to airborne pollution from 2343 swine CAFOs were generated using data from permits that were issued by the North Carolina Division of Water Quality to all CAFOs that house at least 250 animals and use a liquid waste management system. Records contained mandatory information about each CAFO facility, including geographic coordinates and the number, type, and weight of animals (called steady-state live weight [SSLW]) at each operation.[3,24] CAFO operators who filed applications for liquid waste management permits with the state agency provided latitude and longitude coordinates of their operations; the coordinates were verified and corrected, when necessary, when state inspectors visited the operations, although the extent to which the information was corrected by agency inspectors was not recorded in the data (S. Lewis, personal communication, 2002).

Separate exposure estimates were developed on the basis of distances between schools and swine CAFOs and of survey responses about noticeable odors from livestock farms. Distances and geographic directions between schools and CAFOs were calculated using the formulas given by Goldberg et al[25] and Sinnott,[26] respectively. We used calculations of proximity to create 3 metrics of potential exposure for each school: (1) distance to the nearest operation; (2) SSLW within 3 miles; and (3) a weighted SSLW based on the distance between the school and nearby swine CAFOs, the SSLW of each operation, and the proportion of wind measurements in the direction from the operation to the school. We obtained measurements of wind speed and direction recorded at 16 automated weather stations located throughout the state from the State Climate Office of North Carolina (Raleigh, NC). Hourly averages from January 1999 through December 1999 and from the weather station located nearest each school–CAFO pair were used to compute the proportion of time when the wind was blowing from the operation to the school. Weighted SSLW values for each CAFO within 3 miles of a school were the product of the squared inverse of the distance between the school–CAFO pair, the operation's SSLW value, and the proportion of time that regional wind measurements indicated that wind was blowing from the operation toward the school. For each school, weighted SSLW values were summed and the schools were assigned categories of low, medium, and high exposure on the basis of tertiles of the distribution of values among schools with 1 or more swine CAFOs located within 3 miles. A 3-mile radius was selected on the basis of previous research about the impacts of swine CAFOs on health and quality of life among neighbors who live within a 2-mile radius[2,13]; for this research, we expanded the potential zone of exposure to 3 miles because odors from swine CAFOs sometimes are reported at distances of >2 miles.

Study Population

Students in 499 public schools participated in NCSAS, and each student provided data about his or her respiratory health. Schools in 14 counties that did not contain a swine CAFO or border a county with at least 1 swine CAFO (n = 45), schools within the city limits of the 6 cities with populations >100 000 (n = 61), schools within 5 miles of the state border (n = 18), schools with <25 students surveyed (n = 34), schools that had closed or relocated since 2000 (n = 11), and schools that did not respond to the survey about in-school environmental conditions (n = 72) were excluded from our study. The remaining 265 public schools were

included in our study. From these 265 schools, a total of 73 305 boys and girls who were aged 12 to 14 years responded to NCSAS. Of those, 58 169 (79%) who reported black or white race and provided complete data for all asthma survey variables of interest constituted our final study population.

Statistical Analyses

Multivariate analyses were conducted separately for individuals with and without self-reported allergies to cat, dog, dust, grass, and/or pollen. To assess the relationship between the prevalence of wheezing symptoms and the estimates of in-school exposure, we used random-intercepts binary regression. This method accounted for the hierarchical clustering of student-level data within schools. Specifically, we used a variation of the generalized linear mixed model $E(Y\,x) = \exp(\alpha + \Sigma\beta x)$ similar to those described by Singer[27] and McLeod,[28] in which the student's outcome is modeled by a combination of student-level (level 1) and school-level (level 2) models. The student-level model was defined as

$$\log_e(P_{ij}) = \beta_{0j} + \beta_1 x_{1j} + \beta_2 x_{2j} + \ldots + \beta_n x_{nj}, \quad \text{(level 1)}$$

where P_{ij} is the probability of outcome y = 1 for individual i in school j, $p_{ij} \sim$ binomial; β_{0j} is school-specific intercept (intercept for school j); and β is the effect of individual-level predictor x_{ij}. Level 1 models included student-level variables for age, gender, race, Hispanic ethnicity, economic status, allergy status, cigarette smoking experience, number of other smokers in the household, and use of a gas kitchen stove at home. The school-level (level 2) model was defined as

$$\beta_{0j} = \beta_0 + \mu_1 z_1 + \mu_2 z_2 + \ldots + \mu_n z_m + \mu_{0j}, \quad \text{(level 2)}$$

