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Air Pollution from Industrial Swine Operations and Blood Pressure of Neighboring Residents

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Conflict of interest: Steve Wing provided pro bono testimony in legal proceedings related to landfills and provided pro bono advice on radiation and health for a law firm that made a gift to the University of North Carolina and another law firm that did not make a gift to the University of North Carolina. He conducted research, funded by the Water and Environment Research Foundation, on symptoms reported by neighbors of areas where sewage sludge is applied to land.

Abbreviations

CAFO: Confined Animal Feeding Operation

DBP: Diastolic Blood Pressure

H_2S: Hydrogen Sulfide

JHAC: John Henryism Active Coping

mmHg: Millimeters of mercury

PM_{10}: Particulate Matter less than 10 microns in aerodynamic diameter

SBP: Systolic Blood Pressure

SE: Standard Error

Abstract

Background: Industrial swine operations emit odorant chemicals including ammonia, hydrogen sulfide, and volatile organic compounds. Malodor and pollutant concentrations have been associated with self-reported stress and altered mood in prior studies.

Objectives: We conducted a repeated measures study of air pollution, stress, and blood pressure of swine operation neighbors.

Methods: For approximately two weeks, 101 non-smoking adult volunteers living near industrial swine operations in 16 neighborhoods in eastern North Carolina, USA, sat outdoors for 10 minutes twice daily at pre-selected times. Afterwards, they reported levels of hog odor on a 9-point scale and measured their blood pressure twice using an oscillometric, automated device. Simultaneously, we measured ambient levels of hydrogen sulfide (H_2S) and particulate matter $\leq$10 μm in aerodynamic diameter at a central location in each neighborhood. Associations between systolic and diastolic blood pressure (SBP, DBP) and pollutant measures were estimated using fixed effects (conditional) linear regression with adjustment for time-of-day.

Results: Particulate matter showed little association with blood pressure. DBP (±standard error) increased 0.23±0.08 mmHg per unit of reported hog odor during the 10 minutes outdoors and 0.12±0.08 mmHg per 1 ppb increase of H_2S concentration in the same hour. SBP increased 0.10±0.12 mmHg per odor unit and 0.29±0.12 mmHg per 1 ppb increase of H_2S in the same hour. Reported stress was strongly associated with BP; adjustment for stress reduced the odor-DBP association, but the H_2S-SBP association changed little.

Conclusions: Like noise and other repetitive environmental stressors, malodors may be associated with acute blood pressure increases that could contribute to development of chronic hypertension.

Introduction

The rapid global expansion of confined animal feeding operations (CAFOs) has created environmental health concerns at local, regional, and global scales, including infectious and respiratory diseases, reduced quality of life, impacts on the built environment, and environmental injustice (Pew Commission on Industrial Food Animal Production 2008). CAFO airborne emissions, including ammonia, hydrogen sulfide, volatile organic compounds, and endotoxins, originate from confinement buildings, waste storage areas, and land application of animal waste (National Academy of Sciences 2003).

North Carolina (NC) experienced a rapid transformation of swine production during the 1980s and 1990s. The number of producers declined, the size of operations grew, the swine population increased from approximately 2.5 to 10 million, and production shifted to the eastern coastal plain region of the state (Furuseth 1997). In North Carolina swine CAFOs are concentrated in low income communities of color (mostly African-American) where older housing and lack of central air conditioning could increase human exposure to air pollutants (Wing et al. 2000). Studies conducted in Germany and the United States report that neighbors describe odors from swine CAFOs as annoying and offensive (Schiffman 1998; Tajik et al. 2008; Thu 2002; Thu 2003; Thu and Durrneberger 1998; Radon et al. 2007). We previously reported that, in communities neighboring North Carolina CAFOs, self-reported hog odor and hydrogen sulfide (H_2S) are associated with acute irritation of the eyes, nose, and throat, and particulate matter ≤ 10 µm in aerodynamic diameter (PM_{10}) is associated with eye irritation (Schinasi et al. 2011). In addition to physical symptoms and negative mood (Schiffman et al. 1995; Bullers 2005; Horton et al. 2009), CAFO neighbors have reported being unable to engage in valued traditions of rural life, including gardening, family gatherings, cookouts, visiting neighbors, and drying laundry, due to frequent and unpredictable episodes of malodor (Tajik et al. 2008; Thu 2002; Thu 2003; Thu and Durrneberger 1998).

