Acute Respiratory Health in Students Attending Middle Schools Near Concentrated Animal Feeding Operations

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Abstract

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Residents near concentrated animal feeding operations (CAFOs) have expressed concern about effects from associated air pollutants. Previous cross-sectional studies have found increased prevalence of asthma and wheezing among children who attend school near CAFOs.

The Rural Air Pollutants and Children's Health (RAPCH) study used a school-based, longitudinal design to investigate acute respiratory responses in children attending public middle schools near CAFOs in eastern North Carolina. We conducted five sequential waves of data collection at three middle schools in February-November 2009. Each day in science class for 3-5 weeks, students completed a structured diary reporting current symptoms and recent odor observations, then measured their pulmonary function. We measured hydrogen sulfide (H_2S) and particulate matter less than 10µm in diameter (PM_{10}) at two locations: inside a participating classroom and outside the school building. The participatory protocol was designed to provide positive side effects for participants; process evaluation results from interviews with staff in May-June 2010 indicated benefits including increased interest in science, hands-on learning, and environmental awareness.

340 participants (95% participation) generated 5728 diary records (median=17). We used conditional linear fixed effects models to estimate within-person associations between air pollutant measures (12hr livestock odor, morning livestock odor, 12hr mean

H_2S, morning H_2S, 12hr mean PM_{10}, and morning PM_{10}) and pulmonary function parameters (peak expiratory flow and forced expiratory volume in one second). There were substantial within-person decreases in pulmonary function over time-in-study. We found unexpected positive associations in unstratified analyses and larger beta coefficients with greater precision among students reporting wheeze at baseline. In analyses stratified by Week 1 versus Weeks 2-5 to control for time-in-study, we observed small beta coefficients with poor precision for all models.

The RAPCH study had a positive impact on participants and their communities. We found minimal effects of airborne exposures from CAFOs on measured pulmonary function, however time-correlated measurement error, exposure definitions, or additional time-varying confounders may have obscured effects. Future analyses will examine symptom outcomes and explore the use of these data in cross-sectional designs to further characterize the potential impacts of air pollutants from CAFOs on children's respiratory health.

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List of Abbreviations

ATS	American Thoracic Society
ATSDR	Agency for Toxic Substances and Disease Registry
CAFO	Concentrated animal feeding operation
CBPR	Community-based participatory research
CFR	Code of Federal Registry
CH_4	Methane
CHEIHO	Community Health Effects of Industrial Hog Operations
CO_2	Carbon dioxide
DustTrak	DustTrak Aerosol Monitor
FDA	United States Food and Drug Administration
FEV_1	Forced expiratory volume in one second
H_2S	Hydrogen sulfide
hr	Hour
ID	Identification
IRB	Institutional Review Board
ISAAC	International Study of Asthma and Allergies in Childhood
km	kilometers
L	liters
L/min	Liters per minute
L/s	Liters per second
M	meters
mi	miles
MWD	Mini-Wright Digital peak flow meter
NAEPP	National Asthma Education and Prevention Program

NC	North Carolina
NCDA & CS	North Carolina Department of Agriculture and Consumer Services
NH_3	Ammonia
NH_4^+	Ammonium
NRC	National Research Council
PEF	Peak expiratory flow
PM	Particulate matter
PM_{10}	Particulate matter less than 10µm in aerodynamic diameter
$PM_{2.5}$	Particulate matter less than 2.5µm in aerodynamic diameter
ppb	Parts per billion
ppm	Parts per million
RAPCH	Rural Air Pollutants and Children's Health
REACH	Rural Empowerment Association for Community Help
SE	Standard error
sIgA	Secretory immunoglobulin A
SPM	MDA Single Point Monitor
Thermo	Thermo Hydrogen Sulfide - Sulfur Dioxide Analyzer
UK	United Kingdom
UNC	University of North Carolina Gillings School of Global Public Health
US	United States
USDA	United States Department of Agriculture

Chapter I

Introduction & Specific Aims

Industrial livestock production has emerged as a significant source of rural air pollution as numbers of concentrated animal feeding operations (CAFOs) have grown in recent decades. In eastern North Carolina (NC), the increase in CAFOs has placed agricultural livelihoods at odds with public health and enjoyment of rural life. Airborne emissions from confinement barns, voluminous quantities of manure, and frequent manure spraying or spreading reduce air quality and produce intermittent strong odors in surrounding communities. Children may be especially vulnerable to respiratory health insults and exposures may occur at schools they are required to attend. Previous research has suggested an association between school proximity to swine CAFOs and prevalence of wheeze symptoms and asthma (Mirabelli et al. 2006a; Sigurdarson & Kline 2006).

We conducted a longitudinal study comparing reported odors and air pollution measurements at schools with lung function measurements from participating students. We planned the study in collaboration with the community-based Rural Empowerment Association for Community Help (REACH) and sought ways to create positive side effects of data collection. During five waves of data collection lasting 3-5 weeks, we used air pollution monitors to measure indoor and outdoor hydrogen sulfide (H_2S) and particulate matter less than 10µm in aerodynamic diameter (PM_{10}) at schools. Each day in science class, participating students recorded odor observations and symptoms in structured diaries then measured their pulmonary function. To supplement science curricula, we discussed air pollution and respiratory health with the students, demonstrated instruments, and provided an opportunity to interpret preliminary results at the conclusion of data collection. REACH involvement generated further potential for ripple effects in the community.

The data collected will be used to address the following specific aims:

1) Document the rationale for designing a participatory epidemiologic study that intends to provide positive side effects to the participants and their broader communities, including:
    a. Describing our approach in the context of most epidemiologic studies which are designed to minimize side effects on study participants;
    b. Illustrating this rationale with the Rural Air Pollutants and Children's Health study as an example of a collaborative effort to enhance the benefits of an epidemiologic study;
    c. Presenting results of a process evaluation to document observed benefits and drawbacks;
    d. Discussing how our approach can increase the potential for future epidemiologic studies to improve public health.

This aim is intended to produce a methodological article that shares our study design rationale with epidemiologists and others involved in public health research.

2) Determine whether exposure to variation in air pollutants is associated with pulmonary function over time by:
    a. Quantifying associations between levels of PM_{10}, H_2S, and odor and measured pulmonary function parameters;

b. Evaluating whether observed effects are modified by allergies, chronic respiratory health status at baseline, home exposure to livestock, or exposure to smoking.

We hypothesize that increases in CAFO-related air pollutants will be associated with reduced lung function. We also hypothesize that stronger effects will be observed for children with allergies, chronic respiratory symptoms, frequent exposure to livestock, and frequent smoking exposure. This aim is intended to produce a scientific manuscript presenting the results.

The dissertation is organized as follows. After the introduction and description of specific aims, a literature review describes CAFOs in NC, summarizes previous studies of community health impacts from CAFO air pollutants, and highlights opportunities for improving upon these previous studies. The third chapter is written as a manuscript documenting the design and implementation of our data collection methods that includes results from the process evaluation conducted post-data collection. The fourth chapter presents results from quantitative analyses of markers of airborne exposures from CAFOs and pulmonary function outcomes. I then provide a discussion in the final chapter that reflects upon the presented research, describes potential future analyses, and considers public health implications of these results.

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Chapter II

Literature Review

Urban and Rural Air Pollutants

Most studies of health impacts from exposure to air pollution have been conducted in urban settings. An extensive literature provides evidence of acute and chronic health effects from urban pollutants, especially particulate matter, on mortality, cardiovascular health, and respiratory health (Dockery & Pope 1994; Chen & Kan 2008; Jerrett et al. 2009; Pelucchi et al. 2009; Brook & Rajagopalan 2010; Sun et al. 2010; Searing & Rabinovitch 2011). Urban air pollution is commonly composed of particulate matter, ozone, oxides of nitrogen and sulfur, carbon monoxide, and carbon dioxide produced by vehicle emissions, fuel combustion for heating or electricity generation, and other industrial processes (Chen & Kan 2008). Less is known about the composition and effects of air pollution in rural areas. While sources of fossil fuel combustion are found less densely than in urban areas, there are unique industrial contributors such as agricultural facilities, rendering plants for livestock, open burning, landfills, pulp and paper mills, and graineries.

Concentrated Animal Feeding Operations (CAFOs) in North Carolina

In rural eastern North Carolina, one key source of air pollution is concentrated animal feeding operations (CAFOs) used for raising livestock. CAFOs are defined by U.S. federal regulations as facilities that 1) confine animals for at least 45 days in any 12 month period, 2) don’t contain any crops or vegetation for foraging, thus requiring delivered feed to sustain the animals, and 3) exceed a threshold number of animals, e.g., >750 hogs weighing at least 55 pounds or >16,500 turkeys (CFR 2010). The need for regulations has arisen following the drastic consolidation of agriculture that has occurred over the past three decades and the accompanying waste management challenges. This shift is exemplified by hog production in North Carolina (Table 2.1).

Table 2.1. Shift in NC hog production from 1978-2007

Year	Number of Operations	Number of Hogs and Pigs Sold
1978	15,737	3.4 million
2007	2,459	43.2 million

Source: USDA 2009

Agriculture and associated businesses compose the top industry statewide (NCDA&CS 2010). North Carolina is a nationally ranked livestock producer, with inventories (total counts of animals on farms at one point in time) listed in the top five states for hogs, turkeys, and broiler chickens (Table 2.2). Though ranked fifth nationally, broiler production represents the largest proportion of North Carolina farm income at 26.4% (NCDA&CS 2010). As a demonstration of the previously described consolidation, more than 96% of the 43.2 million hogs produced in 2007 were from operations with more than 1,000 animals (USDA 2009). Additionally, CAFOs in North Carolina are mainly located in the eastern coastal plain with further concentration in two counties which house nearly half of North Carolina's pork (4.2 million hogs) and over half of the turkeys (19.3 million) (NCDA&CS 2010). Thus, the environmental and public health burdens of CAFOs excessively affect certain regions. Several studies have documented that swine CAFOs are disproportionately located in communities of color and economically depressed communities in eastern North Carolina (Wing et al. 2000, Mirabelli et al. 2006b).

Table 2.2. NC Livestock Inventory and National Rank for 2009

Type of Livestock	Number of Animals	National Rank	% of US Production
Hogs & Pigs	9.6 million	2	14.8
Turkeys	35.5 Million	2	14.4
Broilers	760 Million	5	8.9

Source: NCDA&CS 2010

As the numbers of CAFOs have increased, so has public concern about health impacts from air pollutants generated by intensive livestock production. In North Carolina, liquid waste management, as used for hogs, typically involves flushing the manure out of the barns into large, open air pits called lagoons, where bacterial decomposition occurs. Periodically, lagoon contents are sprayed on nearby fields using conventional irrigation equipment (NRC 2003). This is done to fertilize the fields and reduce the level of liquid waste in the lagoons. Poultry waste is typically considered "dry" and is handled differently. It is cleaned out of barns between flocks and piled up for storage before being spread on fields (NRC 2003). Airborne contaminants and odor are produced at several stages: ventilation of barns, removing waste from barns, stirring of lagoons, spraying or spreading waste on fields, and evaporation from fields.

It should be noted, however, that the impacts of environmental contamination from CAFOs go beyond respiratory health concerns. Ground and surface water contamination occurs, with specific concerns about microbial pathogens, pharmaceutical chemicals, and excessive nutrient content (Burkholder et al. 2007). There have been documented reductions in the quality of life of nearby residents (Thu et al. 1997; Wing & Wolf 2000; Radon et al. 2004). There is worry about lowered property values and reduced appeal for new industries in areas with significant numbers of CAFOs. CAFOs provide a reservoir for known infectious diseases, e.g. Methicillin-resistant *Staphylococcus aureus* (Smith et al. 2009), and there is concern about development of novel diseases such as influenza viruses (Saenz et al. 2006). There is also growing concern about reproductive impacts from exposure to endocrine disrupting chemicals (animal estrogens) in livestock waste via contaminated water supplies (Hanselman et al. 2003). Hormones are naturally occurring and widely administered in CAFOs.

Airborne Pollutants & Odor from CAFOs

CAFOs generate a complex mixture of particles and gases that is most concentrated inside confinement structures and near waste lagoons but also migrates offsite to the surrounding communities, where diminished concentrations have been detected (Donham et al. 2006; Wing et al. 2008a). Even at reduced levels, these pollutants contribute to characteristic odors reported by neighbors and represent a public health hazard (Donham et al. 2006; Iowa State University and the University of Iowa Study Group 2002). Emissions and their dispersion are influenced by events within CAFOs (e.g., flushing barns or stirring lagoons) as well as atmospheric conditions.

There are several prominent air pollutants associated with CAFOs, including coarse and fine particulate matter, endotoxins, ammonia, hydrogen sulfide, carbon dioxide, and methane (Cole et al. 2000; Donham et al. 2006). Particulate matter (PM) consists of organic dust (animal feed, fecal matter, and dander) and bioaerosols (bacteria, molds, and endotoxins) (Cole et al. 2000; Iowa State University and the University of Iowa Study Group 2002) and approximately half of the generated particulate matter is smaller than 10μm in aerodynamic diameter (PM_{10}), which can penetrate into the lungs (Donham 2010). Endotoxins, which originate from the external cell wall of gram negative bacteria, are frequently measured separately or in addition to other PM constituents because they can independently elicit a strong respiratory response.

Gaseous emissions typically arise from animal manure. Ammonia (NH_3) is produced when urea is metabolized during urine decomposition. As a gas it is a respiratory irritant but conversion to ammonium (NH_4^+) aerosols also contributes to the formation of fine particulates less than 2.5µm in aerodynamic diameter ($PM_{2.5}$) (Aneja et al. 2008; NRC 2003). Hydrogen sulfide (H_2S) is a naturally occurring strong odorant produced by bacteria during the anaerobic decomposition of animal or plant proteins that can be toxic at very high concentrations, e.g., >500 parts per million (ppm) (ATSDR 2011; Iowa State University and the University of Iowa Study Group 2002). At lower levels, it can irritate mucus membranes in the eyes, nose, and throat, and can cause difficulty breathing, especially among those with asthma. Many people can smell H_2S at concentrations of 1-10 parts per billion (ppb) (ATSDR 2011). Two other significant compounds, carbon dioxide (CO_2) and methane (CH_4), are greenhouse gases, though methane is 25 times more potent. Carbon dioxide is released from decomposing manure and methane is a product of ruminant digestion (Iowa State University and the University of Iowa Study Group 2002). Numerous other gases and volatile organic compounds are emitted in smaller concentrations from CAFOs (Cole et al. 2000; Schiffman et al. 2001; Iowa State University and the University of Iowa 2002).

There are other compounds in addition to hydrogen sulfide that contribute to strong odors from CAFOs, including other sulfur containing compounds, organic acids, and nitrogen containing compounds (Iowa State University and the University of Iowa 2002). Odor detection is a complex process that involves two nerves in the upper respiratory tract: the olfactory nerve, which identifies odorant compounds, and the trigeminal nerve, which responds to irritation and odor strength (Shusterman 1992). The response to irritation can result in the stimulation of several protective reflexes such as cough, runny nose, and even changes in respiratory rate (Shusterman 1992). Throughout the life course, children and young adults have the most sensitive sense of smell (though young adults are better at correctly identifying odors); after young adulthood odor sensitivity declines with age (Lehrner et al. 1999). The effects of odor can be as complex as the process of detection. Effects can manifest in symptoms of irritation, as mentioned above, or if someone has been exposed to high concentrations of an odor that elicited physical effects, odor detection at lower concentrations may elicit the same effects (Schusterman 1992). Additionally, odors have been found to exacerbate asthma (Shim & Williams 1986).