where β_0 is the mean of school-level means for outcome y (ie, fixed intercept); μ is the effect of school-level predictor z_j; z_j is the school-level predictor for school j; $\mu_{0j} \sim N(0, \tau_{00})$; and τ_{00} is between-school variance. The level 2 models included main exposure variable(s) and indicator variables for rural school locale, survey-reported presence of indoor respiratory irritants (cockroaches, rodents, mold visible, mold odor, or flooding of school buildings within the past 5 years), and survey-reported industry other than a swine CAFO located near the school. The level 2 model, substituted into the level 1 model, results in a final 2-level random-intercepts model,

$$\log_e(P_{ij}) = \beta_{0j} + \beta_1 x_{1j} + \beta_2 x_{2j} + \ldots + \beta_n x_{nj} + \mu_1 z_1 + \mu_2 z_2 + \ldots + \mu_n z_m + \mu_{0j},$$

where μ_{0j} is the random intercept term. Associations were estimated as PRs ($\exp[\mu]$) using SAS statistical software version 8.2 (SAS Institute Inc, Cary, NC).

RESULTS

More than 26% (15 250 of 58 169) of students who participated in NCSAS during the 1999–2000 school year reported wheezing during the past year (ie, current wheezing). Table 1

shows adjusted PRs for individual-and school-level characteristics. Of the individual-level characteristics, the highest PR was observed for self-reported allergy status (PR: 2.20; 95% confidence interval [CI]: 2.14–2.27). Variations in the prevalence of current wheezing by school-level characteristics and indicators of school-specific environmental health conditions were less pronounced.

Of the 265 schools, 66 (25%), including 10 518 (18%) surveyed students, were located within 3 miles of at least 1 (range: 1–27) swine CAFO. More than 50% of the schools were within 7 miles of the nearest operation (median: 6.7 miles; range: 0.22–42.0 miles). The average SSLW capacity of operations that were located within 3 miles of a school was slightly lower than that of operations that were located beyond 3 miles (556 283 lb vs 605 139 lb), and, overall, the SSLW capacity of swine CAFOs increased with increasing distance from the nearest surveyed school (β [SE] per mile = 15 948 [4791]). On the basis of the environmental health surveys and according to survey respondents, livestock odor was noticeable outside buildings in 86 (33%) schools and inside the buildings in 39 (15%) schools.

Table 2 presents adjusted PRs for wheezing using each exposure measure separately for students with and without allergies. PRs were 1.05 (95% CI: 1.00–1.10) and 1.02 (95% CI: 0.94–1.11) for adolescents who did and did not have allergies, respectively, and attended schools that were located within 3 miles of the nearest swine CAFO. PRs were approximately unity for schools that were closer than 2 miles, compared with schools with no nearby swine CAFOs, and were 1.12 (95% CI: 1.04–1.19) and 1.08 (95% CI: 0.95–1.21), respectively, for students who did and did not have self-reported allergies and attended schools that were located between 2 and 3 miles from the nearest operation. Associations with SSLW and the weighted SSLW exposure categories also tended to be highest for the low exposure groups and closer to unity for higher exposure groups compared with schools with no nearby swine CAFOs. Basing potential exposure estimates on survey-reported livestock odor resulted in 20 fewer schools' and 3315 fewer adolescents' being considered unexposed. The prevalence of current wheezing was 24% and 21% higher among allergic and nonallergic students, respectively, at schools in which livestock odor was noted inside the school building 2 or more times per month relative to the prevalence at schools without any survey reports of livestock odor.

Table 3 presents adjusted associations between school proximity within 3 miles of a swine CAFO and alternative asthma outcomes as well as functional consequences of asthma-related symptoms. Results indicate that larger proportions of adolescents who attended school near at least 1 swine CAFO experienced respiratory symptoms, physician diagnosis, asthma-related medical treatment, activity limitations, and missing school because of their symptoms. In the population of all students, the largest PRs were observed for physician-diagnosed asthma (PR: 1.07; 95% CI: 1.01–1.14), medication use (PR: 1.07; 95% CI: 1.00–1.15), and visit to a physician or an emergency department or hospitalization (PR: 1.06; 95% CI: 1.00–1.12). Most associations were slightly higher in adolescents with self-reported allergies; however, the PR for physician-diagnosed asthma was higher among students without (PR: 1.14; 95% CI: 1.01–1.26) compared with those with (PR: 1.06; 95% CI: 0.99–1.12) self-reported allergies. Adjusted associations between these outcomes and the presence

of livestock odor in and around the schools indicate only slightly elevated proportions of wheezing symptoms, physician diagnosis, use of asthma-related medical care, activity limitations, and missed school among students in schools where employees reported noticeable livestock odor (Table 4). When school-level exposures were assigned on the basis of reported livestock odor (Table 4), the PRs for severe wheezing (PR: 1.05; 95% CI: 1.00–1.10) and frequent severe wheezing (PR: 1.06; 95% CI: 0.98–1.14) were higher than when exposure was assigned on the basis of distance to the nearest swine CAFO (severe wheeze, ≤3 miles: 1.02 [95% CI: 0.97–1.07]; frequent severe wheeze, ≤3 miles: 1.01 [95% CI: 0.92–1.09]; Table 3).