Several studies have found relationships between malodor from swine CAFOs and chronic (Schiffman et al. 1995) or acute (Horton et al. 2009) stress in neighbors. Other studies have reported that environmental stressors are associated with increased blood pressure (Attarchi et al. 2012; Belojevic and Evans 2012; Djindjic et al. 2012), and that odorant compounds perceived as pleasant attenuated exercise-related increases in blood pressure (Nagai et al. 2000). African-Americans and low income people experience an excess prevalence of chronic hypertension (Carson et al. 2011; Liao et al. 2011; Keenan and Rosendorf 2011) and hypertension-related morbidity (Liao et al. 2011) and mortality (Fiscella and Holt 2008). Identification of environmental factors that contribute to blood pressure elevations could inform efforts to prevent upward shifts of blood pressure in populations.

In this paper we evaluate whether measures of swine CAFO air pollution were associated with acute changes in blood pressure among neighbors during follow-up of approximately two weeks. We did not compare blood pressures of CAFO neighbors and other people; rather, we compared each participant's blood pressure during times of more vs. less exposure to swine CAFO air pollution. In this design each participant serves as her or his own control. Characteristics that were essentially constant during the short follow-up (e.g., age, socioeconomic position, medical history, body mass, occupation, personality) cannot cause bias in estimates of the exposure-outcome relationship. Chronic effects of exposure, however, cannot be evaluated.

Methods

Setting and data collection. The study was conducted in partnership with the Concerned Citizens of Tillery (CCT), a community-based organization in Halifax County that promotes the health, environmental, and political interests of predominantly African-American communities in eastern North Carolina (Wing et al. 1996). CCT has partnered with universities to provide medical care through the Tillery People's Clinic and to conduct research on health and environmental justice (Tajik and Minkler 2006). For this study, CCT staff organized community meetings in areas with a high density of swine CAFOs and provided information about our ongoing study to attendees, who were invited to contact CCT or UNC researchers if they were interested in participating in the study (Wing et al. 2008a). We sequentially enrolled between four and 10 volunteers in each of 16 rural communities from 2003-2005, and participants began data collection within 24-36 hours. Enrollment did not occur from mid-December – mid-February due to holidays and cold weather. Numbers of nearby swine CAFOs, participants, and other community-specific characteristics have been reported previously (Wing et al. 2008b).

To be eligible, participants had to be 18 or more years old, non-smokers, and live within 1.5 miles of at least one swine CAFO (Wing et al. 2008a), defined as a facility housing more than 250 head and using a liquid waste management system (Wing et al. 2000). At an initial training session, participants chose morning and evening times when they would sit outside each day for approximately two weeks (in three neighborhoods participants chose to continue up to one more week). They provided information about regular use of medications, and their odor sensitivity was tested using a standard set of butanol dilutions to evaluate the lowest concentration that could be distinguished from zero (see, for example, Croy et al. 2009). They completed the John Henryism Active Coping (JHAC) scale, which measures the predisposition to respond behaviorally to psychosocial environmental stressors (James et al. 1987); higher values indicate a greater predisposition to cope actively. Participants were classified by reported use (yes, no) of antihypertensive medications (e.g., drugs classified as beta blockers, calcium channel blockers, angiotensin-converting-enzyme inhibitors, diuretics, etc.). They learned how to use a structured diary to record levels of swine odor, stress, and symptoms, and practiced measuring their BP with an automated oscillometric device. Time spent outdoors and times of diary completion were tracked using a digital clock provided and set by researchers. Informed consent was obtained at the training session using a procedure approved by the University of North Carolina Institutional Review Board, which reviewed the study annually. We obtained a Certificate of Confidentiality from the National Institutes of Health (Wing et al. 2008a) because of prior attempts by the pork industry to obtain confidential records (Wing 2002).