Health Impacts of Airborne Exposures from CAFOs on Adults

We know from occupational studies that CAFO generated air pollutants can be harmful to respiratory health (Donham et al. 1995; Reynolds et al. 1996; Donham et al. 2000; Cole et al. 2000). As with many air pollutants, larger particulates and microorganisms can be removed by the physiologic defenses of the lungs but smaller particles are capable of penetrating deep into the lungs while some gases can be easily inhaled and absorbed (Iowa State University and the University of Iowa 2002).

Multiple cross-sectional studies have documented health impacts of CAFO pollutants on nearby adults. In perhaps the first study of community effects of CAFO exposures, Schiffman et al. found increased mood disturbance and decreased vigor among residents near CAFOs compared to controls (1995). Later studies found higher prevalence of depression reported among adults living <3km from a hog CAFO compared to adults living ≥9km from a hog CAFO (Villeneuve et al. 2009) and decreased emotional health scores associated with odor reports (Radon et al. 2004). Several studies have found excess symptom reports in CAFO neighbors when compared to non-neighbors, including headache, runny nose, sore throat, coughing, diarrhea, burning eyes, nausea, dizziness, shortness of breath, wheezing, and chest tightness (Thu et al. 1997; Wing & Wolf 2000; Bullers 2005). Odor ratings have been associated with decreased physical health scores and increased prevalence of wheeze, asthma, and allergic rhinitis (Radon et al. 2004; Radon et al. 2007). Increased wheeze and decreased lung function have also been associated with residing within 500m of 12+ barns (Radon et al. 2007). One study used a chamber study to measure the difference in response experienced by adult participants when subjected at separate times to clean air and diluted hog barn air. Comparatively, exposure to diluted hog barn air resulted in increased symptom reports (headaches, eye irritation, nausea) plus a decreased percentage of epithelial cells and an increased percentage of lymphocytic cells assessed via nasal lavage (Schiffman et al. 2005).

Two longitudinal studies have also been conducted with adult participants who live near CAFOs. In a small study (N=15), Avery et al. found odor ratings to be associated with decreased concentration and secretion rate of secretory immunoglobulin A (sIgA), an indicator of immunosuppression (2004). A later participatory study with CAFO neighbors called *Community Health Effects of Industrial Hog Operations* (CHEIHO) used instruments to measure particulate matter, endotoxin, and hydrogen sulfide while participants reported odor, symptoms, and lung function in a structured diary over a two week period. Odor reports correlated with measured pollutant concentrations (Wing et al. 2008a). Higher average odor was associated with irritation symptoms (eye, nose, throat, and skin), runny nose, cough, and difficulty breathing. Increased hydrogen sulfide levels were associated with eye irritation, nasal irritation, runny nose, and difficulty breathing. Elevated particulate matter pollution was associated with eye irritation, poor appetite, nausea, difficulty breathing, and wheezing. Higher levels of endotoxin were associated with chest tightness. Although lung function was measured, only fine particulate matter was associated with a decrease substantially greater than its standard error (Schinasi et al. 2011). In this same longitudinal study, elevated levels of semi-volatile particulate matter, hydrogen sulfide, and reported odor from hog CAFOs were associated with increased reports of being stressed/annoyed and nervous/anxious (Horton et al. 2009).

Health Impacts of Airborne Exposures from CAFOs on Children

Children's respiratory health deserves special consideration. With immune and respiratory systems still developing, children are at risk of lifelong impacts from exposures to air pollutants (Schwartz 2004). Compared to adults, children have a higher resting metabolic rate, greater oxygen consumption per unit of body weight, and a faster inhalation rate, thus breathing a greater volume of air relative to body weight (EPA 2008). In addition to differences in physiology, children can also have different exposure patterns. While adults spend a greater average amount of time outside, children spend a greater proportion of time engaged in moderate to vigorous recreational activities that can increase ventilation rates (EPA 2009).

Initial studies with children have focused on the prevalence of respiratory disease associated with proximity to swine CAFOs. Chrischilles et al. found farm residence and childhood asthma prevalence to be inversely associated in one of two Iowa counties studied, but no association in the second county; this survey was conducted in an area with numerous CAFOs but "farm residence" was not further defined in terms of crops/livestock and size of farm (2004). The Keokuk County Rural Health Study conducted an extensive survey of rural home environments in Iowa and collected parent-reported respiratory outcomes in children as well as clinical measures including spirometry and allergy testing. Children living on farms raising hogs were more likely to report asthma and current wheeze than children on farms that did not raise hogs, with little difference in prevalence for <500 hogs or ≥500 hogs. The highest proportion of asthma related outcomes was found among children living on hog farms with antibiotics added to the feed (Merchant et al. 2005). One study of Canadian residents near a swine CAFO with approximately 1000 sows did not find any difference in the parent-reported prevalence of asthma, wheeze, hayfever, runny nose, or allergies for children living within 3km of the CAFO compared to those living ≥3km of the CAFO (Villenueve et al. 2009).

Several studies have focused specifically on school related CAFO exposures. Sigurdarson and Kline found that asthma prevalence was higher among elementary school children attending a school 0.5mi from a swine CAFO compared to children attending a school >10mi from a swine CAFO, though no difference in asthma severity between the two groups was found (2006). Mirabelli et al. compared the prevalence of asthma and wheeze reported by students during the 1999-2000 North Carolina School Asthma Survey with geographic proximity of schools to swine CAFOs and staff reports of livestock odor at schools. Elevated prevalence of wheezing was found among children attending public middle schools within three miles of a swine CAFO or when livestock odor was reported at least two times per month inside schools, especially among children with allergies (2006a). Additionally, schools with high non-white enrollment and high proportion of subsidized lunches were more likely to be close to swine CAFOs and have stronger livestock odors at school (Mirabelli et al. 2006b). These studies indicate a relationship between the prevalence of respiratory illness in children and exposure to CAFOs that warrants further study.

When reviewing the impact of these exposures on children's respiratory health, it is important to mention that a substantial body of literature has investigated whether farm exposures may have an inverse relationship with asthma incidence as a component of the "hygiene hypothesis." The hygiene hypothesis posits that the increased prevalence of asthma and allergic diseases in recent decades may be a result of reduced exposure to microbial infections in early childhood, first observed as an increased prevalence of hay fever associated with a decrease in family size (Strachan 1989). Farm exposures are of interest because of exposures to microbes and endotoxins from contact with livestock and consumption of unpasteurized milk; the protective effects of these exposures have also been seen in children who do not reside on farms (Perkin & Strachan 2006; von Mutius 2010).

Subsequent studies have supported the inverse association proposed by the hygiene hypothesis, though immunologic mechanisms remain unclear, and are likely to be more complex than originally proposed (Sheikh & Strachan 2004; von Mutius 2010). Additionally, the relationship is less consistent with asthma than with allergic diseases (Ramsey & Celedon 2005; von Mutius & Radon 2008). For example, cross-sectional surveys of families in rural Austria, Germany, and Switzerland have found lower parent-reported prevalence of asthma, hay fever, and atopy in children growing up on a farm compared to those who didn't, especially when children received early life exposures (Von Ehrenstein et al. 2000; Riedler et al. 2001). A study conducted in a region of New Zealand where farms tended to have greater numbers of animals stored in large outdoor pens found that children currently living on farms had a higher prevalence of asthma and allergic disease than their nonfarm counterparts (Wickens et al. 2002). A study in Iowa that compared prevalence of wheeze and asthma diagnosis between farm and rural, nonfarm children found decreased prevalence of these outcomes for farm children in one of the participating counties, but not the other (Chrischilles et al. 2004). Some studies have documented differences in childhood asthma prevalence by agricultural activities (Ege et al. 2007; Elliott et al. 2004; Farthing et al. 2009), however results conflict between studies. For example, Ege et al. found hog farming protective while Elliott et al. did not, although other farming activities were protective in the latter study; Farthing et al. found various farming activities to either have no association with asthma and respiratory symptoms or be associated with increased prevalence of these outcomes. The studies demonstrating protective effects have focused on exposures associated with farm residence, not airborne pollutants from CAFOs, and demonstrate an inconsistent association between farm-related exposures and childhood respiratory disease.

Enhancing Positive Side Effects of Research

Research studies with primary data collection can have “side effects,” or consequences for participants beyond the primary purpose of advancing scientific knowledge. Studies are carefully designed to minimize the negative side effects of research participation in order to protect participants; this is a standard principal of research ethics (Resnick 2008). Some researchers also seek to enhance the positive side effects of research participation (Wing et al. 2008b). There is a spectrum of public involvement in research that includes individual participation, community consent for study conduct, advisory board representation, and community-based participatory research (Brenner et al. 2011). Opportunities to incorporate positive side effects occur at each level of involvement and may be as complex as a community intervention or as simple as providing additional educational resources, but must respect participant values and local needs (Wallerstein et al. 2011).

Strengths and Limitations of Previous Research

Previously conducted studies examining the effect of CAFO exposure on respiratory health in children have strengths and limitations. These studies have found associations that provide a basis for further investigation. All previous studies were cross-sectional and thus examined prevalence of respiratory illness, so one potential next step is a prospective study that enables examination of temporal relationships between CAFO exposures and acute respiratory outcomes. Airborne exposures from CAFOs are transient and unpredictable, thus a longitudinal design will allow the measurement of effects over a time period sufficient to capture both exposed and unexposed periods. Repeated measures will also enable us to characterize individual variations in response to airborne exposures via within-person analyses.

For exposure assessment, all previous studies used metrics of proximity to CAFOs defined as farm residence (Chrischilles et al. 2004; Merchant et al. 2005), residence <3km or ≥3km or a CAFO (Villenueve et al. 2009), attending school 0.5mi versus >10mi from a CAFO (Sigurdarson & Kline 2006), and attending school ≤3mi or >3mi from a CAFO (Mirabelli et al. 2006a). One study also used frequency of indoor livestock odor reports at school as an additional exposure measure (Mirabelli et al. 2006a). Exposure assessment could be improved by measuring ambient concentrations to which participants are exposed. This would allow an estimation of the duration and frequency of CAFO plumes and assignment of mean exposure levels to participants.

Measured exposures have limitations as well. Single ambient pollutant concentrations can be used to represent the presence of CAFO pollution plumes, however more research is needed to understand the interaction between various components in these complex mixtures. There may be times when pollutants do not consistently co-vary and thus levels of one measured pollutant may not accurately represent the presence (or absence) of others (Heederik et al. 2007). In some cases, outdoor ambient pollutant measurements can underestimate personal exposures (Van Roosbroeck, et al. 2008). Odor reports have not been used in previous studies exploring health impacts of CAFOs on children, but children typically have a sensitive sense of smell (Lehrner et al. 1999) and adult swine odor reports have been associated with measured air pollutants from CAFOs (Wing et al. 2008a).

Outcomes in previous studies were measured using both survey responses and clinical measurements. Most previous studies used parent/guardian report to estimate outcome measures in children (Chrischilles et al. 2004; Merchant et al. 2005; Sigurdarson & Kline 2006; Villenueve et al. 2009) although one used surveys completed by children (Mirabelli et al. 2006a). Yawn et al. found that surveys completed by children, though generally comparable to what their parents report, indicated more frequent symptom occurrences and thus may be provide a more sensitive measure of respiratory health status (2006).

It may be ideal to have both student-completed surveys and clinical measures for respiratory outcomes. Only one previous study used clinical measures in addition to survey responses to assess respiratory health status, including spirometry and methacholine challenge testing (Merchant et al. 2005). Pulmonary function testing provides an objective measurement of acute respiratory response, however accurate measurement is dependent on correctly functioning instrumentation, participant effort, and proper technique. The gold standard of pulmonary function testing is spirometry, in which a participant, with guidance from a respiratory therapist or other trained health professional, uses a spirometer to track the course of the respiration cycle and measure numerous pulmonary function parameters. Due to substantial between-person variation, pulmonary function values are most informative when compared to a participant's own levels, though reference values by gender, age, height, and race have been computed.

Portable peak flow meters are small, hand held devices used to measure a subset of pulmonary function parameters outside of the clinical setting. Two commonly measured parameters are forced expiratory volume in one second (FEV_1) and peak expiratory flow (PEF). FEV_1 is the volume of air that can be forcibly exhaled in the first second of exhalation, typically measured in liters (L). PEF is the maximal rate of airflow that can be achieved during forced exhalation, measured in liters per minute (L/min) or liters per second (L/s). Pulmonary function exhibits diurnal variation, in which it is lowest after waking, then peaks near the middle of the wakeful hours (usually between noon and 2pm) so time of measurement can be important to consider (NAEPP Expert Panel on the Management of Asthma 1997). For measurements performed on different days, the time of measurement should not vary by more than two hours (Miller et al. 2005b). Compared to spirometry, measurements with peak flow meters may have reduced precision; in clinical settings, peak flow meters may be used for patient monitoring, but spirometry is used for diagnosis (NAEPP Expert Panel on the Management of Asthma 1997).

In summary, the body of research indicating detrimental effects of airborne CAFO pollutants on children's respiratory health is small. Key opportunities for improvements upon previous research include a longitudinal study design with children as participants, measuring air pollutants directly, and combining symptom reports with clinical measurements such as pulmonary function measurement.

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Chapter III

Enhancing Public Health Benefits Through Engaged Epidemiologic Research

Abstract

Conducting a research study provides an opportunity for meaningful interaction between researchers and participants. Epidemiologists should endeavor to incorporate positive side effects into studies with primary data collection. The Rural Air Pollutants and Children's Health (RAPCH) study illustrates this philosophy. RAPCH was designed in collaboration with a community-based organization to provide educational and environmental health benefits to middle school participants and their communities while collecting epidemiologic data. The study was conducted with 340 students at three middle schools in February-November 2009. In May-June 2010, we interviewed principals, teachers, and research team members about perceived benefits and drawbacks of participating in the study. Qualitative analysis of interview transcripts revealed few drawbacks and many benefits. Positive impacts on students included increased interest in science and research, hands-on learning opportunities, exposure to new technology, reinforcement of science curricula, and contact with higher education. Teachers received exposure to research and additional resources for classroom lessons. The school liaisons described enhanced interest in research and increased environmental health awareness. Given the success of this effort, more epidemiologic research should be designed and conducted with immediate public health benefits in mind.

Introduction

Epidemiologists conduct research aimed at improving public health. When this involves primary data collection, researchers typically endeavor to collect sufficient data while having minimal impact, often perceived as burden, on participants. Yet conducting a study creates the possibility of meaningful interaction between researchers and the public and an opportunity to share resources. Researchers should broaden the purpose of studies to include aspects that can immediately benefit participants - prior to results that can take years to produce and disseminate.