DISCUSSION

We observed elevated prevalences of current wheezing among 12- to 14-year-old students who attended public schools near swine CAFOs, especially among students with self-reported allergies. Such associations are plausible, given that swine CAFOs are sources of bioaerosols, endotoxins, and other airborne asthma triggers. The availability of standardized symptom data and the independence of symptom and exposure data strengthen confidence in the validity of our findings. Overall, estimates of excess current wheezing symptoms among students who attended schools nearby swine CAFOs are as high as 24% among students who attended schools where livestock odor was reported outside as well as inside 2 or more times per month. Excess prevalence of current wheezing tended to be greater among students who reported allergies. Although the majority of the estimates are small in relative terms, the increases are important in absolute terms because of the high prevalence of asthma-related symptoms in this age group; the impact that symptoms have on adolescents' ability to attend school and participate in social, recreational, and physical activities; and the costs and burdens of symptom-related medical care. In these data, the effect estimates for swine CAFO exposures are of similar magnitude to the effects that have been estimated for established risk factors for wheeze, such as age, race, gender, economic status, Hispanic ethnicity, exposure to secondhand cigarette smoke, and use of a gas stove at home.

We estimated potential exposure on the basis of distance and a mailed survey. Although distance is a crude measure of exposure, our findings suggest a consistent trend toward higher symptom prevalence, especially among adolescents with allergies, at schools that were between 2 and 3 miles of a swine CAFO. The finding that schools that were located within 2 miles had a lower prevalence of current wheezing may reflect the lack of a direct relationship between exposure to etiologically active agents and distance. Use of distance and SSLW as exposure measures does not take account of waste management and sanitation practices of swine CAFOs, ages and conditions of the facilities' equipment, localized weather patterns, topography surrounding the school, school building structure, and ventilation practices, all of which may affect the quantity and the duration of the exposures. In addition, swine CAFO practices such as waste and sanitation procedures may be influenced by population density, land availability, and other features of the communities in which the operations are located, although we do not know the extent to which this occurs. Indeed, results of analyses that used exposure metrics of increasing complexity failed to show a monotonic dose-response relationship between the exposure and current wheezing, further suggesting that if the exposure is associated with an increase in respiratory

symptoms, then relevant exposure may not correlate directly with the factors that we used for our distance-based exposure categories.

The higher prevalence of current wheezing among students who attended schools that were located 2 to 3 miles from the nearest swine CAFO compared with the prevalence among students who attended schools within 2 miles also may be attributable to exposures that were experienced at home, in the communities where students lived, and in other locations that could not be assessed in our study. In many of the rural areas in North Carolina, students may live many miles from the public schools that they attend. As the distance between the school and the CAFO becomes small, few homes can be equally close or closer to a CAFO; as the distance increases, more of the students' homes can be located closer to a CAFO than the distance between the CAFO and the school, and school-based exposure estimates will underestimate students' total swine CAFO exposures. In addition, reports of odor from swine CAFOs tend to be more common in early morning and evening hours rather than in the daytime, when students are in school. Although this phenomenon may not affect exposures in geographic areas where both schools and homes are far from CAFOs, identifying exposure as the distance between a school and a CAFO may be more problematic in regions where schools are located very near or within several miles of CAFOs if exposure varies throughout the day. Previous research that was conducted in a rural population of school-aged children who may have experienced swine farm exposures at home indicated a higher prevalence of asthma-related symptoms among children who lived on farms where swine were raised than among children who lived on farms where swine were not raised and among children who did not live on farms,[29] although the extent to which exposures that resulted from residence on a swine farm were attributable to performing chores or occupation-like tasks, rather than simply living close to swine, are unknown. Although information about adolescents' household farming exposures are unavailable in our study population, the majority of swine in North Carolina are raised in nonresidential, factory farm settings; therefore, the proportion of children who perform chores or live on swine farms is expected to be low.