Each morning and evening, participants sat outside for 10 minutes while completing the 1^{st} of 4 pages of a data collection diary. They then returned indoors to complete the remaining pages and measure their blood pressure (Wing et al. 2008a). They rated the strength of swine odor during the 10-minutes outdoors on a nine-level Likert-type scale from 0 (none) to 8 (very strong), and evaluated perceived stress ("How do you feel now . . . stressed or annoyed?) on a nine-level scale from 0 (none) to 8 (extremely). Participants measured their blood pressure twice in a seated position; they were instructed to wait 1 minute between readings, raising their right arm above their head for the 1^{st} 30 seconds, and then resting for the remaining time before taking their blood pressure again. They printed the results and taped the printout with the systolic (SBP) and diastolic (DBP) values and current time into the diary. We treated the average of the two readings as dependent variables.

While participants collected data, we monitored air pollution at a central location in each neighborhood. The mean and median distance from air monitors to participant homes was 0.2 and 0.1 miles, respectively (Wing et al. 2008a). Swine CAFOs release many odorant chemicals including ammonia, hydrogen sulfide, and hundreds of volatile organic compounds (Schiffman et al. 2001). Odorant chemicals may occur as gases or particles. We quantified hydrogen sulfide (H_2S), which is produced by the anaerobic decomposition of fecal waste, as a marker of this complex mixture that is related to hog odor intensity (Wing et al. 2008b; Schiffman et al. 2005). H_2S is a specific marker of swine CAFO pollution in the study areas because other H_2S-emitting industries such as waste water treatment plants, petrochemical plants, and paper mills, were not present. Average ambient H_2S concentrations measured every 15 minutes with an MDA Scientific Single Point Monitor (Zellweger Analytics, Inc., North America, Lincolnshire, IL) were used to calculate hourly averages; 15-minute values below the detection limit of 2 ppb were treated as zero. One-hour average concentrations prior to blood pressure measurements were considered as predictors of SBP and DBP.

We measured hourly levels of particulate matter ≤ 10 μm in aerodynamic diameter (PM_{10}) using a Rupprecht & Patashnick Tapered Element Oscillating Microbalance Series 1400a Ambient Particulate Monitor. A Series 8500 FDMS Filter Dynamics Measurement System (Rupprecht and Patashnick Co, Inc., East Greenbush, NY) was used to quantify semi-volatile PM_{10}. Semi-volatile particles consist of compounds that are present in both vapor and condensed phases. Airborne particulate matter is ubiquitous; although CAFOs are one source, particles are not a specific marker of CAFO pollutants. We reported previously that semi-volatile PM_{10} showed little association with hog odor in the study neighborhoods, and that PM_{10} was only related to hog odor when wind speeds were high (Wing et al. 2008b).

Statistical analysis. In this repeated measures design, each participant served as her or his own control. The sample size is a function of the number of participants and the number of observations (records) per person. We used linear fixed effects regression to model repeated measures for individuals (Allison 2005). This approach estimates the average within-person associations between exposure measures and blood pressure by conditioning on person, and eliminates bias from any measured or unmeasured confounding factors that do not change during follow-up. Relationships between SBP and DBP and air pollution appeared linear across categories of exposure (data not shown), so they were modeled as continuous variables. Blood pressure varies diurnally, as do hog odor and H_2S (Wing et al. 2008b), therefore time-of-day (AM vs. PM) was included as a covariate in all models. In separate analyses we also adjusted for self-reported stress, a potential mediator of associations between pollutants and blood pressure. Gender and odor detection threshold (dichotomized at the median) were considered as potential modifiers related to odor perception, while JHAC score (dichotomized at the median) and use of anti-hypertensive medication (yes, no) were considered as potential modifiers of blood pressure reactivity to environmental stressors. We also considered modification by age (dichotomized at the median) because it could influence either odor perception or blood pressure reactivity.

Observations (records) with missing values for a variable were dropped from models including that variable. Model coefficients represent the average within-person change in blood pressure (mmHg) for each unit increase in pollution. In non-randomized studies confidence limits and p-values do not quantify the confidence or probability that a point estimate would occur within a specified interval due to chance, therefore we report standard errors of the regression coefficients as a measure of precision and t-values as indicators of the improvement in the fit of the model associated with the exposure variable. Degrees of freedom for t-tests, n-1, are large and can be considered equivalent for comparing t-values.

Results

Descriptive characteristics of the 101 participants are given in Table 1. Half of the participants were older than 53 years and two-thirds were women. Among the 97 participants whose odor detection threshold was determined, 55 had a butanol odor detection threshold of 40 ppm or less. 42 participants reported taking one or more blood pressure medications. Among the 96 participants who completed the JHAC, 46 had a score greater than 52. Most participants (85) identified themselves as Black.