There is a continuum of public involvement in research, from individual participation to community consent for study conduct, serving on advisory boards, and extensive involvement via community-based participatory research (CBPR) (Israel et al. 2005; Brenner et al. 2011). At each point on the continuum there are opportunities to incorporate benefits of participation - beyond study incentives that offer fair compensation for participation time. While benefits may be as complex as community interventions, there are also simpler options of great value, e.g., sharing information or providing services to which communities otherwise have limited access. It is essential, however, that benefits or interventions be in accord with participant values and local needs (Wallerstein et al. 2011). Increasing positive impacts may be of special importance when environmental health research is conducted in contexts of disenfranchisement, power imbalance, or distrust (Wing et al. 2008b). This may enhance the worth of research studies to the public, increase participation, be a more just use of resources, and support change to improve public health (Israel et al. 2005).

This paper has several objectives. First, we describe the design and data collection methods for the Rural Air Pollutants and Children's Health (RAPCH) study, a school-based study of acute respiratory health in children designed to provide community benefits. Second, we will share the results of a process evaluation during which principals, teachers, and research team members expressed perceived benefits and drawbacks of study participation. Finally, we will review lessons learned for application to future epidemiologic research.

Study Design

The RAPCH study was developed collaboratively by researchers at the University of North Carolina at Chapel Hill (UNC) and members of the Rural Empowerment Association for Community Help (REACH). REACH is a community based organization in eastern North Carolina with the stated mission of “improving the quality of life for low income families and people of color in rural eastern North Carolina.” UNC researchers and REACH members have collaborated previously on research studies, thus providing a foundation of trust and mutual respect at the outset.

We were interested in investigating the effect of airborne pollutants from concentrated animal feeding operations (CAFOs) on children’s respiratory health. CAFOs are agricultural facilities raising hundreds or thousands of animals in confinement; airborne pollutants are generated by barn ventilation and management of voluminous quantities of manure (NRC 2003). Previous studies have documented community health effects of these exposures in adults (Thu et al. 1997; Wing & Wolf 2000; Avery et al. 2004; Bullers 2005; Schiffman et al. 2005; Radon et al. 2007; Horton et al. 2009; Schinasi et al. 2011), but less is known about effects on children as a sensitive subpopulation. We sought to conduct a prospective study that would build on previous findings of increased prevalence of asthma and wheeze symptoms in children exposed to air pollutants from CAFOs (Merchant et al. 2005; Sigurdarson & Kline 2006; Mirabelli et al. 2006a), noting that one study that found no association (Villenueve et al. 2009).

We designed a longitudinal, school-based study to investigate the association between intermittent exposures to air pollutants from CAFOs and acute respiratory responses in children living in eastern North Carolina. We knew from previous research and community knowledge that some schools are located in close proximity to CAFOs and thus children would likely receive exposures there (Mirabelli et al. 2006a; Sigurdarson & Kline 2006). A longitudinal design has the significant advantage of enabling analysis of within-person effects over time. Using fixed effects regression models, the potential for confounding by between-person differences is eliminated, provided that these factors remain constant during the study period (Allison 2005). For example, age, race, income level, and asthma diagnosis are assumed to be non-varying during our relatively short follow-up of 3-5 weeks. These time-invariant attributes may still serve as potential modifiers of observed effects, but not confounders (Wing et al. 2008b).

Study Population

Participants were students at middle schools in eastern North Carolina located near multiple hog and poultry CAFOs. Each school had a minimum of four hog CAFOs within two miles and the permitted number of hogs, or head count, within that same radius was at least 28,000 hogs. Local residents are familiar with industrial livestock production and employment in related industries is common.

There were several reasons we chose to partner with middle schools for data collection. Asthma prevalence is high among adolescents (Jensen 2006) and most students in this age group (11-14 years) possess the necessary maturity, comprehension, and enthusiasm for completing a daily study protocol for several weeks. By working in the context of science classes, we were able to reach a relatively large number of children in a structured setting. Finally, this setting provided the potential for meaningful interaction between the research team, participating students, and school staff. Students were active participants in data collection and research activities complemented science curricula. The NC Standard Course of Study for 7th graders includes learning about the atmosphere, air pollution, and the human respiratory system, while fundamentals of scientific inquiry and technological design are part of the curriculum for grades 6, 7, and 8 (NC Department of Public Instruction 2004). Research activities informed general concepts of research, air pollution, and respiratory health but did not describe study hypotheses.

Recruitment

School recruitment began in 2008 for a pilot exposure assessment study that also was a collaborative effort between UNC and REACH. Research team members examined the number and proximity of swine CAFOs within 2 miles of NC public schools to generate a list of schools likely to experience measurable air pollution exposure from livestock operations (geographic data for poultry CAFOs are not publicly available). REACH members initially contacted school administrators about participating and if they were interested a meeting with the project team followed. Administrators at two schools who participated in the pilot study accepted the offer to be a part of this subsequent epidemiologic study. REACH recruited one additional school from our original list.

Once school administrators agreed to be involved, the research team met with relevant school staff to discuss study logistics. Participating science classes were chosen by school staff with guidance from the research team. We considered class size, student ability to adopt the research protocol, scheduling, and other preferences expressed by school staff. Teachers received a two hour after-school training prior to the initiation of any study activities in their classrooms.

All students within selected classes were invited to participate. Each class received an introductory presentation about respiratory health and air pollution that highlighted the differences between urban and rural sources. This introduction was attended by representatives from both UNC and REACH. We concluded the presentation with a description of the RAPCH study using artist-rendered illustrations to describe the study protocol, emphasizing that both parental consent and individual student assent were conditions of participation. A packet containing an explanatory letter from the principal and science teacher plus two copies of the parental consent form (both printed in English and Spanish) was distributed to each student and a deadline for return was set by the teacher. The teachers facilitated the form collection process by providing reminders, storing returned forms for the research team, and occasionally clarifying ambiguously completed forms with students or parents.

We collected student assent from those who had obtained parental consent. There were no health conditions that excluded students from participating, but participants had to be proficient in English (teachers gave recommendations when needed; no students were excluded due to this requirement). We reviewed the assent form verbatim as a class, with frequent pauses to summarize and provide time for questions. Students then chose to assent or opt out. Science teachers provided alternate activities in the rare situations when either parents or students declined participation. We made every effort to minimize attention to students who were not participating and included them in supplemental educational activities.

Data Collection

Data collection took place from February through November 2009 with a total of 340 participants in 15 science classes at three middle schools. 96% of eligible students (344/358) provided necessary consent/assent for participation. Three participants were excluded from the final data set because they did not complete both a diary and a baseline survey; one student participated at two different schools and records from the second participation were excluded, resulting in a final sample of 340 students (95% participation). Ten out of fifteen classes had 100% participation with the 14 non-participating students distributed among the remaining five classes.

Baseline Survey

Participants first completed a baseline survey to determine the prevalence of asthma-related symptoms and collect data on time-independent covariates that could be considered effect measure modifiers (Appendix A). This survey was based on the North Carolina Department of Health and Human Services Breathing Survey (Yeatts et al. 2003) and the International Study of Asthma and Allergies in Childhood (ISAAC) video questionnaire (Beasley et al. 1998; Asher et al. 1995).

The baseline survey had a total of 37 questions in three parts: 1) demographic information, 2) frequency of wheezing symptoms, medical diagnosis of asthma, and utilization of medical care, and 3) frequency of symptoms demonstrated by the ISAAC video questionnaire. In part 3, five video clips were shown which demonstrate adolescents experiencing the following symptoms: a) wheezing at rest, b) exercise-induced wheeze, c) waking at night due to wheeze, d) waking at night due to cough, and e) wheezing accompanied by intercostal retractions. After each clip, students indicate the frequency with which they have experienced the demonstrated symptom (ever, in the last year, in the last month).

A research team member guided the participants through the survey at a pace suitable for all. Upon completion, we collected the surveys and exchanged them for binders containing diaries with matching identification (ID) numbers. The survey cover page provided the hardcopy link between each participant’s name and home address and his/her unique ID number. The cover page was removed from the survey and stored in a separate locked location from other participant data.

Student Training

Each participant received a binder containing data structured diary pages (Appendix B) and a Mini-Wright Digital (MWD) peak flow meter (Clement Clarke International, Harlow, UK) stored in a pencil pouch. Participants practiced completing a diary entry with research team guidance using sample pages in the front of the diary. Each section of the diary was separately reviewed, with strategies presented to ensure proper completion (e.g., one check mark on each line) and a discussion of scenarios provided by a research team member that would result in varied completion of the items.

Training students in proper technique for lung function measurement was another essential step. As with all peak flow meters, the technique used with the MWD is critical for achieving accurate measurement (Miller et al. 2005a). Trained research team members first demonstrated proper technique, then observed and coached the students in making their own measurements, either in small groups or individually. We emphasized the need for maximal inhalation, forceful exhalation through the one second beep provided by the instrument, and completing three attempts each day. Students learned to write their measurements in their diary (measurements were also stored electronically by the instrument).

Finally, students personalized the covers of their diaries (for visual recognition since no names were used to protect confidentiality) and had their height measured by a member of the research team (for potential comparison with reference values based upon size). Throughout the training activities we emphasized the scientific importance of accurate and honest measurement. We provided physiologic explanations for different results, especially regarding lung function. We reinforced these lessons frequently during data collection.

During training activities, approximately five research team members were on hand to assist. A training checklist labeled by ID number was located inside each diary, listing five required activities for each student: 1) Diary training, 2) Mini-Wright Training, 3) Measure Height, 4) Baseline Survey, and 5) Decorate Diary. The checklist was an essential tool for coordinating groups of students completing different activities simultaneously. Upon completion of training, these checklists were collected from the students and shredded.

Either during training or the initial days of data collection, engineers on the research team demonstrated the air monitoring instruments to the students. This included a description of instrument components and their respective functions and a demonstration of instrument response to changes in real-time particulate matter concentrations. Some classes also received a demonstration of the process for downloading data from a MWD. Data points were instantly plotted by the MWD software and we discussed the meaning of observed variation in measurements.

Daily Data Collection

Daily diary completion involved five steps that took approximately 10 minutes to complete; this length of time was recommended by former educators on the research team and approved by principals and teachers. First, students reported the presence and strength of eleven symptoms of illness using a five point scale (None, Barely There, Present, Strong, Very Strong). Reported symptoms included backache, bad hearing, burning eyes or nose, chest tight, cough, headache, nausea, runny nose, short of breath, sore throat, and wheeze. Second, students reported observations of three types of odor (engine exhaust, livestock odor, and smoke from fires) for four time periods in the past 24 hours (yesterday afternoon, yesterday evening, last night, and this morning). Odor strength was rated using the same five point scale as symptoms. Third, students reported whether they had used rescue medication for asthma and the number of times used, whether they had taken allergy medications not usually taken daily, whether they had visited a doctor due to respiratory illness, and whether they had been absent from school due to respiratory illness since their last diary entry. Fourth, students categorized the time they spent outside in the previous 24 hours (Less than 1 hour, 1 hour, 2 hours, 3 hours, 4 hours, and 5+ hours).

Finally, students used their Mini-Wright Digital (MWD) peak flow meters to measure their forced expiratory volume in the first second (FEV_1) and peak expiratory flow (PEF) via three maneuvers, and recorded the results in their diaries. Between maneuvers, students were instructed to turn off their instruments to ensure the electronic storage of individual measurements (the MWD stores the maximum FEV_1 and PEF measurements made each time it is turned on).

School Liaisons

There were four research team members from REACH known as *school liaisons* who were responsible for orchestrating daily data collection in the classroom. The teachers often remained in the classroom and occasionally assisted with discipline or logistical instructions, however only the school liaisons handled participant data. Due to this division of responsibilities, the teachers did not need to be trained in the ethics of human subjects research.

The school liaisons were essential for the success of data collection. They were former local educators who were experienced with student dynamics and classroom management. There were typically two liaisons present each day, though there were as many as four during student training and three during the initial days of a data collection period. In the classroom, school liaisons distributed diaries to students, monitored use of peak flow meters, checked diaries for proper completion, collected diaries for storage in a locked trunk or cabinet, and addressed any problems that arose. School liaisons were also responsible for confirming the proper function of air pollution monitors inside and outside the school.

The school liaisons were on our Institutional Review Board (IRB) list of approved study personnel and were fully trained in the ethics of human subjects research as well as our research protocol. Several additional research team members were trained in the responsibilities of the school liaisons and assisted as needed.

Monitoring Air Pollutants

CAFOs emit a complex mixture of airborne pollutants during barn ventilation and manure management. While particles and gases are most highly concentrated inside confinement barns and near waste storage, pollutants can also migrate offsite to surrounding communities. In North Carolina, aerial spraying is commonly used to spread liquid waste on fields; this practice aerosolizes waste particles and contributes to migration.

We focused our exposure assessment on three markers of air pollution from CAFOs: odor, particulate matter, and hydrogen sulfide. CAFOs emit a characteristic odor that is identifiable by local residents; livestock odor was reported by students in their daily diary entries as previously described. Particulate matter less than 10µm in diameter (PM_{10}) originates from organic dust (animal feed, fecal matter, dander) and bioaerosols (endotoxins, bacteria, molds) (Cole et al. 2000; Iowa State University and University of Iowa 2002) as well as other sources including fossil fuel combustion. Hydrogen sulfide (H_2S) is a strong odorant compound generated during anaerobic decomposition of manure with few alternate sources, thus serving as a more specific measure of CAFO emissions. One other key pollutant, ammonia (NH_3), was not measured because active samplers with sufficient time resolution for this longitudinal study were cost prohibitive.

A set of active air monitors for PM_{10} and H_2S were placed at one location inside the school building (a participating classroom) and one location outside of the school building (a site recommended by school staff). Each set included a DustTrak Aerosol Monitor (TSI Inc., Shoreview, MN) for PM_{10} and an MDA Scientific Single Point Monitor (SPM) (Honeywell Analytics, Inc., Lincolnshire, IL) for H_2S. At one of the schools, we added a Thermo Hydrogen Sulfide - Sulfur Dioxide Analyzer (Thermo Fisher Scientific, Waltham, MA) when it became available to provide more sensitive detection of H_2S. Instruments were checked for proper function daily by school liaisons and weekly by staff from the UNC Department of Environmental Sciences and Engineering.

Air pollution monitoring occurred for at least five weeks at each site, beginning one week prior to classroom data collection. Specific sites were subject to pollution plumes at intermittent, unpredictable intervals depending upon activities at nearby CAFOs and atmospheric conditions. We collected several weeks of data to increase the probability of capturing variation in pollutant levels.

Reporting Preliminary Results

At the conclusion of each round of data collection, we prepared a preliminary summary of the data collected and presented the results to each participating class. We shared the number of students who reported allergies, asthma, wheeze, and exposure to smoking. We also described levels of particulate matter and hydrogen sulfide measured inside and outside the school, frequency of symptom and odor reports, and mean lung function measurements by groups (e.g., gender or grade). After viewing and interpreting tables and figures, the students were provided with an additional table of data and completed a graph representing the results with the assistance of research team members.

Incentives

Extensive school involvement merited significant incentives at the student, teacher, and school levels. To encourage return of parental consent forms, participating classes earned a pizza party when 90% of forms were returned, regardless of consent or refusal. Fourteen of fifteen classes earned this incentive. Participating students were given a set of school supplies upon completion of the full data collection period (nonparticipating students received a smaller set of school supplies). Teachers were vital partners in classroom coordination and thus received $50 when 90% of parental consent forms were returned, $25 a week during data collection, and a $100 bonus upon successful completion of a data collection period. REACH members who were former educators emphasized the importance of having incentives that kept the teachers engaged and on board for the entire data collection period. Schools also received a $500 incentive when data collection was finished for all participating classes. Additionally, we coordinated a field trip to UNC for participating students from one school, at the request of the principal.

