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Relation between malodor, ambient hydrogen sulfide, and health in a community bordering a landfill

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Abstract

Background—Municipal solid waste landfills are sources of air pollution that may affect the health and quality of life of neighboring communities.

Objectives—To investigate health and quality of life concerns of neighbors related to landfill air pollution.

Methods—Landfill neighbors were enrolled and kept twice-daily diaries for 14 d about odor intensity, alteration of daily activities, mood states, and irritant and other physical symptoms between Jan–Nov, 2009. Concurrently, hydrogen sulfide (H_2S) air measurements were recorded every 15-min. Relationships between H_2S, odor, and health outcomes were evaluated using conditional fixed effects regression models.

Results—Twenty-three participants enrolled and completed 878 twice-daily diary entries. H_2S measurements were recorded over a period of 80 d and 1-hr average H_2S = 0.22 ppb (SD = 0.27; range: 0–2.30 ppb). Landfill odor increased 0.63 points (on 5-point Likert-type scale) for every 1 ppb increase in hourly average H_2S when the wind was blowing from the landfill towards the community (95% confidence interval (CI): 0.29, 0.91). Odor was strongly associated with reports of alteration of daily activities (odds ratio (OR) = 9.0; 95% CI: 3.5, 23.5), negative mood states (OR = 5.2; 95% CI: 2.8, 9.6), mucosal irritation (OR = 3.7; 95% CI = 2.0, 7.1) and upper respiratory symptoms (OR = 3.9; 95% CI: 2.2, 7.0), but not positive mood states (OR = 0.6; 95% CI: 0.2, 1.5) and gastrointestinal (GI) symptoms (OR = 1.0; 95% CI: 0.4, 2.6).

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HUMAN PARTICIPANT PROTECTION
This study was approved annually by the institutional review board of the University of North Carolina at Chapel Hill. All study participants provided informed consent.

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No commercial support was received for any aspect of this project and the authors declare that they have no conflicts of interest.

Conclusions—Results suggest air pollutants from a regional landfill negatively impact the health and quality of life of neighbors.

Keywords

Community-driven research; solid waste landfills; air pollution; hydrogen sulfide; malodor; health

INTRODUCTION

Municipal solid waste has created public health problems ever since the emergence of cities (Louis, 2004) and, like other forms of waste, can pose a threat to environmental justice. During the last several decades, requirements for engineering controls that limit air and water pollution from municipal solid waste landfills have been adopted to protect the environment and nearby communities (EPA, 1998). In the USA, Subtitle D (EPA, 1998) landfills require liners and leachate collection systems to control surface and ground water pollution, methane capture to prevent fires and explosions, and daily cover of new waste to limit odor and attraction of insects, birds, and mammals. Landfills also create noise from heavy equipment, diesel emissions from heavy equipment and trucks, and safety problems from traffic (Taylor, 1999).

Although newer landfills may be better designed and operated than older facilities, communities near some Subtitle D landfills continue to report problems with noise, malodor, and animal pests. In the USA (Martuzzi et al., 2010) and North Carolina (Norton et al., 2007), landfills tend to be disproportionately located in areas with lower housing value and larger concentrations of people of color. Poorer housing, lack of air conditioning and clothes driers, and dependence on the local neighborhood for recreation, make low income communities more vulnerable to impacts of pollutants than communities with well-insulated homes where residents have the means to travel to other locations for exercise and entertainment at times when their homes and neighborhoods are affected by malodor.

Since 1972, the historically African-American Rogers-Eubanks community in Orange Co., North Carolina, has hosted a number of waste facilities including, most recently, a Subtitle D municipal solid waste landfill. For several decades community members have been concerned about impacts of these waste facilities on their health and quality of life. The purposes of this study, conducted in the Rogers-Eubanks community, are to measure levels of hydrogen sulfide (H_2S), a gas generated by anaerobic decomposition of organic wastes in landfills (ATSDR, 2010), track the occurrence of odors reported by community members, and evaluate relationships between H_2S exposure, reports of malodor, alterations of daily activities, mood states, and physical symptoms.