Distributions of reported hog odor intensity during the 10-minutes outdoors, average pollutant concentrations in the hour prior to the blood pressure measurement, SBP, and DBP, are presented in Table 2. Odor ratings were missing in 6% of the records. There was no odor reported in 48% of the records. Very strong odor (a rating of 6, 7, or 8) was reported 6% of the time. Hourly H_2S measurements were missing in approximately 9% of the records, and most (88%) were below the limit of detection (2 ppb). PM measures were missing in 32.2% of the records primarily due to equipment malfunction during periods of high temperature and humidity (Wing et al. 2008b). 12.4% of semi-volatile particle concentrations were < 0; this occurs at low concentrations because microbalance estimates are derived by subtraction of sequential mass values that are measured with error (Wing et al. 2008b). Blood pressure was missing in 1.4% of the records. SBP readings were below 120 mmHg in approximately 30% of the records and above 140 mmHg in approximately 25% of the records. DBP was below 80 mmHg in 61% of the records and at or above 90 mmHg in 11% of the records. No participants were missing data for all their records.

Associations between air pollutants and blood pressure adjusted for time-of-day (AM or PM) are presented in Table 3. Each unit increase in reported hog odor on the 0-8 intensity scale was associated with average estimated increases of 0.10±0.12 and 0.23±0.08 mmHg for SBP and DBP, respectively. A 1-ppb increase in H_2S was associated with increases of 0.29±0.12 mmHg for SBP and 0.12±0.08 mmHg for DBP. PM_{10} was not associated with blood pressure. Semi-volatile PM_{10} was not associated with SBP and had a small negative association with DBP (-0.06±0.03).

Table 4 provides beta coefficients for hog odor and H_2S according to potential modifying variables. Coefficients for PM_{10} and semi-volatile PM_{10} are not shown because their main effect estimates were small, they are not specific markers of swine CAFO air pollution, and data are missing for almost one-third of the records. Hog odor coefficients for SBP were all positive, but none had t-values bigger than 1.17. Coefficients for DBP were positive and all had t-values near 2 or above except for participants 53.7 years of age or younger, for whom the beta coefficient is 0.08±0.12. Coefficients for both SBP and DBP were larger for older compared with younger participants (0.14±0.15 and 0.33±0.10 versus 0.04±0.18 and 0.08±0.12, respectively) and for men compared with women (0.20±0.23 and 0.36±0.15 versus 0.07±0.13 and 0.19±0.09, respectively). Associations between hog odor and SBP were larger for participants with JHAC scores of 52 or less (0.18±0.17 compared with 0.01±0.16) and for participants who reported no versus any regular use of antihypertensive drugs (0.19±0.16 compared with 0.01±0.17). For H_2S, coefficients for both SBP and DBP were larger for men than women (0.56±0.30 and 0.48±0.19 compared with 0.24±0.13 and 0.05±0.08, respectively), participants with butanol odor sensitivity thresholds >40 ppm than ≤40 ppm (0.33±0.14 and 0.13±0.09 compared with 0.17±0.22 and 0.07±0.14, respectively), and participants with JHAC scores of ≤52 than >52 (0.36±0.14 and 0.17±0.09 compared with 0.02±0.24 and -0.07±0.15, respectively). The SBP coefficient was larger for participants who did not, compared to those who did, report taking BP medications (0.38±0.14 compared with 0.07±0.22).

SBP and DBP were strongly associated with reported stress, increasing on average 0.82±0.21 (t=3.98) and 0.57±0.13 mmHg (t=4.28), respectively, for every unit increase on the 0-8 scale. We included stress in models reported above (in addition to time of day) to evaluate whether associations of blood pressure with hog odor and H_2S change after adjustment for this potential mediator. With adjustment for reported stress, coefficients for the association between hog odor and DBP declined from 0.23±0.08 to 0.15±0.08, while the coefficient for SBP decreased from 0.10±0.12 to -0.04±0.12. With adjustment for reported stress, there was little change in the coefficient for the association between H_2S and DBP (0.15±0.08 versus 0.12±0.08 before adjustment) or SBP (0.26±0.12 versus 0.29±0.12 before adjustment).