Process Evaluation

In May-June 2010, we interviewed teachers, principals, and school liaisons to evaluate the benefits and drawbacks of participating in this epidemiologic study. All teachers, principals, and school liaisons involved with the study were invited to participate. Some interviews were conducted individually and some in groups. Interviewers were familiar with the study but had not been involved on a daily basis. Interviews with school staff took place at the schools and were conducted by pairs of interviewers (one UNC-affiliated and one REACH-affiliated). The school liaisons all participated in one group interview conducted by a UNC-affiliated interviewer at the REACH office. Interview length reflected the extent of involvement in project details: principal interviews lasted 5-15 minutes, teacher interviews lasted 15-30 minutes, and the school liaison group interview lasted 70 minutes. We obtained informed consent and permission to audio record the interviews prior to beginning the interviews.

Interviews began with a reminder of study activities. All interviews included questions about perceived benefits and drawbacks to students as a result of participation as well as logistical recommendations for future studies. In addition, principals were asked what motivated their decision to participate and whether there were any implications for the staff. Teachers were asked about informal feedback they heard from students and whether learning objectives were supported. Liaisons were asked about the challenges/benefits of their role and considered possible benefits to the broader community as a result of the study. Both teachers and school liaisons were asked whether there were any concerns about maintaining confidentiality in the classroom setting.

Interviews were audio recorded and transcribed. Individual transcripts were reviewed and coded for primary themes. Themes repeated across interviews were standardized following the first round of coding. Interviews were recoded with standardized themes during a second round of coding. The occurrence of themes was tallied across interviewees. Finally, themes were grouped into five categories: motivation to participate (principals only), benefits of participating, drawbacks of participating, confidentiality, and logistics.

Process Evaluation Results

A total of 13 people participated in process evaluation interviews, as summarized in Table 3.1. All available principals, teachers, and school liaisons agreed to participate. Three teachers did not participate for the following reasons: two had changed jobs and one was unavailable due to illness at the time interviews were conducted.

Table 3.1. Summary of Process Evaluation Participants

	N	Participation Proportion
Principals	3	100%
Teachers	6	66%
School Liaisons	4	100%
Total participants	**13**	**81%**

In the following tables we present primary themes addressing motivation to participate, benefits of participating, and drawbacks of participating. We also present the number of interviewees that made supporting statements and representative quotes for each theme.

Principals were asked what motivated participation for their school, since they are the primary decision makers in this regard (Table 3.2). All of the principals considered the direct benefits to students that would result from participation, however two principals were mainly concerned with academic enhancement for students while one principal was motivated by observations of respiratory illness among students.

Table 3.2. Motivation to Participate

Theme	N*	Quote
Academic enhancement	2	- The academic piece was so clear here, that's what I focused in on. I see the benefit when I see the kids thinking about other things they can be engaged in and other things they would like to do. - It sounded like a good program to help the students expand their understanding and knowledge of science and get a practical, hands-on approach.
Concern about student respiratory illness	1	- The main reason that I was glad that the study team wanted to work with us is that when we register our students for classes, there are so many students that have asthma or breathing problems.

*Number of interviewees who made statements supporting the theme

Principles, teachers, and school liaisons were asked about perceived benefits for students, teachers, and the broader community, as presented in Table 3.3. Only themes supported by at least two interviewees are included, ordered from most frequent to least frequent mention.

The study was positively reviewed by all of these stakeholders and the benefits cited were profuse and broadly supported. Nine of 13 interviewees (and 100% of teachers) specifically mentioned that students enjoyed participating. All three categories of interviewees noticed increased interest in science and research among the students. The direct involvement of the students resulted in hands-on learning that reinforced basic scientific skills and exposure to new technology. Study involvement was also credited with expanding the perspective of the students, e.g., thinking about college as a result of contact with university staff or considering environmental impacts on health for the first time.

Table 3.3. Benefits of Participation for Students

Theme	N*	Quote
Enjoyed study participation	**9**	- That experience was a totally meaningful thing. They enjoyed it, meeting professors, especially seeing the instruments used to test air quality; that was the biggest thing. They got a thrill from that. - The students really enjoyed the activity based on what I saw. I've been around the students about a year now and this is the stuff that will get these kids above that curve and doing what they need to do.
Increased interest in science & research	**8**	- A lot of kids hate science, it's just too hard and they can't figure it out…being involved in with the study, they realized that it was not all completely dry, bland stuff, that it could be interesting - They asked more questions in class outside the study. Questions like, "Are there other things that people can do like this study? What other studies have been done?"
Hands-on learning	**7**	- Kids will gravitate toward anything hands on and using visual tools, something they can touch, feel, manipulate. - With all the hands-on activities they did, it certainly made it much more meaningful to them and gave them something concrete to experience.
Reinforced basic scientific skills	**7**	- The data recording, having them keep track, reading their instruments, making sure they're in the right place in their diaries, recording the data appropriately, all this is really important for these kids because they are so weak in these areas. - The whole scientific method was reinforced and the steps of following the scientific method. They were actively involved in gathering the data and then when you showed them the graphs that gave them practice interpreting findings, so they really could see the scientific method in action.
Exposure to technology and scientific instruments	**7**	- Students wanted to check the instruments to see what the air quality was…this let them see how the data were handled and how things were measured. - They are attracted to things that 1) they haven't seen before, 2) are electronic, and 3) information that can be downloaded to a computer. The study used peak flow meters and brought in laptops to demonstrate downloading and show the results. It was important to see all the different ways that technology was used to collect data.

Theme	N*	Quote
Connecting environment and health	**6**	- For the sixth graders, air quality is something they haven't even considered. So having to think about that and experience the research process…it helped them to see that we can't take what we breathe for granted. - If some of these students plan on being farmers, which I know some do, the knowledge they gained…allowed them to see some of the things in their environment that could affect them.
Broader perspective from new experience	**6**	- This study has opened up their minds and broadened them to a new world that they hadn't seen before. - A lot of the kids in this area don't really get out. With public school funding slashed, the opportunities are limited. So we have to look at other ways to get them out there, get them exposed, and get them engaged in activities like this, that are going to help them, and pique their thinking, so they can think about getting into college and get that college mindset.
Complemented science curriculum	**4**	- I think the age was good because the study of air and the atmosphere is in the 7^{th} grade science curriculum, so it went right along with the science curriculum for the 7^{th} grade - The graphing activity helps with their math curriculum and they use that on the End of Grade test for science as well – they had to interpret graphs and see what they could determine.

*Number of interviewees who made statements supporting the theme

We also asked about benefits experienced by collaborators who were not research participants (Table 3.4). Teachers and principals appreciated the opportunity to interact with the research team and consider new ways to supplement their curriculum. Liaisons cited many individual benefits, but one cited by multiple liaisons was an increased awareness of the connection between the environment and health.

Table 3.4. Benefits of Participation for Teachers and Liaisons

Theme	N*	Quote
Teachers		
Interacting with researchers	**4**	- Teachers thoroughly enjoyed it, had opportunity to network with people that had this knowledge.

Theme	N*	Quote
		- This was an excellent experience not only for my students but for me. I've never participated in a study before.
Professional development	**3**	- I'm just very happy that we were able to participate, and I appreciate the opportunity for myself and my students both. - Just seeing how they conducted themselves professionally but on a very personal level was very rewarding to me.
Opportunity to enhance curriculum	**3**	- I may incorporate something next year, I might make them do a research study next year just for me, just to give them the idea. - It opened an avenue for integrating new information into the curriculum. The teachers could say, "Hey this is something good that I could use and expand on."
Liaisons		
Connecting environment and health	**3**	- I know before I started working on this I wasn't aware of the environment, I just ride down the road…going where I need to go. Once you learn, you're more aware and you start looking and seeing different things. - WE became more aware of our environment than what we knew already. It helped us, it helped me. I thought about it, I said, look at the things we're going over that we didn't know…now we DO know.

*Number of interviewees who made statements supporting the theme

Each interviewee was asked about drawbacks of participating (Table 3.5). Most said that there were no drawbacks to participating. Two interviewees mentioned that the study activities made classroom management more challenging, but that participating was still a positive experience.

Table 3.5. Drawbacks of Participation

Theme	N*	Quote
None observed	**7**	- With our 8th graders that I had that year, we gave them their binders, they completed it in a timely fashion, and it didn't affect our studies that we had to do. - There's absolutely nothing I can think of as a drawback because of how it was set up. It was done very professionally.

Study hampered classroom management	**2**	- The major thing I noticed is classroom management. The drawback that I saw was that there was a lot of confusion at first…but I'll take that kind of interference over what they usually give me. - One of the biggest drawbacks was some of the children's behavior, in terms of getting them to use the equipment correctly and getting them to record their data accurately.

*Number of interviewees who made statements supporting the theme

Discussion

From its inception, this study was collaboratively designed to provide positive side effects to participants and their broader communities while collecting rigorous epidemiologic data. Based on the results of our process evaluation, we were successful in this endeavor. 95% participation is further evidence of strong community support and student interest in the study. The partnership between UNC and REACH with input from teachers and principals was instrumental in this success.

We successfully engaged our student participants in the research process, increased interest in science and research, provided supplemental hands-on learning opportunities, exposed students to new technology, reinforced the science curriculum, and expanded awareness of future opportunities and connections between environmental exposures and health. There were also stated gains for the teachers and school liaisons. Teachers witnessed the details of the study protocol and helped to manage logistics. This provided them with exposure to university research and consideration for additional resources for classroom lessons. The school liaisons were intimately involved with the daily data collection and equipment monitoring, enhancing their prior interest in research and increasing environmental awareness.

There may have been additional benefits that were not explicitly mentioned during interviews. Everyone involved in the study had the opportunity to learn about research and consider the health impacts of exposure to rural air pollutants, including those generated by CAFOs. Principles gave approval for participation and monitored their school's involvement in the study. Other school staff members were aware of the study and supported the work. Custodial staff assisted with instrument placement and maintained a watchful eye over equipment. Librarians learned of the study when we borrowed equipment and used their space for large group activities such as the presentation of results at the end of data collection. By spending a minimum of several weeks at each school, we became well-known to administrative staff and other teachers, who often asked questions about the study. With 340 student participants, at least as many parents or guardians knew that the study was being conducted in their community. This potential for increased environmental health awareness among various stakeholders has broad value.

Our partnership with a community organization further expanded the influence of this work. Community members served as advisors while planning the study. Research team members from REACH received periodic updates on the data analysis process and contributed ideas for interpretation of results. We also provided summaries of the research activities to community meetings during data collection and plan to work with the community organization to disseminate the results. In many cases, community partners have both the connections and the skills required to most effectively utilize research results for advocacy that spurs change toward improved public health.

To avoid potential bias in reporting, we were careful to discuss air pollution and respiratory health in general terms, describing a variety of urban and rural sources of air pollution, not stating specific research questions or hypotheses, and using a study name that didn't mention CAFOs. In the structured diary, students reported symptom outcomes prior to odor observations. Additionally, daily reporting for several weeks made systematic reporting bias by participants difficult. In addition to odor and symptom reports, we used empirical measurements from air pollution monitors and peak flow meters.

We believed strongly that the students would receive the most benefit if they were active participants in the data collection, however this approach resulted in challenges as well. We had to take additional steps to achieve informed consent and ensure protection of rights, such as obtaining both active parental consent and student assent and providing ample opportunity for questions. We spent hours training each class to follow the protocol and correctly measure lung function. While it was beneficial to include so many students as participants, it was difficult to closely monitor all of the students in our limited time frame for diary completion, especially regarding proper use of peak flow meters. In some classes, discipline problems interrupted training or data collection, though this was rare. We had to adapt to variable class schedules and maintain an efficient study protocol in order to minimize the impact on instruction time.

There were also some limitations to our process evaluation. We did not interview students to assess their perspectives on the benefits and drawbacks of the study. Obtaining this information would have involved collection of additional parental consent and student assent because we did not include the process evaluation in the original consent forms. Many student participants had graduated from middle school when the process evaluation was conducted and would have been difficult to reach. Additionally, our evaluation only asks about data collection, because that is the stage of research that had been completed at the time of the interviews. We do not yet know the impact of the results that will be disseminated to the community. There was also a significant gap between data collection and the process evaluation – over a year for the first two schools that participated, and six to nine months for the third school. On the other hand, some benefits to students may be subtle and take a longer time to manifest than that allowed by the lag between data collection and evaluation. It may have been too soon to see increased interest in science courses, environmental health, or scientific careers.

Epidemiologists should consider ways to positive side effects during primary data collection - there are many possibilities for enhancing research in this way. In the RAPCH study, our opportunities to do so were centered around data collection in an educational setting, with potential ripple effects into the broader community. The dissemination of our results will be an additional opportunity to spark consideration for the public health impacts of rural air pollutants. Public health would benefit if more epidemiologists sought similar approaches to engage communities in various stages of the research process.

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Chapter IV

Pulmonary Function in Children Attending Middle Schools near Concentrated Animal Feeding Operations

Abstract

Previous studies using cross-sectional designs have found associations between proximity to concentrated animal feeding operations (CAFOs) and increased prevalence of asthma and respiratory symptoms in children. The Rural Air Pollutants and Children's Health (RAPCH) study was a longitudinal study designed to assess acute effects of odor and measured air pollutants at schools near CAFOs. From February-November 2009, we measured concentrations of hydrogen sulfide (H_2S) and particulate matter less than 10µm in aerodynamic diameter (PM_{10}) at three schools. Concurrently, 340 student participants in five consecutive waves reported odor observations and measured pulmonary function each day in science class for 3-5 weeks. Conditional linear fixed effects models were used to estimate within-person associations between exposures (morning and 12hr livestock odor, H_2S, and PM_{10}) and two pulmonary function parameters, forced expiratory volume in the first second (FEV_1) and peak expiratory flow rate (PEF). In unstratified analyses, we found unexpected positive associations between PEF and the following: any 12hr livestock odor (β=4.510, SE=2.015, *T* value=2.24), any morning livestock odor (β=5.193, SE=2.210, *T* value=2.35), and 12hr mean PM_{10} (β for 10µg/m^3=0.867, SE=0.420, *T* value=2.06). When results from Week 1 of each wave were compared with Weeks 2-5, however, we observed small beta coefficients with poor precision for all models in both strata. We conclude that our ability to observe effects of these exposures on pulmonary function may be limited by measurement error for

pulmonary function or exposure assessment, and paradoxical results resulted from confounding by time-in-study.

Introduction

Industrial agriculture has become a significant source of rural air pollution as the number of concentrated animal feeding operations (CAFOs) has grown rapidly in recent decades. In eastern North Carolina, the number of swine and poultry CAFOs has risen substantially since the early 1990s, while the number of smaller family farms has simultaneously declined. In 2007, more than 96% of the 43.2 million hogs produced in North Carolina were from operations with more than 1,000 animals (USDA 2009).