MATERIALS AND METHODS

Setting and Data Collection

This research originated from community concerns about health and quality of life in neighborhoods bordering a regional landfill in Orange Co., NC and was linked to community education and organizing efforts for environmental justice (Wing et al., 2008b). The Rogers-Eubanks Neighborhood Association, a 501(c)(3) community-based organization representing predominantly African-American neighborhoods bordering the regional landfill, brought these concerns to the attention of researchers at the Department of Epidemiology at the University of North Carolina at Chapel Hill. Research questions were developed in partnership with the Rogers-Eubanks Neighborhood Association, and the study followed principles of community-based participatory research (Israel et al., 2005; Minkler et al., 2006; O'Fallon and Dearry, 2002) and community-driven research (Heaney et al., 2007). Individuals were eligible to participate if they lived within 0.75 miles of the Orange Co., NC regional landfill and were at least 18 years old. Volunteers recruited by three of us (RLC, DC, BH) participated in the study in rounds of two to eleven members based on the proximity of their homes and availability to collect data during the two-week period. Volunteers were eligible to participate in up to two rounds of data collection. Prior to beginning data collection participants attended a structured training session at which they provided informed consent and practiced data collection activities. Twice daily for 14 days, participants spent 5 minutes outside their homes and then returned indoors to rate landfill odor, usually in the morning and evening; these twice-daily times were chosen at the training session and maintained throughout data collection as closely as possible. Participants rated odor on a 5-point Likert-type scale from 0 (none) to 4 (very strong). They also provided descriptions of the odor. Following the odor rating, participants responded to questions about alteration of daily activities in the previous 12-hr because of landfill odor, 7 mood states, and irritant and physical symptoms. Questions on mood states were also rated on a 5-point Likert-type scale from 0 (not at all) to 4 (severe) and included: “How do you feel now: (a) stressed?, (b) nervous or anxious?, (c) gloomy, blue or unhappy?, (d) angry, grouchy or bad-tempered?, (e) confused or unable to concentrate, (f) active, energetic, or full of pep?, (g) weary, bushed, or exhausted?” The “stressed?” question was an ad-hoc single-item measure (Cohen et al., 1997; Littman et al., 2006), and the remaining 6 questions came from the Profile of Mood States instrument (McNair et al., 1971; Schiffman et al., 1995). Questions on acute irritant and physical symptoms included: “Do you currently have any of the following symptoms?” and covered a range of categories including mucous membrane irritation (“burning, tearing, or irritated eyes”, “burning or irritated nose”, “burning or scratchy throat”), upper respiratory (“excessive cough”, “runny nose or congestion”, “sore throat”, “difficulty breathing”), gastrointestinal (GI) (“loss of appetite”, “nausea or vomiting”, “diarrhea”), skin irritation (“skin irritation or redness”, “ulcer or boils on skin”, “round patches or scaly areas on skin”, “white or moist areas on skin”, “rash with spots or bumps”, “itching”), “headache”, “general ill feeling”, “fever or chills”, “light headed or dizzy”, “trouble urinating” and “ringing in ears”. Participants rated irritant and physical symptoms on a 4-point Likert-type scale from 0 (none) to 3 (severe).

In this study, H_2S measurements are used as a marker of a complex mixture of odorant chemicals produced by landfills. During the study period from January to November, 2009, we placed H_2S monitors along the northern boundary of the Rogers-Eubanks community near the landfill. Monitors were deployed several days before the start of each round of diary data collection. The location was chosen to be free from trees or structures that could affect air flow between the landfill and the community, which is south of the landfill. From January 9 – February 25, 2009, an MDA Scientific Single Point Monitor (Honeywell Analytics, Inc., North America, Linconlnshire, IL) provided concentrations of H_2S (parts per billion – ppb) averaged over 15-min intervals. From September 25 – November 22, 2009, a Thermo Scientific 450C pulsed fluorescence H_2S– SO_2 analyzer (Thermo) (Thermo Fisher Scientific, Waltham, MA) provided concentrations of H_2S (ppb) every 5 minutes. The H_2S detection limit for the single point monitor and Thermo instruments is 1 ppb and 0.5 ppb, respectively (NRC, 2003). Hourly measurements of wind direction from an observation station 0.5 mi from the landfill and community were obtained from the North Carolina state climate office’s Climate Retrieval and Observations Network of the Southeast database (CRONOS, 2010). Diary records were linked in time to H_2S and wind direction variables and 1-hr mean H_2S concentrations were calculated using 2.5 minutes before the end-time of each diary record as the mid-point of the 1-hr mean.

