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Symptom Prevalence and Odor-Worry Interaction near Hazardous Waste Sites

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Retrospective symptom prevalence data, collected from over 2000 adult respondents living near three different hazardous waste sites, were analyzed with respect to both self-reported "environmental worry" and frequency of perceiving environmental (particularly petrochemical) odors. Significant positive relationships were observed between the prevalence of several symptoms (headache, nausea, eye and throat irritation) and both frequency of odor perception and degree of worry. Headaches, for example, showed a prevalence odds ratio of 5.0 comparing respondents who reported noticing environmental odors frequently versus those noticing no such odors and 10.8 comparing those who described themselves as "very worried" versus "not worried" about environmental conditions in their neighborhood. Elimination of respondents who ascribed their environmental worry to illness in themselves or in family members did not materially affect the strength of the observed associations. In addition to their independent effects, odor perception and environmental worry exhibited positive interaction as determinants of symptom prevalence, as evidenced by a prevalence odds ratio of 38.1 comparing headaches among the high worry/frequent-odor group and the no-worry/no-odor group. In comparison neighborhoods with no nearby waste sites, environmental worry has been found to be associated with symptom occurrence as well. Potential explanations for these observations are presented, including the possibility that odors serve as a sensory cue for the manifestation of stress-related illness (or heightened awareness of underlying symptoms) among individuals concerned about the quality of their neighborhood environment.

Background

There are currently 1082 hazardous waste sites on the U.S. Environmental Protection Agency's Superfund National Priority List, 75 of them located in the state of California (*1*). Residents living near such sites typically express concern regarding potential exposures to toxic substances migrating off site. Not infrequently, residents also report physical symptoms which they attribute to dumpsite emissions. Environmental monitoring, while occasionally demonstrating significant off site exposures (particularly when drinking water contamination has occurred), more frequently shows only low (part-per-billion) levels of airborne contaminants—levels insufficient to cause acute or even subacute symptoms by known toxicologic mechanisms (*2*). In an effort to understand this apparent discrepancy between symptom reporting and low-level exposure potential, the issue of "environmental worry" has been examined epidemiologically and shown to be related to symptom reporting, even in neighborhoods distant from hazardous waste sites (*3*). Perception of environmental odors is another factor typically associated with both proximity to hazardous waste sites and symptom reporting (*4–6*). The present study seeks to examine the separate and combined roles of odor perception and environmental worry as determinants of symptom prevalence near hazardous waste sites.

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Methods

Interview studies were conducted by the California Department of Health Services near three hazardous waste sites in Southern California (*4–6*). The announced purpose of each study was to elicit information regarding "environmental health issues." (While the nearby hazardous waste site was not mentioned as the index exposure in the initial phase of questioning, it was impossible to completely "blind" the purpose of the study due to the high level of publicity and community involvement.) In each study, a systematic sample of households was selected near the hazardous waste site, and one adult respondent was questioned per household, either by written questionnaire or by telephone or door to-door interview. All three studies solicited information regarding either new onset or increase in frequency or severity of a number of common physical symptoms; the time period of interest was the interval during which the respondent lived at his or her current residence. Additional questions were asked regarding the frequency of perception of environmental odors, the respondent's degree of environmental worry, patterns of medical care utilization, and other health issues (which varied from study to study). Numbers of respondents, respondent gender ratios, and response rates appear in (Table 1).

Upon retrospective review of the three studies, it was determined that 15 physical symptoms were ascertained in a comparable manner across the studies. Of these, two symptoms were chosen on an *a priori* basis as potentially related to autonomic or stress-induced mechanisms (i.e., "headache" and "nausea") and

Table 1. Study characteristics.

Characteristic	McColl	Operating Industries	Del Amo-Montrose
Type of waste	Acid petroleum sludge	Municipal and sewage; paint and petroleum sludge	Residues from synthetic rubber manufacturing; DDT
Year study completed	1983	1986	1987
Ascertainment	Mailed questionnaire	Telephone interview	Door-to-door interview
Primary respondents	670 adults	514 adults	856 adults
% Male/female	46/54	33/67	50/50
Response rate, %	82	80	68

two as potential irritative processes (i.e.,"eye soreness or irritation" and "throat soreness or irritation"). Prevalence data for the above symptoms were stratified by self-reported frequency of odor perception ("none," "less than or equal to four times per month," or "greater than four times per month") and by self-reported degree of environmental worry ("none," "some," or "very"). Analyses were conducted both with and without respondents who professed worry because of illness or symptoms in themselves or in family members. Prevalence odds ratios (with 95% confidence intervals) were calculated using Epistat, a personal computer-based statistical program (7). Although respondents reported symptoms for both themselves and for other family members, the analysis was confined to respondents' symptoms.