Results of analyses of the distance-based measures of each exposure suggest lower prevalence of wheezing among students who attended schools that were located nearest to CAFOs and located in areas with the highest density of swine compared with those in the highest exposure categories. To assess potential misclassification of exposure, we excluded from all analyses schools with reported livestock odor from the unexposed distance-based categories, schools that were located beyond 3 miles of swine CAFO from the exposed survey-based categories, and schools for which survey respondents specifically identified livestock odor as arising from poultry and found no notable differences in the direction, magnitude, or precision of the PRs generated. An alternative explanation for the lower prevalence of wheezing among students in schools that were located nearby swine CAFOs may be the hygiene hypothesis, which postulates that early-life exposures and childhood infections may confer protection against hay fever, atopy, and asthma.[30,31] Specifically, rural living and early-life exposures to allergens, irritants, and other bioaerosols on farms may be associated with lower rates of atopy and asthma.[29,32–38] In our study, the prevalence of wheezing was slightly lower (−1.2%) in rural compared with non-rural schools. Although we could not assess early-life exposures, higher exposures to animal dander and bacterial

endotoxin during early developmental stages among individuals who attend schools closest to swine CAFOs and therefore often live in rural areas could provide some resistance to exposures later in childhood and lead to lower prevalence of wheezing during adolescence compared with students who attend schools farther away.

Twenty-one percent (n = 72) of schools were excluded from our final analysis because of nonparticipation in our mailed survey about in-school environmental conditions. When we compared the populations of schools that participated and those that did not, we found differences in mean distance to the nearest swine CAFO (participating schools: 8.7 miles; nonparticipating schools: 8.0 miles), percentage of nonwhite enrollment (participating schools: 36%; nonparticipating schools: 42%), and percentage of enrolled students who received subsidized school lunches (participating schools: 48%; nonparticipating schools: 51%). Systematic differences between participating and nonparticipating schools in levels of exposure and prevalences of asthma-related symptoms could have influenced our findings.

We received up to 7 completed surveys per school, and for each survey question, we assigned an exposure to a school when any respondent indicated the presence of the exposure. This method of classifying schools' environmental conditions and, in particular, the presence of livestock odor at the school was sensitive to the number of surveys completed and returned from each school and did not take into account the variation in survey responses from a single school. Our intention was to survey employees in several occupations who would be familiar with different aspects of the school building and students' behaviors: teacher, administrator, maintenance or custodial staff, and school nurse or health care personnel. Previous literature about the economic, political, and social impacts of a strong swine industry presence in communities in Iowa and North Carolina suggested that residents who live near swine CAFOs may be reluctant to voice their concerns for fear of social ostracism or conflict in their communities.[39–42] Although our school survey was anonymous and designed to minimize risks for deductive disclosure of respondents' identities, we recognize the possibility that respondents may have underreported livestock odor out of concern for expressing their opinions, and we cannot know fully the extent to which our survey reports were influenced by the social and political context in the communities in which the schools were located.

Lack of data on medical risk factors, environmental asthma triggers, and classification of allergic status on the basis of survey reports rather than of a clinical assessment of atopy are limitations of this study. Because students self-identified asthma-related symptoms, our current wheezing variable may include other respiratory symptoms that the respondents experience and mistake for the symptoms that were illustrated in the video scenes. Cross-sectional asthma-related symptom data and survey-based exposure data prohibit specific assessment of temporal relationships between the symptoms and exposures evaluated here. Our findings are vulnerable to systematic error if students with asthma-related symptoms changed their environments or behaviors because of symptoms that were caused by exposure to airborne pollution that arose from swine CAFOs; such a systematic error would lead to underestimation of associations between swine CAFOs and asthma symptoms.

CONCLUSIONS

This research was designed to estimate exposures to a source of air pollution that is of great concern to swine CAFO neighbors and to investigate relationships between school exposures and respiratory health of middle school–aged children. Our findings identify a plausible association between exposure to airborne pollution from swine CAFOs and wheezing symptoms among adolescents. Environmental pollution measurement and standardized clinical information about asthma symptoms and atopic status could help to determine better the magnitude and the temporality of the relationships between swine CAFO emissions and respiratory symptoms. Our findings should be used by public health personnel who are interested in understanding possible adverse respiratory health consequences of an important rural environmental exposure.

Acknowledgments

Funding for this research was provided by the National Institutes of Health (NIH), National Heart, Lung, and Blood Institute (1R01HL073113); NIH National Institute of Environmental Health Sciences (2R25ES008206); and the American Lung Association (LH007N).

Abbreviations

CAFO	confined animal feeding operation
PR	prevalence ratio
NCSAS	North Carolina School Asthma Survey
SSLW	steady-state live weight
CI	confidence interval