Airborne emissions from confinement barn ventilation and manure management compromise local air quality. Barns are ventilated to regulate temperature and prevent the accumulation of harmful dusts and gases. "Dry" poultry manure is scooped out of barns between flocks, stored in large piles, then spread on nearby fields (NRC 2003). Liquid swine waste is flushed out of barns into large, open-air pits where bacterial decomposition occurs. In North Carolina, the liquid waste is then sprayed on fields using conventional irrigation equipment, aerosolizing liquid and solid waste in the process (NRC 2003). The resultant air pollution is a complex mixture of particles (feed components, fecal matter, dander, bacteria, molds, and endotoxins) and gases (ammonia, hydrogen sulfide, carbon dioxide, methane, and volatile organic compounds) that contribute to the strong odors associated with these facilities (Cole et al. 2000; Schiffman et al. 2001; Iowa State University and the University of Iowa 2002).

There is a growing body of literature documenting health effects in adult residents near CAFOs (Schiffman et al. 1995; Thu et al. 1997; Wing & Wolf 2000; Avery et al. 2004; Radon et al. 2004; Bullers 2005; Schiffman et al. 2005; Radon et al. 2007; Villenueve et al. 2009; Horton et al. 2009; Schinasi et al. 2011), but fewer studies investigating consequences in children. Children may be especially vulnerable to respiratory health effects due to differences in physiology and exposure patterns. Developing respiratory and immune systems invite lifelong impacts and, compared to adults, children have a faster rate of respiration and a larger lung surface area relative to body weight (Schwartz 2004). Furthermore, exposures can occur at schools they are required to attend.

Initial studies with children indicate an association between the prevalence of respiratory illness in children and exposure to swine CAFOs. The Keokuk County Rural Health Study found that Iowa children living on farms raising hogs were more likely to report asthma and current wheeze than children on farms that did not raise hogs, with the highest proportion of asthma related outcomes found among children living on hog farms with antibiotics added to the feed (Merchant et al. 2005). A study of residents near a single swine CAFO, however, did not find any difference in prevalence of asthma, wheeze, or allergies for children living within 3km of the CAFO compared to those living ≥3km of the CAFO (Villenueve et al. 2009). Sigurdarson and Kline found that asthma prevalence was higher among elementary school children attending a school 0.5 miles from a swine CAFO compared to children attending a school >10 miles from a swine CAFO (2006). Mirabelli et al. found elevated prevalence of wheezing among children attending public middle schools within three miles of a swine CAFO or when livestock odor was reported ≥2x per month inside schools, especially among children with allergies (2006a).

The Rural Air Pollutants and Children's Health (RAPCH) study sought to examine acute respiratory health outcomes in students attending schools near CAFOs. This longitudinal, school-based study was designed collaboratively by the Rural Empowerment Association for Community Help (REACH) and researchers from the University of North Carolina Gillings School of Global Public Health (UNC), drawing from experience gained during the Community Health Effects of Industrial Hog Operations study (Wing et al. 2008a). We hypothesized that increases in odor reports and air pollutant concentrations would be associated with decreases in pulmonary function, especially among sensitive subgroups.

Methods

Overview

Data collection took place from February through November 2009 in three public middle schools in eastern North Carolina. Each school had at least four swine CAFOs within 2 miles of the school (data on locations of poultry CAFOs are not publicly available). Students in 15 science classes participated for 3-5 weeks in five sequential waves of data collection with three classes in each wave. Participants had to have parental consent, provide individual assent, and complete both a baseline survey and a diary. Air pollutants were monitored inside and outside of the school building while participants completed a structured diary of symptom reports, observed odors, time outside, asthma and allergy medication use, and measured pulmonary function. Study activities were reviewed and approved annually by the Institutional Review Board at the University of North Carolina at Chapel Hill.

Recruitment, Consent, and Confidentiality

School recruitment began in 2008 for a pilot study assessing air pollution exposures at schools near CAFOs. Two schools from the pilot study agreed to participate in this epidemiologic study and we recruited one additional school. Participating science classes were then chosen by school staff with input from the research team. Teachers of participating classes received a two hour after-school training prior to study commencement. We introduced the study in class following a presentation about respiratory health and air pollution. All students received a packet with a letter from the principal and science teacher plus two parental consent forms printed in English and Spanish and were asked to return one signed copy to their teacher. Students who obtained parental consent then chose to assent or opt out after we reviewed the assent form verbatim with the entire class and discussed confidentiality. Science teachers provided alternate activities in cases when either parents or students declined study participation. All students took part in planned educational activities.

Baseline survey and training

Participants completed a baseline survey to assess prevalence of asthma-related symptoms and other time-independent respiratory health risk factors, e.g., gender, age, race (Appendix A). This survey was based on the North Carolina Department of Health and Human Services Breathing Survey (Yeatts et al. 2003) and the International Study of Asthma and Allergies in Childhood (ISAAC) video questionnaire (Beasley et al. 1998; Asher et al. 1995). Next, each participant received a binder containing a structured daily diary (Appendix B) and a Mini-Wright Digital (MWD) peak flow meter (Clement Clarke International, Harlow, UK). Participants practiced completing a diary entry and learned to measure their own pulmonary function with guidance from research team members. We emphasized the need for maximal inhalation, forceful exhalation through the one second beep from the MWD, and the completion of three attempts each day.

Daily data collection

Daily diary completion took 10 minutes. First, students reported presence and strength of eleven symptoms using a five point scale (None, Barely There, Present, Strong, Very Strong). Second, students used the same scale to report odor observations for engine exhaust, livestock odor, and smoke from fires during four time periods in the past 24 hours: yesterday afternoon, yesterday evening, last night, and this morning. Third, students reported recent asthma or allergy medication use and physician visits or absences for respiratory illness since their last entry. Fourth, students categorized the time spent outside in the previous 24 hours (Less than 1 hour, 1 hour, 2 hours, 3 hours, 4 hours, and 5+ hours). Finally, students used their peak flow meters to measure forced expiratory volume in the first second (FEV_1) and peak expiratory flow rate (PEF) via three maneuvers, and recorded the results in their diaries.

Several research team members from REACH with experience as local educators were responsible for facilitating data collection in the classroom each day. These *school liaisons* typically worked in pairs to manage diary distribution and collection, monitor diary completion and use of peak flow meters, and ensure diary storage in a locked trunk or cabinet. School liaisons also confirmed that air pollution monitors (described below) were functioning properly or notified the project manager in the event of malfunction.

Air pollution monitoring

Although CAFOs emit a complex mixture of pollutants, individual pollutants are often measured to serve as markers of complex mixtures. We measured particulate matter less than 10µm in diameter (PM_{10}) and hydrogen sulfide (H_2S). PM_{10} is produced by fossil fuel combustion and other industrial processes, as well as from CAFO dust. Hydrogen sulfide is a strong odorant compound generated during anaerobic decomposition of manure, thus serving as a more specific measure of CAFO emissions. One other common CAFO-associated pollutant, ammonia (NH_3), was not measured because active samplers with comparable time resolution were cost prohibitive.

Air pollution monitors were placed in two locations: a participating classroom and an outdoor site recommended by school staff. Each set of instruments included an MDA

Single Point Monitor (SPM) for H_2S (Honeywell Analytics, Inc., Lincolnshire, IL) and a DustTrak Aerosol Monitor (DustTrak) for PM_{10} (TSI Inc., Shoreview, MN). It should be noted that DustTrak instruments utilize light scatter to determine particulate matter concentrations and are calibrated to Arizona road dust particles, so means may not be directly comparable to measurements from gravimetric methods. At School 3, we also used a Thermo Hydrogen Sulfide - Sulfur Dioxide Analyzer (Thermo) for outdoor H_2S for most of the data collection period (Thermo Fisher Scientific, Waltham, MA). The Thermo is more sensitive and has a lower detection threshold (0.5ppb) than the SPM (1.0ppb), however it was not available for use at Schools 1 & 2. Air pollution concentrations were measured for at least five weeks at each school, beginning one week prior to classroom data collection. School sites are subject to pollution plumes at intermittent intervals that depend on the activities at nearby CAFOs and atmospheric conditions such as ambient temperature, humidity, wind speed, and wind direction.

Analysis

The RAPCH study was designed to assess within-person responses to varying air pollution exposures over a period of several weeks. Data were analyzed using linear fixed effects regression models. By classifying each participant as a separate stratum, this approach accounts for correlation from repeated measures while also controlling for common between-person confounders that are non-timevarying (e.g., age, race/ethnicity, income) (Allison 2005). This approach is well suited for transient exposures and acute effects of short duration, allowing each participant to serve as his or her own control.

Exposures were assigned in two ways. Odor reports from each diary entry were summarized into binary exposure variables representing any odor in the past 12 hours (last night and this morning) and any odor the morning of the diary entry (this morning).

Though livestock odor was the main odor of interest, vehicle exhaust and smoke from fires were considered potential time-varying confounders. For continuously measured outdoor PM_{10} and H_2S, we calculated the 12hr mean prior to the time of diary completion as well as a 2hr mean for 6-8am on the morning of diary completion (the exposure window during which students would be outdoors while traveling to school).

Outcome measures were the daily maximum FEV_1 in liters (L) and PEF in liters per minute (L/min) measurements from each diary record, recorded electronically by the MWD. We used written records for three participants due to MWD malfunction during data download. We then restricted our analysis to only those records that met American Thoracic Society (ATS) repeatability standards, for which the highest and second highest values differed by ≤ 0.15 L for FEV_1 and ≤ 40 L/min for PEF (Miller et al. 2005a).

Estimates of associations from linear fixed effects regression models were constructed using SAS software, version 9.2 (SAS, Cary, NC). There were substantial effects of time-in-study on diary responses and pulmonary function measurements, so all models were adjusted for time-in-study using a linear day-in-study term stratified by wave of data collection. Models with livestock odor as exposure were also adjusted for other odors. We explored several effect measure modifiers, including wheeze at baseline, school, dichotomized time-in-study (Week 1 vs. Weeks 2-5), frequent livestock exposure, allergy status, and frequent second hand smoke exposure. We obtained comparable results using mixed models with random intercepts by ID, but reported results from fixed effects models because this method fully adjusts for measured and unmeasured time-invariant confounders (Allison 2005).

Results

340 students from 15 science classes in three middle schools participated, with over half from School 3 (Table 4.1). 96% of eligible students (344/358) provided

necessary consent/assent for participation. For analysis, we excluded three students who did not complete both a diary and a baseline survey and the second set of records for one student who participated at two different schools, resulting in a final N of 340 participants (95%). Participating students were diverse regarding race/ethnicity and two-thirds received federally funded free or reduced lunch. At baseline, 23% of participants reported that their family raises livestock or that they perform livestock chores every day or almost every day. During the study period, 75% of participants reported livestock odor, and other odors were reported by a similar proportion of participants. Livestock odor in the previous 24 hours was reported in 29% of daily diary records.

Participants contributed a total of 5728 daily diary records, with a median of 17 records and a range of 6-25. Most records (88%) had pulmonary function measurements; there was a smaller proportion of records with pulmonary function at school 2 due to a delayed shipment of instruments. A larger proportion of PEF than FEV_1 measurements satisfied ATS standards (81% vs 69% respectively).

Table 4.1. Study Population	School 1 N (%)	School 2 N (%)	School 3 N (%)	Total N (%)
Participants	**55**	**81**	**204**	**340**
Male	21 (38)	36 (44)	98 (48)	155 (46)
Female	34 (62)	45 (56)	106 (52)	185 (54)
Grade 6	20 (36)	27 (33)	0 (0)	47 (14)
Grade 7	15 (27)	27 (33)	69 (34)	111 (33)
Grade 8	20 (36)	27 (33)	135 (66)	182 (54)
Black	32 (58)	23 (28)	22 (11)	77 (23)
Hispanic	10 (18)	14 (17)	70 (34)	94 (28)
Mixed	4 (7)	12 (15)	23 (11)	39 (11)
White	8 (15)	28 (35)	83 (41)	119 (35)
Other	1 (2)	4 (5)	6 (3)	11 (3)
Receive Free or Reduced Lunch	41 (75)	48 (59)	136 (67)	225 (66)
Diagnosed asthma*	8 (15)	18 (22)	36 (18)	62 (18)
Asthma at baseline*	5 (9)	14 (17)	15 (7)	34 (10)
Wheeze at baseline*	14 (25)	33 (41)	37 (18)	84 (25)
Allergies*	18 (33)	28 (35)	52 (25)	98 (29)
Family raises livestock	7 (13)	9 (11)	53 (26)	69 (20)
Frequent livestock chores*	1 (2)	6 (7)	33 (16)	40 (12)
Family raises livestock or frequent chores	8 (15)	10 (12)	59 (29)	77 (23)
Reported livestock odor	41 (75)	66 (81)	148 (73)	255 (75)
Reported exhaust odor	40 (73)	57 (70)	161 (79)	258 (76)
Reported smoke odor	46 (84)	55 (68)	139 (68)	240 (71)
Records	**1008**	**1876**	**2844**	**5728**
Records with measured FEV1	937 (93)	1288 (69)	2801 (98)	5026 (88)
Fulfills ATS standard for FEV1	*595 (64)*	*806 (63)*	*2060 (74)*	*3461 (69)*
Records with measured PEF	935 (93)	1288 (69)	2801 (98)	5024 (88)
Fulfills ATS standard for PEF	*742 (79)*	*993 (77)*	*2351 (84)*	*4086 (81)*
Records with livestock odor reported	182 (18)	597 (32)	883 (31)	1662 (29)
Records with exhaust odor reported	243 (24)	475 (25)	931 (33)	1649 (29)
Records with smoke odor reported	185 (18)	268 (14)	533 (19)	986 (17)

**Diagnosed asthma* = ever told by a doctor or other health professional that s/he had asthma; *Asthma at baseline* = diagnosed asthma plus reporting symptoms in the past year via the ISAAC portion of the baseline survey; *Wheeze at baseline* = reporting symptoms in the past year via ISAAC regardless of diagnois; *Allergies* = responding yes to at least one of four possible allergies (dog, cat, dust, or grass/pollen); *Frequent livestock chores* = Almost every day or every day.

Outdoor hydrogen sulfide and PM_{10} measurements collected from February-November 2009 during the five waves of diary completion are presented in Table 4.2.

Measurements from one day prior to the start of each wave are included to represent exposures preceding the first diary entry. H_2S measurements are from the Thermo when available and the SPM otherwise (parallel data from the two instruments are presented in Appendix C). Instruments recorded measurements at 5 minute intervals, although the SPM values represent a 15-minute average. There were fewer PM_{10} measurements due to instrument malfunction at Schools 2 & 3. Most individual H_2S measurements were 0, but measurements of at least 1ppb were documented on over half of study days. PM_{10} concentrations were more normally distributed.