Statistical Analysis

We analyzed twice-daily odor ratings, which were recorded by participants at their homes at roughly the same time of day, in relation to H_2S. We analyzed twice daily reports of landfill odor during the previous 12-hr in relation to reports of alteration of daily activities because of landfill odor in the previous 12-hr. Finally, we examined the association between twice-daily ratings of landfill odor and reports of mood states and irritant and other physical symptoms. Relationships between 1-hr average H_2S concentration and twice-daily odor ratings were evaluated by conditional fixed effects linear regression models (Allison, 2005). Since the goal of this analysis is to make inferences about within-person variation of transient explanatory variables while controlling for stable characteristics of individuals (both measured and unmeasured), conditional fixed effects models are more appropriate than mixed models or generalized estimating equations (Allison, 2005). Conditional fixed effects models evaluate within-individual effects by differencing across repeated measures within each person and then averaging those differences across all persons in the study, rather than by making assumptions about the distribution of individual effects (Allison, 2005). In this design, conditional fixed effects models estimate exposure-outcome relationships by treating each individual as his or her own control. We fit an interaction term between H_2S and wind direction to assess potential modification of the H_2S-odor relationship by wind direction – during periods when the wind was blowing towards the community (northerly) compared to time periods when the wind was blowing away from the community (non-northerly). We assessed the relation of average odor ratings during the previous 12-hr (on a scale from none (0) to very strong (4)) with reports of alteration of daily activities in the previous 12-hr and the relation of participants' twice-daily odor ratings with mood states and irritant and physical symptoms by conditional fixed effects logistic regression (Allison, 2005). In these logistic models, symptoms were defined as absent vs. present (i.e., 0 vs.≥1), and the number of informative observations is dependent upon individuals showing variability in both exposure and outcome. Conditional fixed-effects regression models were adjusted for morning and evening diary record time periods because time-of-day could act as a confounder due to its potential to be related to both air pollutants and health outcomes. We report 95% confidence intervals even though they are often misinterpreted in non-randomized studies as reflecting the probability that the true value of the effect lies within the interval. Results were also compared with mixed models using SAS PROC MIXED with an AR(1) covariance structure, generalized estimating equation models in PROC GENMOD with an AR(1) covariance structure, and SAS PROC NLMIXED with random intercepts. All analyses were completed using SAS version 9 (SAS Institute Inc., Cary, NC).

RESULTS

During 5 rounds of data collection, 23 volunteers participated, including 12 men and 11 women, 22 who self-identified as Black, and 14 who reported that they had grown up near a landfill (Table 1). These participants completed 878 twice-daily diary records (8 people participated in two rounds of data collection). The 15-min average H_2S concentration was 0.28 ppb (SD = 0.52; range = 0–14.86 ppb). The 1-hr mean H_2S concentration during diary data collection was 0.22 ppb (SD = 0.27; range = 0–2.30 ppb). Ambient H_2S was above the detection limit during 586 (72%) diary time periods and landfill odor was reported during 213 (26%) diary recording time periods (Table 2). Participants reported a range of odor intensity, from faint (13%), moderate (5%), strong (7%), to very strong (1%) (Table 2).

Relationship Between Hydrogen Sulfide (H_2S) and Landfill Odor

Figure 1 compares the distributions of odor ratings during times when 1-hr average H_2S was below versus above the detection threshold. Although the distribution of odor ratings is shifted downwards when H_2S was below threshold, the strongest odor reports (ratings of 3 and 4) were more common when H_2S was below threshold. Landfill odor increased 0.30 points (on a 5-point Likert-type scale) for every 1 ppb increase in hourly average H_2S (95% confidence interval (CI): 0.09, 0.52)) (Table 3). The magnitude of the H_2S-odor relationship was greater during times when the wind was blowing in a Northerly direction towards the community (beta = 0.63; 95% CI: 0.29, 0.91) (Table 3) compared to times when the wind was blowing in a non-Northerly direction away from the community (beta = 0.08; 95% CI: −0.18, 0.36) (Table 3). Estimates of the H_2S-odor association using the AR(1) covariance structure and random intercepts were similar to results of conditional fixed effects linear models (data not shown).