Discussion

In this community-based, participatory, repeated-measures study we found that, on average, blood pressure of swine CAFO neighbors increased in association with increases in markers of transient plumes of odorant air pollution. Because each participant served as her or his own control, factors that did not change during the two-week study, including body mass, race, socioeconomic position, medical and dietary history, and prior blood pressure, could not confound these associations. Estimated DBP was almost 2 mmHg higher during periods of very strong odor (a rating of 8) compared to none, and estimated SBP was almost 3 mmHg higher when H_2S concentrations were 10 ppb compared to times when H_2S was zero (below the limit of detection). This magnitude of effect could have public health importance due to the frequency and duration of odor episodes near CAFOs. The 101 people who participated in this study for approximately two weeks reported 1,655 episodes of outdoor hog odor, 38% of which lasted more than 1 hour, and 17% of which had a mean odor ≥ 5; participants also reported 500 episodes of indoor odor (Wing et al. 2008b). If the associations were causal, and if malodors from other sources such as sewage, landfills, and chemical refineries produce similar effects, then control of environmental malodor might help prevent repeated acute elevations of BP that could contribute to development of chronic hypertension.

With approximately 29 measures per person, the sample size for this study was primarily suited to examining within-person co-variation in exposures and outcomes. Although estimates within subgroups defined by non-time-varying factors are imprecise, some interactions are of interest. Associations between H_2S and SPB were similar for older and younger participants, whereas the odor–DBP association was observed primarily among older participants. Beta coefficients for both odor and H_2S were larger for men than women. The magnitude of the association between blood pressure and hog odor was not related to butanol odor sensitivity threshold. Because the effectiveness of their active coping is reduced by lack of resources, people with high John Henryism and low socioeconomic position are expected to be more physiologically reactive to psychosocial stressors than people with high John Henryism and high socioeconomic position, or people with low John Henryism (James et al. 1987). Contrary to our expectation, even though all participants in this study lived in low income areas, associations between hog air pollution markers and blood pressure were not stronger among participants with high John Henryism. Associations for SBP were generally weaker among participants who were taking blood pressure medications, which may dampen responses to environmental stimuli.

Although the repeat-measures design and fixed effects analysis precludes confounding from time-independent factors that differ between people, time-related factors associated with both air pollution and BP could have either attenuated or exaggerated associations. Time of day (AM vs. PM) was included in all models, therefore potential time-related factors would need to be associated with pollution and blood pressure within times of day in order to act as confounders. Time-related confounding could occur if a cause of acute blood pressure change that is not a consequence of CAFO air pollution co-varied with the CAFO air pollutants in participants' neighborhoods.

Measurement errors could also impact estimates of association between odorant pollutants and blood pressure. In a clinical or experimental setting, blood pressure is typically measured by a trained technician in a standardized manner. In contrast, in the current study, each participant measured her or his blood pressure twice each day in the home, which could reduce the precision of the effect estimates. Use of a portable printer with a time stamp to record blood pressure values in the diaries prevented transcription errors that could have introduced systematic errors related to odor intensity. The temporal sequence of sitting outside prior to blood pressure measurement was reversed in fewer than 2% of records (Schinasi et al. 2009).

Although participants recognized hog odor and could rate it on the 0-8 scale from "none" to "very strong", we did not evaluate the reproducibility of their ratings, which could be affected by physical and social context. For example, participants might rate an odor as more intense on a day that they expected company if they were ashamed of their expected guests' reactions to the presence of fecal odor at their home. More precise measures of odor can be made in units of dilution-to-threshold using an olfactometer (Lambert et al. 2000), however it was not feasible to use such a device in this participatory study. We evaluated participants' odor sensitivity threshold using a butanol standard and expected that associations between hog odor and BP might be attenuated among participants with poorer odor sensitivity; however, associations with hog odor differed little by odor sensitivity. Authors of a recent experiment on 44 volunteers report that butanol odor threshold was not related to ratings of environmental odorants (van Thriel et al. 2008).