Table 4.2. Summary of Outdoor Air Pollutants Measured at Each School Site*

Exposure	School 1	School 2	School 3	Total
Outdoor H2S (ppb)^				
N	7560	11733	18507	37800
Mean	0.15	0.03	0.49	0.28
Standard deviation	0.37	0.18	0.69	0.56
99th percentile	1.55	0.76	3.08	2.17
95th percentile	0.85	0	1.19	1.19
50th percentile	0	0	0.15	0
5th percentile	0	0	0	0
1st percentile	0	0	0	0
Days >1ppb H2S detected, N (%)	11 (41%)	4 (10%)	59 (91%)	74 (56%)
Outdoor PM10 (µg/m³)				
N	7561	9958	15454	32973
Mean	30.56	21.53	29.90	27.53
Standard deviation	15.07	11.36	24.60	19.76
99th percentile	76	54	98	85
95th percentile	60	42	71	62
50th percentile	28	19	24	23
5th percentile	12	6	3	5
1st percentile	9	3	1	1

*Date ranges correspond to diary completion dates for each of five waves plus one day prior: Feb 22-Mar 20 for School 1, Mar 29-May 8 for School 2, and for School 3, Sept 7-Oct 2, Oct 11-29, and Nov 5-25.

^Results presented are from the SPM through Sept 15 and from the Thermo from Sept 16 onward.

Associations between individual pollutants and pulmonary function outcomes are presented in Table 4.3. For these linear fixed effects models, we provide beta coefficients to represent the change in pulmonary function per unit of exposure, standard errors (SE) as a measure of precision, and *T*-values to indicate contribution to model fit (the T distribution is normally distributed with a large sample size; a value of 1.96 corresponds to a p-value of 0.05). We found 12hr livestock odor, morning livestock odor, and 12hr mean PM_{10} to be positively associated with PEF. For example, a morning report of livestock odor was associated with an increase in PEF of 5.193 L/min (SE=2.210, *T* value=2.35). Nearly all other beta coefficients indicated increases in pulmonary function, although less precise.

Table 4.3. Single Pollutant Linear Fixed Effects Models of Livestock Odor, Hydrogen Sulfide, and Particulate Matter <10μg/m³ as Predictors of Lung Function

	FEV1 (L)				PEF (L/min)			
Exposure	**Records**	**β**	**SE**	**t**	**Records**	**β**	**SE**	**t**
12hr livestock odor*	3383	0.019	0.011	1.71	4004	4.510	2.015	2.24
Morning livestock odor*	3391	0.019	0.012	1.59	4013	5.193	2.210	2.35
12hr H2S (ppb)^	3425	0.005	0.011	0.44	4049	1.126	1.914	0.59
Morning H2S (ppb)^	3409	0.006	0.006	1.02	4032	0.773	1.109	0.70
12hr PM10 (10μg/m³)^	3171	-0.000	0.002	-0.11	3747	0.867	0.420	2.06
Morning PM10 (10μg/m³)^	2942	0.002	0.002	1.10	3483	0.717	0.386	1.86

*Adjusted for other odors and day in study by round of participation
^Adjusted for day in study by round of participation

When stratified by wheeze status at baseline (Table 4.4), we found larger positive beta coefficients that were substantially greater than their standard errors among participants with wheeze. In this stratum, we found positive associations between 12hr and morning livestock odor and both FEV_1 and PEF. Morning livestock odor was notably associated with an increase in PEF of 11.639 L/min (SE=4.851, *T* value=2.40).

We also observed elevated FEV_1 associated with 12hr and morning H_2S exposures among participants with wheeze; in unstratified analyses these point estimates were much smaller and less precise.

Table 4.4. Single Pollutant Linear Fixed Effects Models of Livestock Odor, Hydrogen Sulfide and Particulate Matter <10µg/m³ as Predictors of Lung Function Stratified by Wheeze at Baseline

	FEV1 (L)				**PEF (L/min)**			
Exposure	**Records**	**β**	**SE**	**t**	**Records**	**β**	**SE**	**t**
	Wheeze at baseline							
12hr livestock odor*	813	0.063	0.023	2.70	987	8.865	4.340	2.04
Morning livestock odor*	817	0.072	0.026	2.75	992	11.639	4.851	2.40
12hr H2S (ppb)^	823	0.063	0.029	2.20	997	9.089	4.970	1.83
Morning H2S (ppb)^	822	0.040	0.017	2.40	995	4.483	2.844	1.58
12hr PM10 (10µg/m³)^	751	-0.002	0.006	-0.29	909	1.375	1.034	1.33
Morning PM10 (10µg/m³)^	697	0.003	0.006	0.50	846	1.523	0.956	1.59
	No wheeze at baseline							
12hr livestock odor*	2570	0.005	0.013	0.40	3017	2.969	2.267	1.31
Morning livestock odor*	2574	0.004	0.014	0.33	3021	3.257	2.469	1.32
12hr H2S (ppb)^	2602	-0.007	0.011	-0.64	3052	-0.643	2.039	-0.32
Morning H2S (ppb)^	2587	-0.001	0.007	-0.08	3037	-0.062	1.185	-0.05
12hr PM10 (10µg/m³)^	2420	0.000	0.003	0.08	2838	0.725	0.453	1.60
Morning PM10 (10µg/m³)^	2245	0.002	0.002	1.00	2637	0.504	0.416	1.21

*Adjusted for other odors and day in study by round of participation
^Adjusted for day in study by round of participation

Table 4.5 presents results stratified by school. These analyses revealed that at school 3, our third site and from which over half of participants arose, beta coefficients were small and imprecise, despite having the highest mean exposure to H_2S, most frequent H_2S measurements ≥1ppb, and nearly the highest mean exposure to PM_{10}. Paradoxical associations with increases in pulmonary function were still seen at schools

1 & 2. Positive beta coefficients that were substantially larger than their standard errors were seen for FEV_1 and PEF predicted by morning and 12hr livestock odor reports at School 2, and for FEV_1 and morning livestock odor at School 1. Morning PM_{10} was associated with increases in both FEV_1 and PEF at School 1. Both 12hr mean H_2S and morning H_2S were associated with increases in FEV_1 at School 2.

Table 4.5. Single Pollutant Linear Fixed Effects Models of Livestock Odor, Hydrogen Sulfide and Particulate Matter <10µg/m³ as Predictors of Lung Function Stratified by School

	FEV1 (L)				PEF (L/min)			
Exposure	**Records**	**β**	**SE**	**t**	**Records**	**β**	**SE**	**t**
				School 1				
12hr livestock odor*	583	0.042	0.030	1.40	729	4.911	5.025	0.98
Morning livestock odor*	584	0.079	0.037	2.11	730	10.852	6.005	1.81
12hr H2S (ppb)	595	-0.025	0.055	-0.47	742	-7.859	9.019	-0.87
Morning H2S (ppb)	595	-0.006	0.031	-0.20	742	-0.647	5.407	-0.12
12hr PM10 (10µg/m³)	595	0.007	0.009	0.72	742	1.458	1.499	0.97
Morning PM10 (10µg/m³)	595	0.020	0.008	2.54	742	4.818	1.367	3.52
				School 2				
12hr livestock odor*	788	0.083	0.029	2.87	973	10.474	4.293	2.44
Morning livestock odor*	789	0.108	0.032	3.34	975	14.194	4.827	2.94
12hr H2S (ppb)	806	0.292	0.111	2.62	993	20.316	17.132	1.19
Morning H2S (ppb)	806	0.102	0.046	2.22	993	5.750	7.107	0.81
12hr PM10 (10µg/m³)	704	0.003	0.010	0.26	856	1.983	1.511	1.31
Morning PM10 (10µg/m³)	645	0.014	0.011	1.24	782	2.467	1.553	1.59
				School 3				
12hr livestock odor*^	2012	-0.009	0.012	-0.74	2302	1.437	2.548	0.56
Morning livestock odor*^	2018	-0.018	0.013	-1.41	2308	0.133	2.700	0.05
12hr H2S (ppb)^	2024	0.001	0.009	0.14	2314	1.261	1.880	0.67
Morning H2S (ppb)^	2008	0.004	0.005	0.68	2297	0.683	1.097	0.62
12hr PM10 (10µg/m³)^	1872	-0.001	0.002	-0.53	2149	0.687	0.442	1.55
Morning PM10 (10µg/m³)^	1702	-0.000	0.002	-0.12	1959	0.163	0.403	0.40

All models are adjusted for day in study.
*Adjusted for other odors
^Adjusted for day in study by round

We found pulmonary function values to be highest in the first week of each wave of data collection. Thus, we stratified data into records from Week 1 and records from Weeks 2-5 due to concerns for effects of time-in-study on data quality (Table 4.6). We found small beta coefficients with relatively large standard errors for all models in both strata, including some negative, though imprecise, associations.

Table 4.6. Single Pollutant Linear Fixed Effects Models of Livestock Odor, Hydrogen Sulfide and Particulate Matter <10μg/m³ as Predictors of Lung Function Stratified by Time in Study

	FEV1 (L)				PEF (L/min)			
Exposure	**Records**	**β**	**SE**	**t**	**Records**	**β**	**SE**	**t**
				Week 1				
12hr livestock odor*	1011	0.001	0.018	0.08	1151	4.840	3.183	1.52
Morning livestock odor*	1017	0.005	0.019	0.26	1157	5.528	3.353	1.65
12hr H2S (ppb)^	1034	0.035	0.031	1.12	1174	2.987	5.652	0.53
Morning H2S (ppb)^	1034	0.031	0.021	1.46	1174	3.408	3.770	0.90
12hr PM10 (10μg/m³)^	875	0.001	0.006	0.16	1005	-1.151	1.097	-1.05
Morning PM10 (10μg/m³)^	861	-0.001	0.006	-0.18	989	-1.546	0.995	-1.55
				Weeks 2 to 5				
12hr livestock odor*	2372	0.011	0.014	0.77	2853	-0.914	2.403	-0.38
Morning livestock odor*	2374	0.015	0.016	0.98	2856	-2.125	2.670	-0.80
12hr H2S (ppb)^	2391	-0.008	0.013	-0.67	2875	-2.235	2.125	-1.05
Morning H2S (ppb)^	2375	0.001	0.007	0.09	2858	-0.080	1.119	-0.07
12hr PM10 (10μg/m³)^	2296	-0.004	0.003	-1.26	2742	-0.384	0.542	-0.71
Morning PM10 (10μg/m³)^	2081	-0.000	0.003	-0.15	2494	0.015	0.509	0.03

*Adjusted for other odors and day in study by round of participation
^Adjusted for day in study by round of participation

We conducted additional analyses for which results are not presented. We assessed effect measure modification by frequent exposure to livestock, allergy status, and frequent exposure to second hand smoke, but no clear patterns emerged (Appendix C). When models were stratified by wave of data collection, waves 3-5 at school 3 consistently showed similar results, so we presented results by school rather than wave. We ran all models with adjustment for the 1hr mean indoor PM and found only slight changes in results that did not modify our conclusions. Finally, we ran mixed models in addition to fixed effects models, and obtained comparable results.

Discussion

Students in our study received measurable exposures to markers of air pollutants from CAFOs based on odor reports and concentrations of H_2S and PM_{10} at their schools. We found unexpected positive associations for pulmonary function predicted by these exposures, especially among children reporting wheeze at baseline. We had hypothesized that morning exposures would result in an acute effect with larger decreases in pulmonary function, but instead found larger positive beta coefficients for several morning exposure models compared to 12hr exposures. These paradoxical results occurred at Schools 1 & 2 but not at School 3. This was especially troubling for the models with PM_{10} exposure, for which there is a substantial body of literature documenting deleterious health impacts, including pulmonary function outcomes. When analyses were stratified by time-in-study, however, there were no associations seen for Week 1 or Weeks 2-5, indicating previous confounding by time-in-study. There are several possible explanations for these effects, with limitations in both our exposure and outcome measures.

We chose to use pulmonary function testing as an objective and continuous measure of respiratory health. Accurate measurements with peak flow meters rely upon proficient technique, however, especially regarding the effort needed for maximal inhalation and exhalation. This maneuver is strenuous and susceptible to waning effort over time (Enright et al. 1994). The MWD peak flow meters were easy to use and United States Food and Drug Administration (FDA) approved for multi-participant use, however there are no immediate feedback mechanisms, e.g., error codes, indicating a faulty maneuver. Additionally, our study design in which entire classes completed the daily study protocol in 10 minutes did not allow for close monitoring of technique by trained staff, as would have been ideal. Over the course of the study our competence in training on the MWDs improved and later participants (i.e., School 3) received more frequent attention and reminders about their technique. We initially trained participants to use the MWD in small groups, but evolved to an approach that began with a group overview but concluded with individual participants demonstrating satisfactory technique to research staff. Even with improved training, pulmonary function measurements decreased over time-in-study for 2 of 3 data collection waves at School 3.

The pulmonary function parameter used most commonly to measure airway obstruction is FEV_1 (Watkins 1999) due to its close correlation with airway diameter (Enright et al. 1994). For valid measurement, participants must forcibly exhale for longer than one second. The MWD provides an indicator sound at one second, but users must notice the sound and repeat the measurement if the full length of exhalation is not achieved; a short effort was frequently observed by research staff. Statistics in Table 4.1 show that a smaller proportion of daily FEV_1 measurements achieved ATS repeatability standards than PEF measurements, with the largest proportions of records retained at School 3. Substantial measurement error may have resulted in bias that produced paradoxical effects on pulmonary function. It is also possible that application of ATS standards biased our results. There is evidence that failure to generate reproducible results is associated with reports of respiratory symptoms (Kellie et al. 1987) and may itself be an outcome (Becklake 1990). Finally, pulmonary function parameters may not be sensitive enough to reflect exposures described here; future analyses with self-reported symptoms may provide a more sensitive outcome measure.

Our exposure definitions may also have resulted in misclassification. The high density of CAFOs in participating areas leads to exposure opportunities at homes as well as schools, however it was not feasible to conduct monitoring at individual homes. The school-based measurements of PM_{10} and H_2S are intended to serve as direct exposure measures while children are at school and indicators of regional pollutant plumes when children are away from school; however this assumption may not be accurate. Even for the times children were at schools, we know that the majority of the time they were inside. Indoor concentrations of hydrogen sulfide were lower than those measured outside with <10 (0.02%) individual measurements exceeding 1ppb and zero 1hr means >1ppb. While means for indoor PM_{10} were lower than those for outdoor PM_{10}, we observed substantial short term spikes in indoor particulate concentrations, such as when the heat/air conditioning started in the morning, during sweeping or cleaning, and during class changes. Finally, air monitoring instruments provide continuous measurements with precise time resolution; however there may be times when plume constituents do not co-vary with each other and thus single pollutants may not accurately represent pollutant plumes (Heederik et al. 2007).

Although odor reports in the previous 12 hours encompass exposures at home as well as school, this exposure measure is self-reported and requires short-term recall. A key advantage is that the human nose can detect a much wider array of chemicals and may be sensitive to lower concentrations than individual instruments can measure (Bunton et al. 2007), while also best representing the direct exposures participants receive. Odor reports depend upon individual odor sensitivity, however adolescent olfactory threshold is similar to that of young adults, in whom olfactory function peaks (Lehrner et al. 1999). We also found a within-person decrease in odor reports predicted by day-in-study; this may have contributed to paradoxical associations in unstratified analyses.

There were 85 participants (25%) who never reported livestock odor during several weeks of participation, despite living in an area with high CAFO density. This seemed improbable to local research team members (who also speculated that embarrassment may affect reporting) and indicated potential measurement error for exposure assessment based on odor reports. The distributions of gender, school, grade, and race/ethnicity among these students approximated those of the entire study population, however there were 10 students whose families raised livestock or who were frequently involved in chores who never reported livestock odor (data not shown).