Relationship Between Landfill Odor and Alteration of Daily Activities

A strong positive relationship was observed between reports of landfill odor in the 12-hr before each twice-daily diary record and reports of alteration of daily activities in the previous 12-hr. The odds of reporting any alteration of daily activities when there was odor in the previous 12-hr was 9.0 (95% CI: 3.5, 23.5) times the odds of reporting any alteration of daily activities in the previous 12-hr when there was no odor in the previous 12-hr) (Table 4). The average odor rating during the 12-hr before each outdoor diary recording period was positively associated with reports of doing things differently or with difficulty during the previous 12-hr (OR = 3.3; 95% CI: 1.9, 5.6) (Table 4) and deciding not to do things because of landfill odor during the previous 12-hr (OR = 2.9; 95% CI: 1.7, 4.7; Table 5) (Table 4). Estimates of this association using the AR(1) covariance structure and random intercepts were similar to results of conditional fixed effects logistic models (data not shown).

Relationship Between Landfill Odor and Mood States, Irritant, and Physical Symptoms

Reports of landfill odor during twice-daily periods of sitting outside were positively associated with mood states and acute irritant and other physical symptoms (Tables 5 and 6). The magnitude of associations between twice-daily odor reports and acute outcomes (from strongest, to weakest) was: any negative mood states (OR = 5.2; 95% CI: 2.8, 9.6), any upper respiratory symptoms (OR = 3.9; 95% CI: 2.2, 7.0), and any mucous membrane irritation (OR = 3.7; 95% CI: 2.0, 7.1) (Table 6). Strong positive associations were also observed between twice-daily odor reports and feeling “dizzy or lightheaded” (OR = 4.1; 95% CI: 1.3, 12.5), “headache” (OR = 3.3; 95% CI: 1.5, 7.4), and a “general ill feeling” (OR = 2.7; 95% CI: 1.6, 6.6) (Table 5). We observed little evidence that twice-daily odor reports were related to feeling “active, energetic, or full of pep” (OR = 0.6; 95% CI: 0.2, 1.5) (Table 5), skin symptoms (e.g., skin rash, OR = 1.2; 95% CI: 0.2, 6.3) (Tables 5), ringing in the ears (OR = 2.9; 95% CI: 0.6, 14.2) and reports of any gastrointestinal symptoms (OR = 1.0; 95% CI: 0.4, 2.6) (Table 6). Estimates of the odor-symptom association using the AR(1) covariance structure and random intercepts were similar to results of conditional fixed effects logistic models (data not shown). Relationships of H_2S levels with mood, daily activities, and physical symptoms tended to be positive but were highly imprecise (data not shown), and some models did not converge.

DISCUSSION

Landfills are unequally distributed by race and class (Martuzzi et al., 2010; Norton et al., 2007) and produce a complex mixture of odorant and irritant air pollutants (Muezzinoglu, 2003; Sadowska-Rociek et al., 2009) that may interfere with activities of daily living, negatively impact mood states, and trigger acute irritant physical symptoms among neighbors of these facilities. Results of this study showed a positive association between ambient H_2S concentrations and neighbors’ ratings of landfill malodor when the wind was blowing in the direction of the community. Additionally, reports of landfill odor were associated with negative ratings of health and quality of life.

Although ambient H_2S concentrations were associated with reports of landfill odor, even the highest hourly average H_2S concentrations were at or below the odor detection threshold, approximately 0.5–8 ppb (ATSDR, 2010; NRC, 2003; Powers, 2010; Saral et al., 2009). H_2S is emitted from landfills in low quantities compared to several other gases, and in this study serves as a marker of a complex mixture that is dominated by other odorant compounds. This observation is underscored by the fact that the strongest odor levels (3–4) were reported about 9% of the time when H_2S was not detectable versus only about 7% of the time when H_2S concentrations were above the detection threshold of the single point monitor and Thermo (Fig 1). Participants' qualitative descriptions of landfill odor, included rotting (garbage, food, carcasses), smoke (burning gasses), and chemical fumes, suggests that the strongest odors came from fresh garbage added to the surface of the landfill, rather than from the rotten-egg smell of H_2S, which comes from anaerobic decay of buried organic material. These qualitative descriptions of landfill odor also may reflect variability in how individuals perceive odorant chemicals.