References

1. Thu KM. Piggeries and politics: rural development and Iowa's multibillion dollar swine industry. Cult Agric. 1995; 53:19–23.
2. Wing S, Wolf S. Intensive livestock operations, health, and quality of live among Eastern North Carolina residents. Environ Health Perspect. 2000; 108:233–238. [PubMed: 10706529]
3. Wing S, Cole D, Grant G. Environmental injustice in North Carolina's hog industry. Environ Health Perspect. 2000; 108:225–231. [PubMed: 10706528]
4. Donham KJ, Thu KM. Relationships of agricultural and economic policy to the health of farm families, livestock, and the environment. J Am Vet Med Assoc. 1993; 202:1084–1091. [PubMed: 8473219]
5. Vogelzang PF, van der Gulden JW, Folgering H, Heederik D, Tielen MJ, van Schayck CP. Longitudinal changes in bronchial responsiveness associated with swine confinement dust exposure. Chest. 2000; 117:1488–1495. [PubMed: 10807840]
6. Vogelzang PF, van der Gulden JW, Folgering H, et al. Endo-toxin exposure as a major determinant of lung function decline in pig farmers. Am J Respir Crit Care Med. 1998; 157:15–18. [PubMed: 9445272]
7. Vogelzang PFJ, van der Gulden JWJ, Preller L, Heederik D, Tielen MJM, van Schayck CP. Respiratory morbidity in relationship to farm characteristics in swine confinement work: possible preventive measures. Am J Ind Med. 1995; 30:212–218. [PubMed: 8844052]
8. Radon K, Weber C, Iversen M, Danuser B, Pedersen S, Nowak D. Exposure assessment and lung function in pig and poultry farmers. Occup Environ Med. 2001; 58:405–410. [PubMed: 11351057]

9. Heederik D, Brouwer R, Biersteker K, Boleij JS. Relationship of airborne endotoxin and bacteria levels in pig farms with the lung function and respiratory symptoms of farmers. Int Arch Occup Environ Health. 1991; 62:595–601. [PubMed: 1856016]
10. Haglind P, Rylander R. Occupational exposure and lung function measurements among workers in swine confinement buildings. J Occup Med. 1987; 29:904–907. [PubMed: 3681501]
11. Dosman JA, Senthilselvan A, Kirychuk SP, et al. Positive human health effects of wearing a respirator in a swine barn. Chest. 2000; 118:852–860. [PubMed: 10988215]
12. Donham K, Rubino M, Thedell T, Kammermeyer J. Potential health hazards to agricultural workers in swine confinement buildings. J Occup Med. 1977; 19:383–387. [PubMed: 559729]
13. Thu K, Donham K, Ziegenhorn R, et al. A control study of physical and mental health of residents living near a large-scale swine operation. J Agric Saf Health. 1997; 3:13–26.
14. Thu KM. Public health concerns for neighbors of large-scale swine production operations. J Agric Saf Health. 2002; 8:175–184. [PubMed: 12046804]
15. Schiffman SS, Miller EA, Suggs MS, Graham BG. The effect of environmental odors emanating from commercial swine operations on the mood of nearby residents. Brain Res Bull. 1995; 37:369–375. [PubMed: 7620910]
16. Sotir M, Yeatts K, Shy C. Presence of asthma risk factors and environmental exposures related to upper respiratory infection-triggered wheezing in middle school-age children. Environ Health Perspect. 2003; 111:657–662. [PubMed: 12676631]
17. International Study of Asthma and Allergies in Childhood (ISAAC) Steering Committee. [Accessed December 21, 2005] ISAAC Manual. 2Dec. 1993 Available at: isaac.auckland.ac.nz/PhaseOne/Manual
18. Shaw RA, Crane J, Pearce N, et al. Comparison of a video questionnaire with the IUATLD written questionnaire for measuring asthma prevalence. Clin Exp Allergy. 1992; 22:561–568. [PubMed: 1628254]
19. Yeatts K, Davis KJ, Sotir M, Herget C, Shy C. Who gets diagnosed with asthma? Frequent wheeze among adolescents with and without a diagnosis of asthma. Pediatrics. 2003; 111:1046–1054. [PubMed: 12728087]
20. Yeatts K, Shy C, Wiley J, Music S. Statewide adolescent asthma surveillance. J Asthma. 2000; 37:425–443. [PubMed: 10983620]
21. Sturm JJ, Yeatts K, Loomis D. Effects of tobacco smoke exposure on asthma prevalence and medical care use in North Carolina middle school children. Am J Public Health. 2004; 94:308–313. [PubMed: 14759947]
22. Yeatts K, Johnston Davis K, Peden D, Shy C. Health consequences associated with frequent wheezing in adolescents without asthma diagnosis. Eur Respir J. 2003; 22:781–786. [PubMed: 14621085]
23. Yeatts K, Shy C, Sotir M, Music S, Herget C. Health consequences for children with undiagnosed asthma-like symptoms. Arch Pediatr Adolesc Med. 2003; 157:540–544. [PubMed: 12796233]
24. Wing S, Freedman S, Band L. The potential impact of flooding on confined animal feeding operations in eastern North Carolina. Environ Health Perspect. 2002; 110:387–391. [PubMed: 11940456]
25. Goldberg MS, Siemiatyck J, DeWar R, Desy M, Riberdy H. Risks of developing cancer relative to living near a municipal solid waste landfill site in Montreal, Quebec, Canada. Arch Environ Health. 1999; 54:291–296. [PubMed: 10433189]
26. Sinnott RW. Virtues of the Haversine. Sky Telescope. 1984; 68:159.
27. Singer J. Using SAS PROC MIXED to fit multilevel models, hierarchical models, and individual growth models. J Educ Behav Stat. 1998; 24:323–355.
28. McLeod, A. Multivariate multilevel models. In: Leyland, AH.; Goldstein, H., editors. Multilevel Modelling of Health Statistics. New York, NY: Wiley; 2001. p. 59-73.
29. Merchant JA, Naleway AL, Svendsen ER, et al. Asthma and farm exposures in a cohort of rural Iowa children. Environ Health Perspect. 2005; 113:350–356. [PubMed: 15743727]
30. von Mutius E. Influences in allergy: epidemiology and the environment. J Allergy Clin Immunol. 2004; 113:373–379. [PubMed: 15007331]