One additional time-varying factor that may be influencing observed results is atmospheric conditions. Odor and pollution plumes from CAFOs are known to be affected by temperature, humidity, wind speed, and direction. One study found that swine odor reports were correlated with hydrogen sulfide levels at low wind speeds and PM_{10} levels at high wind speeds (Wing et al. 2008b). Additional analysis classifying study days as low or high atmospheric stability may be warranted, since we would expect that plumes could be more locally relevant on days with high atmospheric stability.

On a final note, the RAPCH study was conducted in partnership with public middle schools with the broader goal of providing community benefits while conducting an epidemiologic study. We achieved educational benefits and increased community awareness of environmental health through the involvement of hundreds of students and their parents, teachers, and principals, as well as members of the REACH organization.

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Chapter V

Discussion

The Rural Air Pollutants and Children's Health study had two key objectives. The first was to conduct a community-based epidemiologic study that generated positive side effects. Specifically, we worked with middle school science classes to provide educational activities for the students, while also creating the potential for ripple effects for others involved, including school staff, parents, and REACH members. The second objective was to determine the effect of transient airborne exposures from CAFOs on acute respiratory responses in children. The analyses presented here focus on exposures to PM_{10}, H_2S, and odor with pulmonary function parameters as outcome measures.

The foundation of this study was a partnership between academic researchers from UNC and a community-based organization, REACH, which is concerned about the health impacts of CAFOs and sees research involvement as one avenue for positive change. Both partners bring different strengths to the partnership. Academics bring training in study design, conduct of research, analysis, and access to instrumentation for exposure and outcome assessment. Community members bring direct experience of air pollutants from CAFOs, not only regarding individual observations but also knowledge of community perceptions and the history of the industry in their neighborhoods. REACH also brings knowledge of community dynamics that influence openness to research participation, an aspect that is especially important in rural areas where academics can be perceived as unwelcome outsiders. We agreed that we wanted the process of research to be beneficial to the community regardless of the eventual results.

The study was carefully designed for participatory data collection. We worked with middle school science classes so that research activities were placed in a meaningful context for the students. We developed a simple but thorough study protocol that documented both self-reported and clinical outcomes, odor reports, daily time outside, and medication and medical care use. Students learned to collect their own data, including measuring their lung function with individually assigned peak flow meters. We provided interactive presentations about air pollutants and respiratory health, demonstrated scientific equipment, and shared preliminary results with students via graphs that they helped to interpret before making a figure of their own.

Our collaborative approach necessitated relationships with school staff – primarily teachers, but also principals, librarians, and custodial personnel. Hundreds of parents were informed about study activities. We also presented information about the study at REACH monthly meetings, though only research team members knew the specific schools involved. The school liaisons were REACH members interested in research with previous experience as educators. Academic members of the research team represented two departments at the UNC Gillings School of Global Public Health, Epidemiology and Environmental Sciences and Engineering. The potential ripple effects of study involvement are extensive.

The results of the process evaluation indicate that we achieved our goal of providing benefits during data collection. According to teachers, principals, and school liaisons, we increased student interest in science and research, provided valuable hands-on learning opportunities, reinforced the science curriculum, provided exposure to higher education, and raised awareness of environmental health. Teachers were exposed to university research and additional resources for classroom lessons. The school liaisons cited an enhanced interest in research and increased environmental awareness.

It is probable that there were broader community benefits beyond those stated in process evaluation interviews. Conducting a study brought attention to the potential health impacts of local air pollutants with CAFOs as a contributing source. This industrial approach to agriculture has become common in eastern North Carolina in the past several decades. The RAPCH study took place in the context of local efforts to understand the health and environmental impacts of CAFOs and an increasing awareness nationally of the externalized costs of industrial agriculture. Community organizations such as REACH often have the resources and skills to most effectively leverage information that spurs change toward improved public health (Leung et al. 2004; Wing 2005; Minkler et al. 2008).

A significant limitation of our process evaluation was that we did not interview student participants, due to prohibitive logistics of obtaining additional parental consent and student assent and conducting the interviews at the end of the school year. There was also a significant gap between data collection and the process evaluation – over a year for the first two schools that participated, and six to nine months for the third school. There may also be positive side effects for students that take longer to manifest, such as increased interest in science courses, environmental health, or scientific careers.

The quantitative results presented here are unexpected. We hypothesized that elevated levels of measured pollutants would produce negative within-person associations with pulmonary function parameters. We chose to analyze pulmonary function first in the RAPCH data as a continuous, clinical measure of respiratory response. We encountered challenges with measurement, however, and found evidence of substantial within-person decreases in lung function measurements over the course of the study, with the highest measurements immediately following training.

We used two definitions for each exposure, morning and 12hr. We had hypothesized that morning exposures would result in a more evident acute effect with larger decreases in pulmonary function, but instead found larger positive beta coefficients for several morning exposure models compared to models with 12hr exposures. We explored several subgroups to further examine these associations. Between strata of wheeze status, we found larger positive beta coefficients for participants reporting wheeze at baseline than for participants who didn't, which was contrary to our hypothesis that we would see larger negative beta coefficients among participants with wheeze. We knew there were differences between the five waves of participation, due to differing sites and increasing staff familiarity with participant training and the study protocol over time. Paradoxical results occurred at Schools 1 & 2 but not School 3, even though School 3 was the school with the most participants and highest exposures. It was also the school at which we were most experienced in administering the study protocol.

We had observed that pulmonary function and other measures reported in the diary decreased over time in study, so we employed two methods to control for possible confounding by time-correlated errors in measurement. We included a covariate for linear day-in-study by wave of data collection in all models, however it appeared that residual confounding remained. When data were stratified into Week 1 or Weeks 2-5, there were no associations seen in either stratum, as we would expect if previously observed associations were due to time-correlated measurement error. There are multiple aspects of our protocol that made valid measurement challenging: consistent maximal inhalation and exhalation is required for all pulmonary function measurement, the MWD peak flow meters provide no immediate feedback indicating a poor quality maneuver, and we were not able to closely monitor all student technique over time, which would have been ideal.

To our knowledge, there is only one other study of community exposures from CAFO air pollutants that used daily pulmonary function measurements; this study found decreased FEV_1 associated with exposure to fine particulates in the previous 12 hours (Schinasi et al. 2011). Schinasi et al. used a different peak flow meter that provided error flags for invalid measurements; only error-free values were analyzed and the influence of study time on measurements was not reported. In an effort to provide quality control in this analysis, we defined valid measurements as those in compliance with ATS repeatability standards. Yet there is evidence that failure to generate reproducible results is associated with reports of respiratory symptoms (Kellie et al. 1987) and may itself be an outcome (Becklake 1990). Further analyses are warranted that compare results with and without the application of ATS standards, employ relaxed standards, or define the outcome as failure to achieve ATS standards.

Our exposure definitions may also have limited our ability to see potential effects in the hypothesized direction. Odor reports reflect the personal exposures received by participants and can be triggered by numerous odorant chemicals associated with CAFOs in addition to H_2S, but they are self-reported and subject to recall. We also observed a decreased in odor reporting over time-in-study. Air monitoring instruments provide continuous measurements with precise time resolution; however ambient measurements at a single location may over or underestimate actual individual exposures. We were concerned that indoor PM_{10} values may have confounded associations, but saw no substantial change in results when we adjusted for the 1hr mean indoor PM_{10} just prior to diary completion. This adjustment also had limitations, however, because we only had an instrument in one of the three participating classrooms and students often changed rooms. It would also be ideal to account for possible confounding or modification by changing atmospheric conditions over time, such as temperature, humidity, wind speed, and direction.

While acknowledging limitations, the RAPCH study had many strengths. The longitudinal design allows us to estimate temporal associations between varying airborne exposures from CAFOs and acute respiratory response. By focusing on within-person affects, we eliminated potential sources of confounding between participants. The participatory approach provided a structure for building understanding of the research process (especially among students and community members), encouraged research participation among populations that typically do not participate in research studies, employed local knowledge from REACH members and school staff in the planning process, and ensured that study process and results will be of interest to the public.

The intent of the RAPCH study was to contribute to the documentation of societal costs of industrial agriculture (Merchant 2011) and inform policies and regulations addressing the health impacts of CAFOs, with children as a susceptible subpopulation. One point of action is the siting of CAFOs near schools and vice versa. Results from pulmonary function analyses presented here may suggest that additional precautions to protect children's respiratory health are not needed. We maintain that this study experienced limitations due to measurement error and additional research is needed to characterize impacts on pulmonary function. Additionally, pulmonary function is only one measure of respiratory health outcomes – respiratory symptoms have been more frequently associated with exposure to CAFO air pollutants in studies of adults that have measured both (Radon et al. 2007; Schinasi et al. 2011). Preliminary RAPCH analyses with symptom outcomes indicate that there are increased reports of irritation and respiratory symptoms associated with exposures to livestock odor in the previous 24 hours, especially among participants with allergies and wheeze at baseline. Documented effects on children from previous studies must also be considered (Merchant et al. 2005; Mirabelli et al. 2006a; Sigurdarson & Kline 2006). It may be that CAFO air pollutants do not affect daily changes in pulmonary function, but other impacts support a need for precautionary measures.

There are further analyses to conduct with the RAPCH data. One step will be to analyze symptom reports as another outcome measure. These results will likely be reported in combination with pulmonary function results so the two outcomes can be compared. We may also incorporate time-varying meteorological data into models as covariates.

Acknowledging the limitations of a single pollutant exposure assessment, we would also like to develop a more comprehensive exposure index. This could incorporate a combination of time-variant and time-invariant measures including indoor and outdoor pollutant concentrations at schools, characterization of particulate matter from passive monitors, estimates of home exposures using geocoded home addresses and proximity to CAFOs, reports of time outside in the previous 24 hours, and meteorological data. This would enable us to better characterize individual exposures over time.

RAPCH data may also be utilized in a cross-sectional design to avoid the influence of time-correlated measurement error. In this scenario, only high quality values from supervised training periods or the first day after training would be used as outcome measures. Exposures could be defined using estimates from geocoded home locations or measured air pollutants (monitors were measuring concentrations during training periods). We would no longer be able to investigate within-person responses over time, however we could still examine temporal associations between the preceding exposures and pulmonary function defined as a percent of predicted reference values. Alternatively, we could also compare home and school exposures with the prevalence of respiratory outcomes reported in the baseline survey.

The experience gained here also prompts recommendations for future studies. If pulmonary function is used as a repeatedly measured outcome, additional care must be taken to ensure data quality. Proper training is always essential, but ideally pulmonary function measurements would be undertaken with supervision from trained staff to encourage maximal inhalation and exhalation and sufficient time between maneuvers to allow full recovery. Instruments that provide immediate feedback regarding invalid technique may be preferable. Additionally, priority should be placed on analyzing data early in data collection to detect potential problems, something that was difficult to do between the first two waves of data collection (schools 1 & 2) due to a limited time frame. Most diary responses exhibited a decrease over time, likely due to study fatigue or comfort with the protocol that resulted in reduced attention to detail. For future studies a shorter follow-up period, e.g., 2 weeks, may provide a better balance between adequate repeat measures and higher quality data. Finally, future studies should have aspects of participation that benefit participants. This was a success of the RAPCH study, and public health would be served well if other research studies sought to do the same.

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Appendix A. Baseline Survey

Hello!

Thank you for participating in the Rural Air Pollutants and Children's Health study.

The questions you will answer here will help us to determine your breathing history, current health, and other characteristics about you that affect breathing. We'll guide you through the survey. There are three parts.

Please begin by writing your name below.

NAME:

____

HOME ADDRESS:

____________________	____________________	__________
Number and Street	*City, State*	*ZIP code*

Instructions:

Part I. When we say to start, please answer the questions in Part I by checking the box next to your answer. Please stop when you are done with this section. You may skip any questions that you don't want to answer.

Part II. When we say to start, please answer the questions in Part II by checking the box next to your answer. Please stop when you are done with this section. You may skip any questions that you don't want to answer.

Part III. For this section, we will watch a video together and then you will answer questions based on the video clips. Please check the box next to your answer as we go along.

Part I.
Please place an "X" in the box next to your answer.

Example:	☒	YES
	☐	NO

1. What grade are you in?

☐ **5th**

☐ **6th**

☐ **7th**

☐ **8th**

☐ **9th**

2. What is your birthday?

_________ / ________/ _________
(MONTH) (DAY) (YEAR)

3. What is your gender?

☐ **Female**

☐ **Male**

4. Which of the following groups best describe your race? You may check more than one.

☐ **Asian or Pacific Islander**

☐ **Black, African American**

☐ **Native American**

☐ **White**

☐ **Other**

5. Do you consider yourself to be Latino or Hispanic?

☐ **Yes**

☐ **No**

6. Where were you <u>born</u>? ***If you're not sure, you can leave parts blank.***

______________________	______________________	______________________
Country	***State or province***	***City***

7. Which of the following best describes how you pay for lunch at school?

- ☐ **I bring my lunch to school**
- ☐ **I pay the full price for lunch at school**
- ☐ **I get a reduced price lunch at school**
- ☐ **I get a free lunch at school**

8. Do you have any of the following allergies? ***Mark YES, NO, or DO NOT KNOW for each.***

	YES	NO	DO NOT KNOW
Dog allergies	☐	☐	☐
Cat allergies	☐	☐	☐
Dust allergies	☐	☐	☐
Grass or pollen allergies	☐	☐	☐

9. Does your family raise any livestock (farm animals) such as chickens, turkeys, hogs, or cattle?

- ☐ **Yes**
- ☐ **No**

10. How often do you assist with chores around livestock (farm animals)?

- ☐ **Never**
- ☐ **Once or twice a month**
- ☐ **Once or twice a week**
- ☐ **Almost every day**
- ☐ **Every day**

11. Have you ever smoked cigarettes?

- ☐ **Yes**
- ☐ **No**

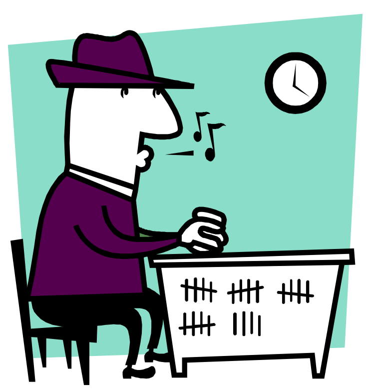
12. ***During the past 30 days,*** **on how many days did you smoke cigarettes?**

- ☐ **0 days**
- ☐ **1 - 7 days**
- ☐ **8 – 14 days**
- ☐ **15 – 20 days**
- ☐ **Almost every day**

13. About how often are you near enough to smell or breathe in the smoke from other people's cigarettes?

- ☐ **Never**
- ☐ **Less than once a week**
- ☐ **Once a week**
- ☐ **2 – 4 times per week**
- ☐ **Nearly every day**

Please STOP when you are finished with Part I and wait for further instructions.



Part II.

Please answer questions 1-9 by placing an "X" in the box next to your answer.