Results

Numbers of respondents in each of the odor perception and worry strata (pooled across studies) are presented in Table 2. Because of a concern that environmental worry might reflect a secondary, rather than primary process (i.e., that personal or family illness might result in environmental worry), the analysis was repeated after eliminating respondents who ascribed their environmental worry to illness ("secondary worry"). The numbers of respondents remaining after this exclusion are presented in Table 3 (180, or 11% of those who reported some degree of environmental worry were so excluded).

Symptom reporting rates by odor and worry strata (excluding respondents with secondary worry) are presented in Tables 4–7; Figures 1–4 present the same data graphically. Table 8 contains prevalence odds ratios comparing the extremes for each variable (i.e., frequent odors versus no odors; very worried versus not worried).

Table 2. Numbers of respondents by frequency of odor perception and degree of environmental worry (all sites combined, no exclusions).

Degree of environmental worry	Frequency of odor perception: >4×month	≤4×month	Never	Total
Very	560	113	61	734
Some	409	286	152	847
None	65	91	194	350
Total	911	457	407	1931[a]

[a]Missing data on one or both variables: 2040 − 1931 = 109 respondents.

Table 3. Numbers of respondents by frequency of odor perception and degree of environmental worry (all sites combined; secondary worry excluded).

Degree of environmental worry	Frequency of odor perception: >4×month	≤4×month	Never	Total
Very	481	110	54	645
Some	365	256	135	756
None	65	91	194	350
Total	911	457	383	1751

Table 4. Prevalence of headaches per 100 respondents[a] by frequency of odor perception and degree of environmental worry (all sites combined, secondary worry excluded).

Degree of environmental worry	Frequency of odor perception: >4×month	≤4×month	Never
Very	37.8	30.9	16.7
Some	17.6	15.3	9.6
None	15.4	3.3	1.6

[a]New onset or worsened severity since moving to current residence.

Table 5. Prevalence of nausea per 100 respondents[a] by frequency of odor perception and degree of environmental worry (all sites combined, secondary worry excluded).

Degree of environmental worry	Frequency of odor perception: >4×month	≤4×month	Never
Very	22.2	11.8	7.4
Some	7.1	7.8	4.4
None	3.1	2.2	1.5

[a]New onset or worsened severity since moving to current residence.

Table 6. Prevalence of throat soreness or irritation per 100 respondents[a] by frequency of odor perception and degree of environmental worry (all sites combined, secondary worry excluded).

Degree of environmental worry	Frequency of odor perception: >4×month	≤4×month	Never
Very	29.4	23.6	11.3
Some	15.5	8.6	10.4
None	6.2	5.5	2.1

[a]New onset or worsened severity since moving to current residence.

Table 7. Prevalence of eye soreness or irritation per 100 respondents[a] by frequency of odor perception and degree of environmental worry (all sites combined, secondary worry excluded).

Degree of environmental worry	Frequency of odor perception: >4×month	≤4×month	Never
Very	46.5	30.3	18.5
Some	22.7	20.9	14.1
None	18.5	17.6	6.7

[a]New onset or worsened severity since moving to current residence.

Significant positive relationships were observed between the prevalence of each the index symptoms (headache, nausea, eye and throat irritation) and both frequency of odor perception and degree of worry. Headaches, for example, showed an odds ratio of 5.0 comparing respondents who reported perceiving environmental odors frequently versus those reporting no such odors and 10.8 comparing those who described themselves as "very worried" versus "not worried" about environmental conditions in their neighborhood. Elimination of secondary worry did not materially affect the strength of the observed associations, with corrected odds ratios for headaches of 5.6 (frequent versus no odors) and 11.1 (very worried versus not worried).