31. Strachan DP. Family size, infection and atopy: the first decade of the “hygiene hypothesis”. Thorax. 2000; 55(suppl 1):S2–S10. [PubMed: 10943631]
32. Ernst P, Cormier Y. Relative scarcity of asthma and atopy among rural adolescents raised on a farm. Am J Respir Crit Care Med. 2000; 161:1563–1566. [PubMed: 10806155]
33. von Ehrenstein OS, von Mutius E, Illi S, Baumann L, Bohm O, von Kries R. Reduced risk of hay fever and asthma among children of farmers. Clin Exp Allergy. 2000; 30:187–193. [PubMed: 10651770]
34. Riedler J, Braun-Fahrlander C, Eder W, et al. Exposure to farming in early life and development of asthma and allergy: a cross-sectional survey. Lancet. 2001; 358:1129–1133. [PubMed: 11597666]
35. Ownby DR, Johnson CC, Peterson EL. Exposure to dogs and cats in the first year of life and risk of allergic sensitization at 6 to 7 years of age. JAMA. 2002; 288:963–972. [PubMed: 12190366]
36. Braun-Fahrlander C, Riedler J, Herz U, et al. Environmental exposure to endotoxin and its relation to asthma in school-age children. N Engl J Med. 2002; 347:869–877. [PubMed: 12239255]
37. Chrischilles E, Ahrens R, Kuehl A, et al. Asthma prevalence and morbidity among rural Iowa schoolchildren. J Allergy Clin Immunol. 2004; 113:66–71. [PubMed: 14713909]
38. Elliott L, Yeatts K, Loomis D. Ecological associations between asthma prevalence and potential exposure to farming. Eur Respir J. 2004; 24:938–941. [PubMed: 15572535]
39. Greenberg DS. Conference deplores corporate influence on academic science. Speakers argue that corporate funds should be separated from science to prevent undue influence. Lancet. 2003; 362:302–303. [PubMed: 12894798]
40. Thu, KM.; Durrenberger, EP.; Schiffman, SS.; Morgan, R. Pigs, Profits, and Rural Communities. Albany, NY: State University of New York Press; 1998.
41. Thu KM. Agriculture, the environment, and sources of state ideology and power. Cult Agric. 2001; 23:1–7.
42. Wing S, Grant G, Green M, Stewart C. Community based collaboration for environmental justice: south-east Halifax environmental reawakening. Environ Urban. 1996; 8:129–140.

TABLE 1

Characteristics of North Carolina School Asthma Survey Participants and Public Schools in North Carolina

	N	Students Who Reported Current Wheezing, *n* (%)	PR (95% CI)[a]
Total	58 169	15 250 (26.2)	—
Age, y[b]			
12	17 905	4873 (27.2)	1.06 (1.04–1.08)
13	28 130	7268 (25.8)	1.00[c]
14	12 134	3109 (25.6)	0.95 (0.93–0.96)
Race			
White	43 590	10 919 (25.1)	1.00
Black	14 579	4331 (29.7)	1.04 (1.01–1.08)
Gender			
Male	28 342	6798 (24.0)	1.00
Female	29 827	8452 (28.3)	1.07 (1.04–1.10)
SES indicator			
Lunch not subsidized	41 719	10 088 (24.2)	1.00
Lunch subsidized	16 450	5162 (31.4)	1.16 (1.12–1.20)
Hispanic ethnicity			
No	54 827	14 236 (26.0)	1.00
Yes	3342	1014 (30.3)	1.11 (1.06–1.16)
Allergies			
No	31 480	5149 (16.4)	1.00
Yes	26 689	10 101 (37.9)	2.20 (2.14–2.27)
Ever smoked			
No	40 632	9154 (22.5)	1.00
Yes	17 537	6096 (34.8)	1.35 (1.31–1.39)
No. of other smokers in household[b]			
0	27 662	6138 (22.2)	1.00
1	16 079	4447 (27.7)	1.09 (1.07–1.10)
2	10 209	3178 (31.1)	1.18 (1.15–1.21)
≥3	4219	1487 (35.3)	1.29 (1.24–1.34)
Frequency of gas kitchen stove use			
Less than once per more	45 546	11 384 (25.0)	1.00
Once per month or more	12 623	3866 (30.6)	1.14 (1.11–1.17)
Rural school locale			
No	30 154	8074 (26.8)	1.00
Yes	28 015	7076 (25.6)	0.96 (0.92–1.00)
In-school asthma triggers[d]			
No	4619	1147 (24.8)	1.00
Yes	53 550	14 103 (26.3)	1.03 (0.95–1.11)
Location near non-livestock industry[e]			