Example:		
	☒	YES
	☐	NO

1. Have you <u>ever</u> had wheezing or whistling in the chest?

☐ **YES**

☐ **NO**

*IF YOU ANSWERED "NO" PLEASE SKIP TO **QUESTION 6** AND **WAIT** FOR INSTRUCTIONS.*

2. Have you had wheezing or whistling in the chest <u>in the last 12 months?</u>

☐ **YES**

☐ **NO**

*IF YOU ANSWERED "NO" PLEASE SKIP TO **QUESTION 6** AND **WAIT** FOR INSTRUCTIONS.*

3. How many attacks of wheezing have you had <u>in the last 12 months?</u>

- ☐ **1 to 3**
- ☐ **4 – 12**
- ☐ **More than 12**

4. <u>In the last 12 months</u>, how often, on average, has your sleep been disturbed due to wheezing?

- ☐ **Never**
- ☐ **Less than one night per week**
- ☐ **More than one night per week**

5. <u>In the last 12 months</u>, has wheezing been severe enough to limit your speech to only one or two words at a time between breaths?

- ☐ **YES**
- ☐ **NO**

6. Has a doctor or other health professional <u>ever</u> told you that you have asthma?

☐ **YES**

☐ **NO**

7. <u>In the last 12 months</u>, has your chest sounded wheezy during or after exercise?

☐ **YES**

☐ **NO**

8 <u>In the last 12 months</u>, have you had a dry cough at night, apart from a cough associated with a cold or chest infection?

☐ **YES**

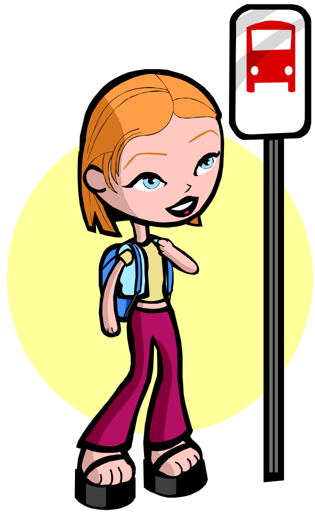
☐ **NO**

9. During the past 12 months, have you visited an emergency room or urgent care center because of wheezing or asthma?

☐ **YES**

☐ **NO**

Please STOP when you are finished with Part II and wait for further instructions.



Part III.
Now we will watch a video and then answer questions that match each clip. We will help by telling you when to answer each question. Please check the box for your answer to each question.

		YES	NO
1.	**Has your breathing been like this at any time in your life?**	☐	☐
	If yes, has this happened in the last year?	☐	☐
	If yes, has this happened at least once a month?	☐	☐
2.	**Has your breathing been like the boy's in the dark shirt following exercise at any time in your life?**	☐	☐
	If yes, has this happened in the last year?	☐	☐
	If yes, has this happened at least once a month?	☐	☐
3.	**Have you been awakened like this at night?**	☐	☐
	If yes, has this happened in the last year?	☐	☐
	If yes, has this happened at least once a month?	☐	☐
4.	**Have you been awakened like this at night?**	☐	☐
	If yes, has this happened in the last year?	☐	☐
	If yes, has this happened at least once a month?	☐	☐
5.	**Has your breathing been like this at any time in your life?**	☐	☐
	If yes, has this happened in the last year?	☐	☐
	If yes, has this happened at least once a month?	☐	☐

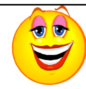
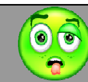
Thank you for your cooperation in completing this survey!

Appendix B. Structured Daily Diary

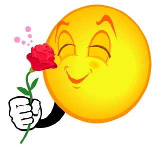
Instructions: There are 5 steps to complete for each day. Work through them one by one and let your teacher know if you have any questions!

STEP #1
SYMPTOMS

How much do you feel each symptom in the list below? Fill in ONE box in each row.

	 Not at all	Barely feel it	Present	Strong	 Very Strong
Ex**: My throat hurts a little today.* ***SORE THROAT	☐	■	☐	☐	☐
RUNNY NOSE	☐	☐	☐	☐	☐
HEADACHE	☐	☐	☐	☐	☐
NAUSEA	☐	☐	☐	☐	☐
SORE THROAT	☐	☐	☐	☐	☐
COUGH	☐	☐	☐	☐	☐
WHEEZE	☐	☐	☐	☐	☐
SHORT OF BREATH	☐	☐	☐	☐	☐
CHEST TIGHT	☐	☐	☐	☐	☐
TROUBLE HEARING	☐	☐	☐	☐	☐
BACK ACHE	☐	☐	☐	☐	☐
BURNING EYES OR NOSE	☐	☐	☐	☐	☐

Step #2
ODORS



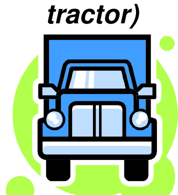
How much odor from engine exhaust, livestock, or smoke have you smelled during the last 24 hours? For each odor, please fill in ONE box in each row.

a) If you *did not* smell the odor, fill in "NONE" for that time. You don't need to fill in anything else.
b) If you *did* smell the odor, fill in ONE box for how strong it was.

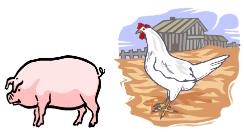
***Example**: If yesterday afternoon you smelled some poultry odor but it wasn't very strong, and yesterday evening you didn't smell any poultry odor, your boxes would be filled in completely like this:*

LIVESTOCK					
	NONE	Barely There	Present	Strong	Very Strong
Yesterday Afternoon	☐	☐	■	☐	☐
Yesterday Evening	■	☐	☐	☐	☐

How much engine exhaust did you smell during each time period?

#1 ENGINE EXHAUST *(car, truck, bus, tractor)* 		NONE	Barely There	Present	Strong	Very Strong
	Yesterday Afternoon	☐	☐	☐	☐	☐
	Yesterday Evening	☐	☐	☐	☐	☐
	Last Night	☐	☐	☐	☐	☐
	This morning	☐	☐	☐	☐	☐

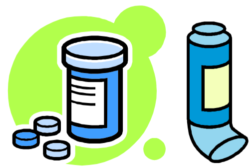
How much <u>livestock odor</u> did you smell during each time period?

		NONE	Barely There	Present	Strong	Very Strong
#2 LIVESTOCK 	Yesterday Afternoon	☐	☐	☐	☐	☐
	Yesterday Evening	☐	☐	☐	☐	☐
	Last Night	☐	☐	☐	☐	☐
	This morning	☐	☐	☐	☐	☐

How much <u>smoke</u> did you smell during each time period?

		NONE	Barely There	Present	Strong	Very Strong
#3 SMOKE *(burning trash, leaves, or other waste)* 	Yesterday Afternoon	☐	☐	☐	☐	☐
	Yesterday Evening	☐	☐	☐	☐	☐
	Last Night	☐	☐	☐	☐	☐
	This morning	☐	☐	☐	☐	☐

STEP #3
MEDICATION & ILLNESS



Answer each question below by filling in YES or NO:

1) In the past 24 hours, did you take any **medication for breathing problems** that you don't take every day (also called "**rescue meds**")?

☐ **YES** *If yes, how many times did you use your medication?* ___

☐ **NO**

2) In the past 24 hours, did you take any medication for **allergies** that you don't take every day?

☐ **YES**

☐ **NO**

3) In the past 24 hours, have you **seen a doctor** because of respiratory illness?

☐ **YES**

☐ **NO**

4) *Since your last diary entry*, have you **missed school** because of respiratory illness?

☐ **YES**

☐ **NO**

STEP #4
TIME OUTSIDE

How many hours did you spend outside in the last 24 hours? Please fill in a box below.

☐ **Less than 1 hour**	☐ **1 hour**	☐ **2 hours**	☐ **3 hours**	☐ **4 hours**	☐ **5 hours or more**

STEP #5
BREATHING

How is your breathing today? Follow these instructions to measure it:

1) Go.
2) Breathe in.
3) **BLAST through the BEEP!!!**
4) Record.
5) Turn off.
6) Turn on and repeat.

Example	1^{st} Try	2^{nd} Try	3^{rd} Try
FEV_1: 1.71 L	**FEV_1:____ L**	**FEV_1:____ L**	**FEV_1:____ L**
PEF: 233 L/min	**PEF :____ L/min**	**PEF :____ L/min**	**PEF :____ L/min**

GOOD JOB! YOU FINISHED TODAY'S DIARY!

APPENDIX C. Supplemental Tables

Table C.1. Comparison of Outdoor Hydrogen Sulfide Measurements from the Single Point Monitor (SPM) and Thermo Hydrogen Sulfide - Sulfur Dioxide Analyzer (Thermo)*

Instrument	School 1	School 2	School 3	Total
SPM^				
N	7560	11733	18291	37584
Mean	0.15	0.03	0.16	0.12
Standard deviation	0.37	0.18	0.48	0.39
99th percentile	1.55	0.76	2.00	1.55
95th percentile	0.85	0	0.80	0.71
50th percentile	0	0	0.00	0
5th percentile	0	0	0	0
1st percentile	0	0	0	0
Days >1ppb H2S detected, N (%)	11 (41%)	4 (10%)	27 (41%)	42 (31%)
Thermo**				
N	--	--	16107	16107
Mean	--	--	0.53	0.53
Standard deviation	--	--	0.72	0.72
99th percentile	--	--	3.08	3.08
95th percentile	--	--	1.25	1.25
50th percentile	--	--	0.15	0.15
5th percentile	--	--	0.09	0.09
1st percentile	--	--	0.09	0.09
Days >1ppb H2S detected, N (%)	--	--	55 (96%)	55 (96%)

*Date ranges correspond to diary completion dates for each wave plus one day prior: Feb 22-Mar 20 for School 1, Mar 29-May 8 for School 2, and for School 3, Sept 7-Oct 2, Oct 11-29, and Nov 5-25.

^15 minute averages reported every 5 minutes

**5 minute averages, deployed from Sept 15-Nov 25

-- indicates no data collected

Table C.2. Single Pollutant Linear Fixed Effects Models of Livestock Odor, Hydrogen Sulfide and Particulate Matter <10µg/m³ as Predictors of Lung Function Stratified by Frequent Livestock Exposure‡

	FEV1 (L)				PEF (L/min)			
Exposure	**Records**	**β**	**SE**	**t**	**Records**	**β**	**SE**	**t**
	Frequent Livestock Exposure							
12hr livestock odor*	739	0.010	0.026	0.40	887	3.984	4.144	0.96
Morning livestock odor*	742	0.025	0.029	0.85	890	4.525	4.595	0.98
12hr H2S (ppb)^	754	0.003	0.025	0.13	897	1.557	3.519	0.44
Morning H2S (ppb)^	751	0.004	0.015	0.28	893	2.059	2.172	0.95
12hr PM10 (10µg/m³)^	692	0.004	0.006	0.71	820	0.803	0.824	0.97
Morning PM10 (10µg/m³)^	638	0.005	0.005	1.01	762	0.726	0.728	1.00
	No Frequent Livestock Exposure							
12hr livestock odor*	2621	0.016	0.012	1.32	3093	4.821	2.288	2.11
Morning livestock odor*	2626	0.014	0.013	1.06	3099	5.854	2.501	2.34
12hr H2S (ppb)^	2648	0.004	0.011	0.35	3128	0.615	2.255	0.27
Morning H2S (ppb)^	2635	0.006	0.007	0.98	3115	0.207	1.276	0.16
12hr PM10 (10µg/m³)^	2459	-0.002	0.003	-0.88	2906	0.843	0.485	1.74
Morning PM10 (10µg/m³)^	2285	0.001	0.002	0.38	2701	0.641	0.454	1.41

‡Frequent = Family raises livestock or involved in livestock chores almost every day or every day
*Adjusted for other odors and day in study by round of participation
^Adjusted for day in study by round of participation

Table C.3. Single Pollutant Linear Fixed Effects Models of Livestock Odor, Hydrogen Sulfide and Particulate Matter <10µg/m³ as Predictors of Lung Function Stratified by Allergy Status‡

	FEV1 (L)				PEF (L/min)			
Exposure	**Records**	**β**	**SE**	**t**	**Records**	**β**	**SE**	**t**
				Allergy				
12hr livestock odor*	1047	0.029	0.018	1.58	1227	4.814	3.426	1.41
Morning livestock odor*	1051	0.019	0.020	0.96	1232	4.202	3.836	1.10
12hr H2S (ppb)^	1054	-0.013	0.018	-0.73	1237	-1.389	3.720	-0.37
Morning H2S (ppb)^	1049	-0.003	0.010	-0.26	1231	0.391	2.082	0.19
12hr PM10 (10µg/m³)^	992	-0.005	0.004	-1.15	1153	1.532	0.782	1.96
Morning PM10 (10µg/m³)^	914	-0.000	0.004	-0.08	1067	1.878	0.746	2.52
				No Allergy				
12hr livestock odor*	2291	0.019	0.014	1.35	2720	4.876	2.504	1.95
Morning livestock odor*	2295	0.020	0.015	1.30	2724	5.860	2.715	2.16
12hr H2S (ppb)^	2324	0.013	0.013	0.97	2753	2.030	2.250	0.90
Morning H2S (ppb)^	2313	0.013	0.008	1.58	2743	0.755	1.330	0.57
12hr PM10 (10µg/m³)^	2134	0.002	0.003	0.57	2538	0.572	0.503	1.14
Morning PM10 (10µg/m³)^	1989	0.003	0.003	1.17	2367	0.236	0.454	0.52

‡Allergy = any allergy to at least one of the following: dog, cat, grass or pollen, or dust
*Adjusted for other odors and day in study by round of participation
^Adjusted for day in study by round of participation

Table C.4. Single Pollutant Linear Fixed Effects Models of Livestock Odor, Hydrogen Sulfide and Particulate Matter <10μg/m³ as Predictors of Lung Function Stratified by Frequent Second Hand Smoke Exposure‡

	FEV1 (L)				PEF (L/min)			
Exposure	**Records**	**β**	**SE**	**t**	**Records**	**β**	**SE**	**t**
	Frequent Second Hand Smoke Exposure							
12hr livestock odor*	963	0.019	0.020	0.94	1170	3.442	3.432	1.00
Morning livestock odor*	966	0.012	0.022	0.57	1174	3.880	3.716	1.04
12hr H2S (ppb)^	980	-0.003	0.019	-0.17	1189	-2.150	3.470	-0.62
Morning H2S (ppb)^	979	0.000	0.014	0.02	1188	-2.784	2.327	-1.20
12hr PM10 (10μg/m³)^	875	0.003	0.005	0.62	1058	0.712	0.806	0.88
Morning PM10 (10μg/m³)^	816	0.006	0.004	1.43	984	0.890	0.697	1.28
	No Frequent Second Hand Smoke Exposure							
12hr livestock odor*	2406	0.017	0.013	1.28	2814	4.508	2.488	1.81
Morning livestock odor*	2411	0.021	0.015	1.40	2819	5.614	2.744	2.05
12hr H2S (ppb)^	2431	0.007	0.013	0.57	2840	2.271	2.298	0.99
Morning H2S (ppb)^	2416	0.007	0.007	1.05	2824	1.614	1.272	1.27
12hr PM10 (10μg/m³)^	2285	-0.001	0.003	-0.45	2673	0.958	0.495	1.94
Morning PM10 (10μg/m³)^	2115	0.001	0.003	0.53	2483	0.736	0.465	1.58

‡Frequent second hand smoke exposure is defined as responding "Nearly every day" at baseline
*Adjusted for other odors and day in study by round of participation
^Adjusted for day in study by round of participation

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