The results of our study suggest that neighbors of a regional landfill experience malodor frequently. Participants reported malodor during 213 of 816 odor ratings periods. We also observed that H_2S was positively associated with reports of malodor. The H_2S-odor association was primarily observed during periods when the wind direction was blowing from the landfill towards the study community. Participants' average ratings of landfill malodor 12-hr prior to diary data collection periods were strongly associated with reports of alteration of daily activities in the previous 12-hr. We also observed a strong positive association of odor ratings during the twice-daily 5-min period of sitting outdoors with negative mood states, mucosal irritation, upper respiratory symptoms, headache, and feeling dizzy or lightheaded. Landfill malodor was not associated with reports of reports of positive mood states (feeling "active, energetic, peppy"), a composite of any gastrointestinal symptoms, or reports of skin irritation.

Potential for reporting bias is a limitation of analyses in which both the independent and dependent variables are based on the diary. Of particular concern is that people could over-report negative outcomes when they notice landfill odor (e.g., there could be correlated errors). This could occur if malodor increases negative mood states such as anger or annoyance, and if such moods lead to greater sensitivity to, or tendency to report, negative moods and physical symptoms. Although we believe participants understood the importance of accurate reporting and made an effort to provide consistent ratings, such a process could occur unconsciously, and would lead to an overestimate of the relationship between landfill odor and self-reported outcomes. If such a bias did occur, however, it was clearly not so large as to result in a generalized over-reporting of symptoms during odor episodes, because some types of symptoms showed no relationship with odor (e.g., some skin symptoms, "ringing in the ears", and any gastrointestinal symptoms (Table 5; Table 6)). Furthermore, analyses in which H_2S is the independent variable should not be subject to this potential source of bias. Inclusion of objective measures of health outcomes in future studies would reduce potential for reporting bias.

Although respiratory symptoms (291 of 820 diary records) and negative mood states (275 of 815 diary records) were reported most frequently by study participants, the strongest associations were observed between odor reports during the 12-hr before each twice daily data collection time period and alteration of daily activities in the previous 12-hr (42 of 819 diary records). There was some evidence of a positive association between 12-hr average H_2S (defined as a binary presence versus absence variable) and reports of having to do things differently in the previous 12-hr period because of landfill odor. For example, the odds of reporting having to do things differently in the previous 12-hr when H_2S was present was 2.5 times the odds of reporting having to do things differently in the previous 12-hr when H_2S was absent (95% CI: 0.8, 7.9). Relationships between measures of other acute changes in health and well-being as a function of varying concentrations of H_2S were more imprecise and in some instances exhibited a lack of model convergence in conditional fixed-effects logistic regression models with H_2S included as a main effect independent (predictor) variable (data not shown).

Future studies of landfill odor and health and quality of life among neighbors may be able to improve evaluation of health outcomes as a function of objective environmental measures of airborne landfill emissions by examining H_2S as well as other air pollutants (non-methane organic compounds, mercaptans, ammonia, PM) (ATSDR, 2010; Kim, 2006) at multiple locations during diary data collection, for longer time periods, focusing on landfills with higher emissions of odorant gases, and including objective measures of health outcomes (e.g., lung function, stress biomarkers) to reduce potential for reporting bias. Although we attempted to stagger participants' 14 day enrollment periods evenly during the 80 days of data collection between Jan.-Nov. 2009, it was not possible to initiate enrollments during the summer months (June-August, 2009). Future studies should include data collection during summer months to better capture seasonal variation of odorant air pollutants from landfills.