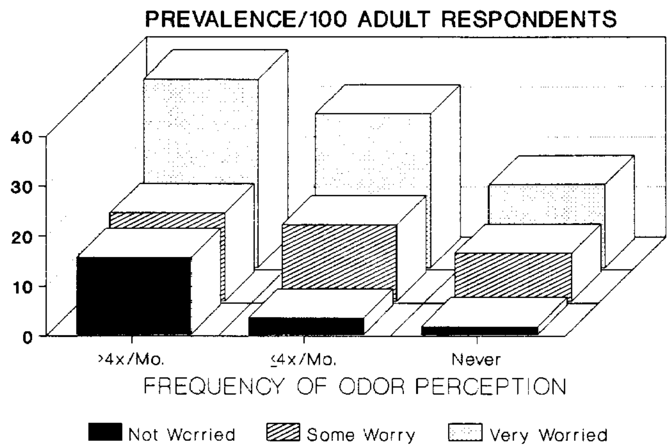

FIGURE 1. Prevalence of headaches per 100 respondents (new onset or worsened severity since moving to current residence) by freqency of odor perception and degree of environmental worry (all sites combined; secondary worry excluded).

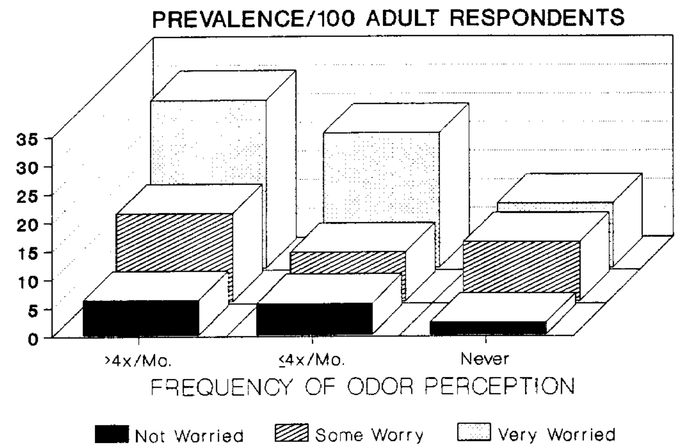

FIGURE 3. Prevalence of throat soreness or irritation per 100 respondents (new onset or worsened severity since moving to current residence) by frequency of odor perception and degree of environmental worry (all sites combined; secondary worry excluded).

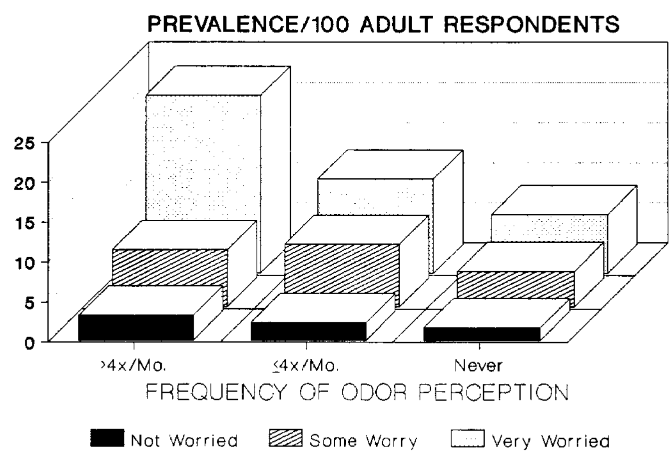

FIGURE 2. Prevalence of nausea per 100 respondents (new onset or worsened severity since moving to current residence) by frequency of odor perception and degree of environmental worry (all sites combined; secondary worry excluded).

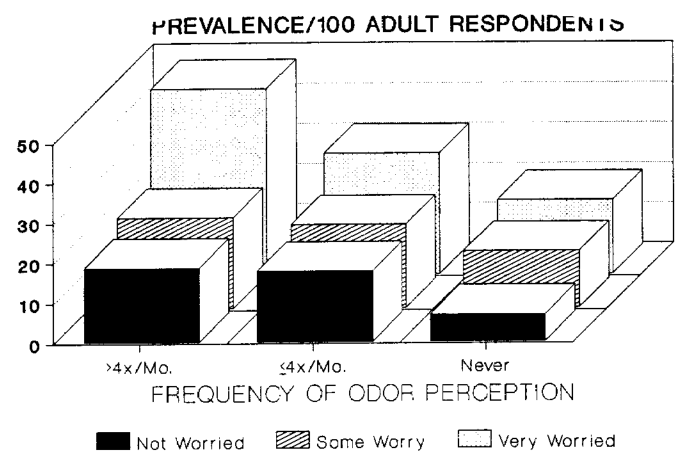

FIGURE 4. Prevalence of eye soreness or irritation per 100 respondents (new onset or worsened severity since moving to current residence) by frequency of odor perception and degree of environmental worry (all sites combined; secondary worry excluded).