H_2S was the chemical marker of odorant swine CAFO air pollution that we could quantify over short time period; these measures cannot be affected by response bias. Because there are no other major industrial sources of H_2S in the study communities, it is a specific marker of swine CAFO emissions, but not sensitive, in part due to the detection threshold of the instrument, about 2 ppb. Hog odor, which has a distinctive character due to a complex mixture of volatile organic compounds (Schiffman et al. 2001; Karageorgos et al. 2010), was often reported when H_2S levels were below the detection limit. Another source of measurement error comes from the placement of the H_2S monitor at a central location in rural neighborhoods, which was as far as approximately one mile from some participants' residences (median 0.1 mile). Narrow plumes of odorant compounds from swine CAFOs could be present at participants' homes but not at the monitor, or vice versa. We expect this type of exposure misclassification would attenuate any real associations between H_2S and blood pressure.

Relationships between odorant air pollutants and blood pressure could be produced by psychophysiological or pharmacological mechanisms (Shusterman 1992). Our findings that odor and H_2S, but not PM, were associated with blood pressure increases, are consistent with a psychophysiological mechanism. The lack of an association with PM could also be related to the lower levels or different composition of PM in rural communities compared to urban areas typically studied. Furthermore, many observations were missing for PM. We evaluated blood pressure in this study because environmental exposure to swine odor in this population has been associated with self-reported stress (Horton et al. 2009), and acute stress is associated with transient blood pressure elevation (Sparrenberger et al. 2009). Odorant pollution could also produce other changes in a person's environment that cause acute changes in blood pressure, for example, irritability of a household member.

The pharmacological actions of swine CAFO air emissions on blood pressure are unknown and difficult to predict because emissions include many chemical compounds and fine particles (Schiffman et al. 2001). Although we measured H_2S as an indicator of the odorant component of this mixture, growing evidence suggests that H_2S, an endogenous gasotransmitter, acts as a vasodilator (Wagner 2009). To the extent that exogenous H_2S plays a similar role, its presence in odorant plumes could therefore attenuate associations between swine odor and blood pressure.

The setting for our study, the coastal plain of eastern North Carolina, has one of the highest densities of swine production in the world (Pew Commission on Industrial Food Animal Production 2008). Historically, it is part of both the Black Belt, home to a majority of rural African-Americans, and the stroke belt, an area of high mortality from cerebrovascular and cardiovascular diseases (Casper et al. 1995). Swine CAFOs in the state are highly disproportionately located in low-income communities of color (Wing et al. 2000). If swine CAFO air pollution contributes to high blood pressure in this region, the associated cardiovascular morbidity and mortality would be among the consequences of environmental injustice.

Malodors are produced by other types of CAFOs, waste disposal sites, refineries, chemical plants, waste water treatment plants, and land application of sewage sludge. These facilities and activities expose communities that lack political power to environmental malodors while benefiting consumers and producers in non-impacted areas. Therefore the generalizability of findings reported here is relevant to public health protection. Communities with low levels of political influence are less able to prevent siting of such facilities than communities with political power, and they are less able to demand the best technologies for reducing resulting pollutants. Repeated acute physical environmental stressors such as malodor and noise may be aspects of the built environment that contribute to racial and economic disparities in high blood pressure and its sequelae.

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Table 1: Characteristics of participants (n, % of non-missing observations), Community Health Effects of Industrial Hog Operations study

Variable	Number of Participants N=101	Number of Records N=2,949
Age (years)		
Age≤53.7	51 (50.5)	1410 (47.9)
Age>53.7	50 (49.5)	1539 (52.2)
Gender		
Women	66 (65.3)	1945 (66.0)
Men	35 (34.7)	1004 (34.0)
Odor threshold		
Missing[a]	4 (4.0)	91 (3.1)
Butanol ≤40ppm	55 (56.7)	1559 (54.5)
Butanol >40ppm	42 (43.3)	1299 (45.5)
Blood Pressure medication		
No medications	59 (58.4)	1680 (57.0)
Any medications	42 (41.6)	1269 (43.0)
John Henryism Score[b]		
Missing[a]	5 (5.0)	117 (4.0)
≤52	50 (52.1)	1480 (52.3)
>52	46 (47.9)	1352 (47.7)

[a]Percent of all observations
[b]Higher John Henryism indicates higher active coping with psychosocial stressors

Table 2: Distributions of odor, hydrogen sulfide, and blood pressure, Community Health Effects of Industrial Hog Operations study