Numerous studies in areas near landfills in Europe have relied on odor ratings as a preferred method of characterizing odor (Aatamila et al., 2010; Capelli et al., 2008; Drew et al., 2007; Heroux et al., 2004; Nicolas et al., 2006; Van Langenhove and Van Broeck, 2001), supporting an understanding that reported odor could be a better measure of the complex mixture of air pollutants from landfills than H_2S measurements at a single location within a community. Belgian researchers developed an estimation of odor emission rates from landfills using the sniffing team method whereby teams of field observers follow odor rating protocols to delineate regions in which odor impact is experienced (Nicolas et al., 2006). We expect that participants' ratings of odor at roughly the same time twice each day at the same location outside their homes would provide more accurate classification of odor exposure than measurement of H_2S at a single location within the community.

In this study, the aim was to make valid within-participant comparisons to determine if increases in ambient H_2S concentrations or odor ratings were associated with alterations of daily activities, mood states, and physical symptoms. The strengths of this study include use of an analytic method which achieves complete control of potential confounding from time-invariant measured or unmeasured characteristics of individuals, concurrent measurement of H_2S and acute changes in health and quality of life, and community participation in research that is tied to community efforts to address environmental injustice related to landfills. Weaknesses of the study include the small sample size, generalizability, lack of measurements during the summer months, lack of measurements of landfill air pollutants other than H_2S, and a lack of clinical measures of symptoms.

CONCLUSIONS

To the best of our knowledge, this is one of the first studies to measure ambient concentrations of malodorous gaseous emissions from a landfill concurrently with neighbors' reports of acute changes in odor and states of health and well-being. Our study demonstrates a positive association of low-level H_2S exposure from a landfill with reports of malodor when the wind was blowing from the landfill towards the community. Malodor has been shown to negatively impact the health and well-being of populations neighboring confined animal facilities, wastewater treatment plants, and biosolids recycling operations

(Avery et al., 2004; Horton et al., 2009; Schiffman et al., 2004; Schiffman and Williams, 2005; Schinasi et al., 2011; Shusterman, 1992a; Shusterman, 1992b; Wing et al., 2008a). Our findings support research suggesting that H_2S and other malodorous gases can trigger irritant and physical symptoms (Schiffman and Williams, 2005; Shusterman, 1992b). With an understanding of health as, "a state of complete physical, mental, and social well-being and not merely the absence of disease or infirmity" (WHO, 1948), our results provide evidence of impacts of landfill malodor on health and health-related quality of life in a disproportionately African-American community bordering the Orange Co., NC regional landfill. Concerns about these impacts have been raised by landfill neighbors in Orange Co., NC since 1972 when a regional landfill was sited in the community. In NC, solid waste facilities are disproportionately located in communities of color and of low-wealth (Norton et al., 2007). Martuzzi et al., (2010), observed similar patterns across the US and Europe (Martuzzi et al., 2010). With 3,581 active municipal landfills in the US, according to US Environmental Protection Agency estimates (EPA, 1996), malodor and ambient air pollutant concentrations should be considered in future studies of health impacts of environmental injustice in communities bordering landfills.

Research Highlights

- We investigate health and quality of life concerns of landfill neighbors related to air pollution.
- We evaluate relationships between ambient hydrogen sulfide, odor, and health.
- Landfill odor increased when hydrogen sulfide increased when the wind was blowing towards the community.
- Landfill odor was positively related to altered activities and mood and physical symptoms.
- Results suggest landfill air pollutants negatively impact neighbors' health and quality of life.