	N	Students Who Reported Current Wheezing, *n* (%)	PR (95% CI)[a]
No	52 184	13 603 (26.1)	1.00
Yes	5985	1647 (27.5)	1.06 (0.99–1.13)

PR indicates prevalence ratio; SES, socioeconomic status.

[a] Adjusted for all individual-level and school-level covariates in the table.

[b] Included in the model as a continuous variable.

[c] Referent category.

[d] Environmental Health Survey responses about cockroaches, rodents, mold, and/or flooding in school buildings (no: 24 schools; yes: 241 schools).

[e] Environmental Health Survey responses about non-livestock industries located near the school (No: 236 schools; Yes: 29 schools).

TABLE 2

Associations Between the Prevalence of Wheezing and Exposure to Confined Swine Feeding Operations by Adolescents' Self-Reported Allergic Status, North Carolina

	Total No. of Schools	Self-Reported Allergies (n = 26 689)			No Self-Reported Allergies (n = 31 480)			All (N = 58 169)		
		Total No. of Students	Wheeze, n (%)[a]	PR (95% CI)[b]	Total No. of Students	Wheeze, n (%)	PR (95% CI)[b]	Total No. of Students	Wheeze, (%)	PR (95% CI)[c]
Current wheeze			10 101 (37.9)			5149 (16.4)			15 250 (26.2)	
Miles to nearest swine CAFO										
>3	199	21 898	8145 (37.2)	1.00	25 753	4138 (16.1)	1.00	47 651	12 283 (25.8)	1.00
≤3	66	4791	1956 (40.8)	1.05 (1.00–1.10)	5727	1011 (17.7)	1.02 (0.94–1.11)	10 518	2967 (28.2)	1.04 (0.99–1.09)
2 to ≤3	22	1865	822 (44.1)	1.12 (1.04–1.19)	2107	396 (18.8)	1.08 (0.95–1.21)	3972	1218 (30.7)	1.10 (1.02–1.18)
≤2	44	2926	1134 (38.8)	1.01 (0.95–1.07)	3620	615 (17.0)	0.99 (0.89–1.09)	6546	1749 (26.7)	1.01 (0.95–1.07)
Hog pounds (in millions) within 3 miles of school										
None	199	21 898	8145 (37.2)	1.00	25 753	4138 (16.1)	1.00	47 651	12 283 (25.8)	1.00
0.1 to <2.0	42	3342	1388 (41.5)	1.07 (1.01–1.12)	4017	713 (17.8)	1.03 (0.93–1.12)	7359	2101 (28.6)	1.05 (1.00–1.11)
2.0 to <5.0	12	733	294 (40.1)	1.04 (0.93–1.14)	858	150 (17.5)	0.99 (0.81–1.16)	1591	444 (27.9)	1.01 (0.91–1.12)
≥5.0	12	716	274 (38.3)	1.00 (0.89–1.11)	852	148 (17.4)	1.04 (0.85–1.23)	1568	422 (26.9)	1.02 (0.91–1.13)
Exposure category										
None	199	21 898	8145 (37.2)	1.00	25 753	4138 (16.1)	1.00	47 651	12 283 (25.8)	1.00
Low	21	1655	711 (43.0)	1.10 (1.03–1.18)	1922	359 (18.7)	1.09 (0.95–1.23)	3577	1070 (29.9)	1.09 (1.01–1.18)
Medium	22	1741	771 (40.8)	1.04 (0.97–1.12)	2139	378 (17.7)	1.01 (0.89–1.13)	3880	1089 (28.1)	1.03 (0.96–1.11)
High	23	1395	534 (38.3)	1.01 (0.93–1.08)	1666	274 (16.5)	0.97 (0.84–1.10)	3061	808 (26.4)	1.00 (0.92–1.08)
Livestock odor										
None	179	19 055	7188 (37.7)	1.00	22 438	3694 (16.5)	1.00	41 493	10 882 (26.2)	1.00
Outside school only	47	4625	1766 (38.2)	1.04 (0.98–1.09)	5593	843 (15.1)	0.94 (0.85–1.02)	10 218	2609 (25.5)	1.00 (0.95–1.06)
Outside + inside <2 times/mo	36	2745	1022 (37.2)	0.99 (0.93–1.06)	3137	550 (17.5)	1.04 (0.93–1.15)	5882	1572 (26.7)	1.01 (0.94–1.07)
Outside + inside ≥2 times/mo	3	264	125 (47.4)	1.24 (1.03–1.44)	312	62 (19.9)	1.21 (0.85–1.57)	576	187 (32.5)	1.23 (1.01–1.44)