Variable	Number, percent of non-missing records N=2,949	
Odor (0-8)		
Missing[a]	177	(6.0)
None	1419	(48.1)
1-2	779	(26.4)
3-5	407	(13.8)
6-8	167	(5.7)
Stress (0-8)		
Missing[a]	58	(2.0)
None	2331	(80.6)
1-2	436	(15.1)
3-5	91	(3.2)
6-8	33	(1.2)
Hydrogen sulfide (ppb)		
Missing[a]	255	(8.6)
0	2412	89.5
0-2	170	(6.3)
2 – 4.99	77	(2.9)
5-47.5	35	(1.3)
PM_{10} ($\mu g/m^3$)		
Missing[a]	948	(32.1)
<10	415	(20.7)
10 – 19.9	783	(39.1)
20 – 29.9	528	(26.4)
30-502.0	275	(13.7)
Semi-volatile PM_{10} ($\mu g/m^3$)		
Missing[a]	948	(32.2)
<0	366	(18.3)
0 – 2.99	638	(31.9)
3 – 7.99	767	(38.3)
8+	230	(11.5)
SBP (mmHg)		
Missing[a]	41	(1.4)
Less than 120	897	(30.8)
120 - 139	1257	(43.2)
140 - 159	510	(17.5)
160+	244	(8.4)
DBP (mmHg)		
Missing[a]	41	(1.4)
Less than 80	1804	(62.0)
80-89	781	(26.9)
90-99	221	(7.6)
100+	102	(3.5)

[a]Percent of all records

Table 3: Linear fixed effects beta coefficients±standard errors and t-values for associations of one-unit increases in pollutants with SBP and DBP, adjusted for time-of-day (AM or PM), Community Health Effects of Industrial Hog Operations study

	SBP		DBP	
Pollutant	beta±SE	t-value	beta±SE	t-value
Odor (0-8)	0.10±0.12	0.86	0.23±0.08	3.02
H_2S (ppb)	0.29±0.12	2.45	0.12±0.08	1.52
PM_{10} ($\mu g/m^3$)	-0.01±0.01	-0.78	-0.00±0.01	-0.41
Semi-volatile PM_{10} ($\mu g/m^3$)	-0.02±0.05	-0.45	-0.06±0.03	-1.66

Table 4: Linear fixed effects beta coefficients±standard errors and t-values for potential modifiers of associations of blood pressure with one-unit increases in hog odor and H_2S, adjusted for time-of-day (AM or PM), Community Health Effects of Industrial Hog Operations study

	SBP		DBP	
Modifier	beta±SE	t-value	beta±SE	t-value
Hog odor (0-8)				
Age≤53.7	0.04±0.18	0.23	0.08±0.12	0.68
Age>53.7	0.14±0.15	0.93	0.33±0.10	3.34
Women	0.07±0.13	0.50	0.19±0.09	2.11
Men	0.20±0.23	0.85	0.36±0.15	2.37
Butanol threshold≤40ppm	0.10±0.15	0.67	0.21±0.10	2.17
Butanol threshold>40ppm	0.10±0.19	0.54	0.24±0.12	2.03
JHAC score≤52	0.18±0.17	1.07	0.22±0.11	2.05
JHAC score>52	0.01±0.16	0.06	0.20±0.11	1.92
No BP meds	0.19±0.16	1.17	0.25±0.11	2.31
Any BP meds	0.01±0.17	0.04	0.21±0.11	1.96
H_2S (ppb)				
Age≤53.7	0.30±0.15	1.97	0.13±0.10	1.32
Age>53.7	0.28±0.19	1.45	0.10±0.12	0.78
Women	0.24±0.13	1.85	0.05±0.08	0.58
Men	0.56±0.30	1.90	0.48±0.19	2.51
Butanol threshold≤40ppm	0.17±0.22	0.78	0.07±0.14	0.48
Butanol threshold>40ppm	0.33±0.14	2.40	0.13±0.09	1.49
JHAC score≤52	0.36±0.14	2.67	0.17±0.09	1.90
JHAC score>52	0.02±0.24	0.08	-0.07±0.15	-0.45
No BP meds	0.38±0.14	2.70	0.10±0.09	1.12
Any BP meds	0.07±0.22	0.34	0.15±0.14	1.07