ABBREVIATIONS

CI	confidence interval
H_2S	hydrogen sulfide
OR	odds ratio
PM	particulate matter

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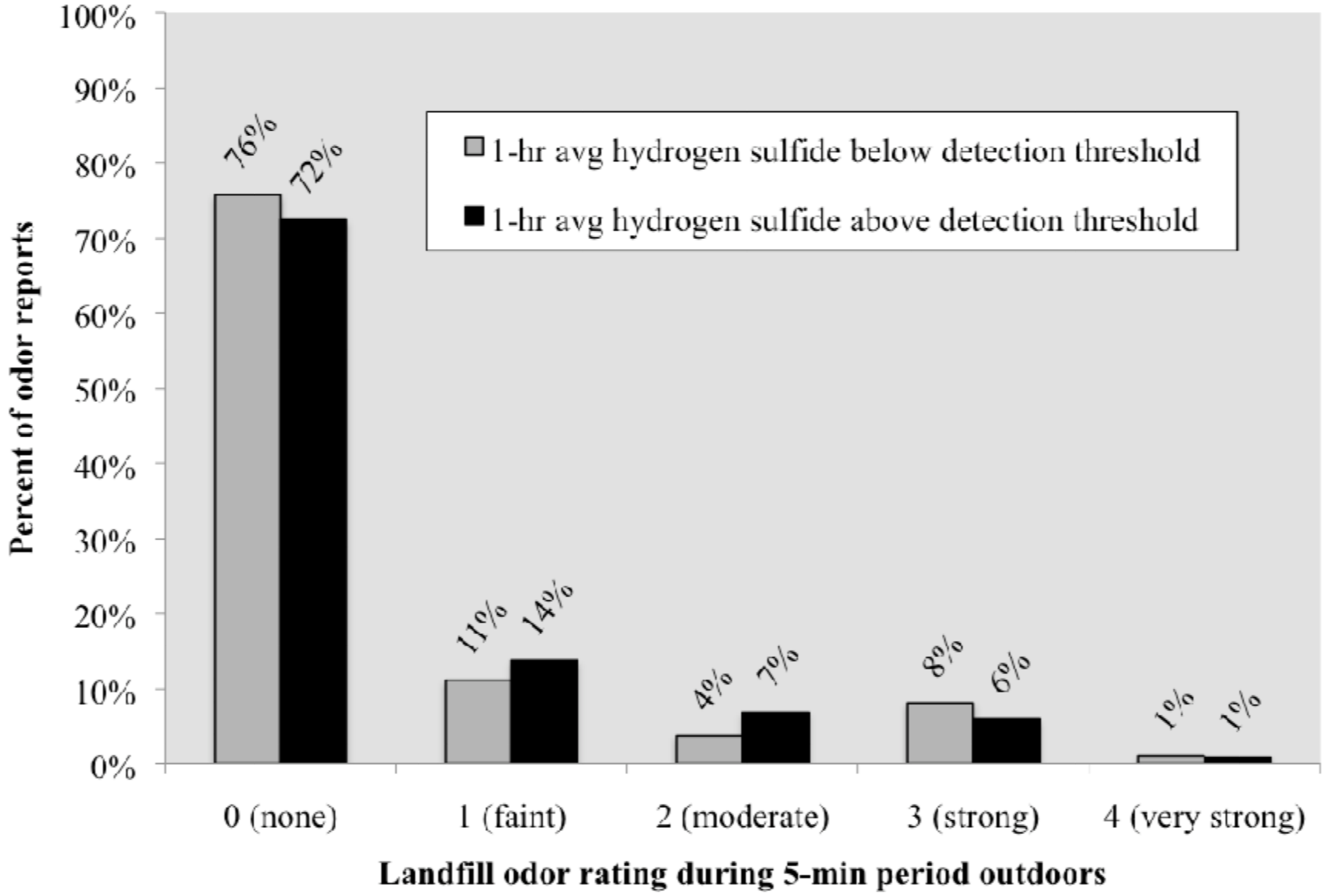

Figure 1.
Distribution of odor ratings by study participants during times when 1-hr average H_2S was below versus above the detection threshold.

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Table 1

Participant demographic characteristics.

	No. (%)
Age	
18–29	4 (17)
30–39	0 (0)
40–49	3 (13)
50–59	9 (39)
60–69	5 (22)
≥70	2 (9)
Race/Ethnicity	
Black	22 (96)
White	1 (4)
Sex	
Female	11 (48)
Male	12 (52)
Grew up near landfill	
Yes	14 (61)
No	6 (26)
Missing	3 (13)

Table 2

Intensity of participants' twice-daily reports of odor while sitting outside.

	N (%)
Total no. of diary records	878 (100)
Total no of odor ratings	818 (93)
None	605 (74)
Faint	103 (13)
Moderate	45 (5)
Strong	57 (7)
Very strong	8 (1)

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Table 3

Relation between hydrogen sulfide (H_2S) with landfill odor and variability of the relation by wind direction.