[a] Any wheeze in the past 12 months (current wheeze).

[b] Adjusted for individual-level characteristics (gender, age, race, Hispanic ethnicity, economic status, smoking status, exposure to second-hand smoke at home, and use of a gas stove more than once per month) and school-level characteristics (rural locale, indoor air quality, and reports of other non-livestock industries nearby).

[c] Adjusted for variables listed above plus self-reported allergy to cats, dogs, dust, grass, and/or pollen.

TABLE 3

Associations Between the Prevalence of Asthma-Related Symptoms and School Location Within 3 Miles of a Confined Swine Feeding Operation by Adolescents' Self-Reported Allergic Status, North Carolina

	PR (95% CI) for ≤3 vs >3 Miles From Nearest Swine CAFO		
	Self-Reported Allergies (*n* = 26 689)	**No Self-Reported Allergies (*n* = 31 480)**	**All (*N* = 58 169)**
Wheezing symptoms			
Current wheeze	1.05 (1.00–1.10)	1.02 (0.94–1.11)	1.04 (0.99–1.09)
Current wheeze without physician diagnosis	1.08 (1.01–1.15)	0.99 (0.90–1.08)	1.04 (0.98–1.11)
Severe wheeze[b]	1.01 (0.96–1.07)	1.05 (0.96–1.14)	1.02 (0.97–1.07)
Frequent severe wheeze[a]	1.02 (0.92–1.11)	0.97 (0.80–1.14)	1.01 (0.92–1.09)
Physician-diagnosed asthma	1.06 (0.99–1.12)	1.14 (1.01–1.26)	1.07 (1.01–1.14)
Medical care			
Asthma-related physician visit, emergency visit, and/or hospitalization in past year	1.06 (1.00–1.13)	1.03 (0.92–1.13)	1.06 (1.00–1.12)
Asthma medication use in past year	1.09 (1.00–1.18)	1.03 (0.88–1.18)	1.07 (1.00–1.15)
Functional consequences of symptoms			
Activity limitations in past year as a result of asthma symptoms	1.09 (1.01–1.16)	__[b]	—
Missed school in past year as a result of asthma symptoms	1.06 (0.98–1.14)	—	—

[a] Among individuals with current wheeze.

[b] Nonconvergent model.

TABLE 4

Associations Between the Prevalence of Asthma-Related Symptoms and the Presence of Livestock Odor at the School by Adolescents' Self-Reported Allergic Status, North Carolina

	PR (95% CI) for Livestock Odor Reported Outside or Inside School Building Versus No Reported Odor		
	Self-Reported Allergies (*n* = 26 689)	**No Self-Reported Allergies (*n* = 31 480)**	**All (*N* = 58 169)**
Wheezing symptoms			
Current wheeze	1.03 (0.98–1.07)	0.99 (0.91–1.06)	1.01 (0.97–1.06)
Current wheeze without physician diagnosis	1.04 (0.97–1.10)	0.99 (0.90–1.07)	1.01 (0.96–1.07)
Severe wheeze[a]	1.06 (1.01–1.12)	1.00 (0.91–1.08)	1.05 (1.00–1.10)
Frequent severe wheeze[a]	1.04 (0.95–1.14)	1.10 (0.92–1.28)	1.06 (0.98–1.14)
Physician-diagnosed asthma	1.00 (0.94–1.06)	1.04 (0.93–1.15)	1.01 (0.95–1.06)
Medical care			
Asthma-related physician visit, emergency visit, and/or hospitalization in past year	0.99 (0.94–1.05)	1.01 (0.91–1.10)	1.00 (0.95–1.05)
Asthma medication use in past year	1.03 (0.96–1.11)	1.02 (0.89–1.15)	1.03 (0.96–1.10)
Functional consequences of symptoms			
Activity limitations in past year as a result of asthma symptoms	1.02 (0.96–1.08)	—[b]	—
Missed school in past year as a result of asthma symptoms	1.02 (0.94–1.09)	—	—

[a] Among individuals with current wheeze.

[b] Nonconvergent model.