	No. of records	1-hour mean H_2S (SD)	Beta coefficient[a]	95% CI	t-value
H_2S (ppb)	816	0.22 (0.27)	0.30	0.09, 0.52	2.75
Wind direction (otherwise)	816	0.19 (0.24)	0.08	–0.18, 0.36	0.61
Wind direction (toward community)	816	0.36 (0.36)	0.63	0.29, 0.91	3.63

[a]The beta coefficient is the increase in odor on a 0–4 scale for every 1 ppb increase in H_2S. Coefficients are derived from conditional fixed effects linear regression models adjusted for time of day (morning/evening) of diary record. ppb=parts per billion; SD=standard deviation; CI=confidence interval. The 815 d.f. t-value of the interaction term for H_2S by wind direction = 2.55.

Table 4

Relation between odor reports during previous 12-hr and alteration of daily activities in previous 12-hr.

	No. of records	Any odor in previous 12-hr OR[a] (95% CI)	Avg odor in previous 12-hr OR[a] (95% CI)
Did things differently because of landfill odor	214	7.4 (2.9, 18.8)	3.3 (1.9, 5.6)
Had to change daily activities because of landfill odor	160	8.4 (3.2, 22.1)	2.9 (1.7, 4.7)
Any alteration of daily activities (did things differently or had to change things because of landfill odor)	215	9.0 (3.5, 23.5)	3.2 (1.9, 5.4)

[a] Conditional fixed effects logistic regression models adjusted for time of day (morning/evening) of diary record. OR = odds ratio; CI = confidence interval.

Table 5

Relation between twice-daily odor reports, mood states, and irritant and physical symptoms.

	No. of records	Binary odor OR[a] (95% CI)
Mood states		
Stressed	558	2.1 (1.2, 3.8)
Angry, grouchy, bad-tempered	336	3.9 (1.8, 8.5)
Weary, bushed, exhausted	469	1.8 (0.8, 4.0)
Gloomy, blue, unhappy	358	3.1 (1.6, 6.1)
Nervous or anxious	420	2.5 (1.3, 5.0)
Confused, poor concentration	262	0.3 (0.03, 2.1)
Active, energetic, peppy	415	0.6 (0.2, 1.5)
Mucous membrane irritation		
Burning eyes	368	5.3 (2.5, 11.6)
Burning nose	386	5.0 (2.5, 10.2)
Burning throat	309	3.3 (1.5, 7.1)
Upper respiratory		
Cough	334	2.0 (1.0, 3.9)
Difficulty breathing	310	1.9 (0.9, 4.2)
Runny nose	555	2.6 (1.4, 4.9)
Sore throat	359	1.9 (0.8, 4.2)
Gastrointestinal		
Diarrhea	164	2.6 (0.2, 29.5)
Nausea or vomiting	127	2.7 (0.5, 14.2)
Loss of appetite	181	0.7 (0.2, 2.2)
General ill feeling	310	2.7 (1.1, 6.6)
Headache	387	3.3 (1.5, 7.4)
Dizzy or lightheaded	176	4.1 (1.3, 12.5)
Skin		
Skin rash	210	1.2 (0.2, 6.3)
Skin boils	166	4.6 (0.6, 37.8)
Itchy skin	295	1.9 (0.6, 5.6)
Skin irritation	187	4.7 (1.1, 21.0)
Ringing in ears	176	2.9 (0.6, 14.2)

[a]Conditional fixed effects logistic regression models adjusted for time of day (morning /evening) of diary record. OR = odds ratio; CI = confidence interval.

Table 6

Relation between twice-daily odor ratings and index variables of negative mood states, and irritant and physical symptoms.

	No. of records	Binary odor OR[a] (95% CI)
Any negative mood states (stressed, angry, weary, gloomy, nervous, confused)	578	5.2 (2.8, 9.6)
Any mucous membrane irritation (burning eyes, nose, throat)	414	3.7 (2.0, 7.1)
Any upper respiratory symptoms (cough, difficulty breathing, runny nose, sore throat)	604	3.9 (2.2, 7.0)
Any gastrointestinal (diarrhea, nausea or vomiting, loss of appetite)	293	1.0 (0.4, 2.6)

[a]Conditional fixed effects logistic regression models adjusted for time of day (morning /evening) of diary record. OR = odds ratio; CI = confidence interval.