Table 8. Odds ratios (with 95% confidence intervals) of new or increased symptoms.

Symptom	Frequent odor vs. no odor	Very worried vs. not worried	Frequent odor + very worried vs. no odor + not worried
Headaches			
All respondents	5.0 (3.3–7.7)	10.8 (6.2–16.8)	36.7 (11.2–77.7)
Secondary worry excluded	5.6 (3.5–8.2)	11.1 (6.4–19.5)	38.1 (11.6–80.8)
Nausea			
All respondents	5.2 (2.9–9.4)	11.9 (5.3–28.1)	18.5 (5.6–43.5)
Secondary worry excluded	5.0 (2.7–9.3)	11.6 (5.2–27.5)	18.2 (5.5–43.3)
Throat (irritation or soreness)			
All respondents	4.3 (2.8–6.7)	9.3 (5.1–15.3)	19.2 (6.7–40.5)
Secondary worry excluded	4.2 (2.7–6.8)	9.5 (5.2–15.6)	19.6 (6.9–41.5)
Eye (irritation or soreness)			
All respondents	4.6 (3.2–6.5)	5.4 (3.7– 7.8)	12.0 (6.5–22.7)
Secondary worry excluded	4.4 (3.0–6.1)	5.3 (3.7– 7.5)	12.1 (6.5–22.9)

Examination of the remaining symptoms confirmed that the effect of eliminating secondary worry was both small and nonsystematic.

All of the comparisons outlined above were statistically significant (i.e., the 95% confidence intervals did not include 1.00). However, the associations, in general, were stronger for worry (odds ratios with secondary worry eliminated ranging from 5.3 to 11.6) than for odor (odds ratios 4.2–5.6). For two of the symptoms examined (nausea and throat irritation), odor was neither a strong nor a consistent predictor of symptom prevalence among those professing low degrees of worry (Figs. 2 and 3). Thus, when symptom prevalence was examined as a function of odor perception using data from all three odor levels, the chi-square test for trend was highly significant ($p < 10^{-6}$) for each of the four symptoms, providing the worry strata were combined. However, when the worry strata were examined separately, the chi-square test for trend lost significance for nausea with either "no" or "some" worry, and for throat irritation with "no" worry.

In addition to their independent effects, odor perception and environmental worry exhibited positive interaction as determinants of symptom prevalence. This ranged from a minimal effect (in the case of eye irritation or soreness) to a nearly multiplicative relationship (in the case of headaches). For eye symptoms, the corrected odds ratio comparing the high-worry/frequent-odor group and the no-worry/no-odor group was 12.1. (By comparison, the anticipated odds ratio using an additive model was 9.7: 4.4 for odor plus 5.3 for worry). For headaches, the odds ratio with both risk factors was 38.1, versus a predicted of 16.7 (5.6 for odor plus 11.1 for worry). The implications of this positive interaction are discussed below.

A number of potential confounding factors were examined in the original studies. These included age, sex, educational level, ethnicity, smoking status, alcohol consumption, length of residence in the respondent's current home, and self-reported occupational exposures. Observed relationships between odor exposure zones and symptom prevalence in the original studies were unaffected by adjustment for the above variables (*4–6*). Correction for confounders was not repeated for the pooled data.

It should be noted that this analysis applies to neighborhoods near hazardous waste sites only. Odor-worry interaction was not examined in control neighborhoods, since in two of the three studies the rate with which respondents in control areas reported frequent environmental odors was very low (i.e., 2–3%). (The one exception was the Del Amo study, in which almost one-quarter of controls reported frequent refinery odors.) Also not addressed is the issue of whether odor-worry interaction confounds comparisons between exposed and control neighborhoods.

Discussion

The elevated symptom prevalence rates reported in these three studies are consistent with observations near other hazardous waste sites (*8–10*). Other authors have likewise commented on the apparent discrepancy between low-level airborne chemical exposures and prominent symptom reporting (*8–10*). Speculation regarding these discrepancies have centered upon the issues of recall bias (*9*), respondent personality variables (e.g., hypochondriasis) (*10*), and possible health effects due to low-level chemical exposures (*8*). In virtually all studies of hazardous waste site neighbors in which population exposures occurred exclusively by the airborne route, so-called "serious" health effects (e.g., cancer, total mortality, and adverse reproductive outcomes) have been found to be no more common in the exposed than in the control neighborhoods (*4–6,8–10*). Also with rare exception (*9*), perception of "chemical odors" by community members figured prominently in the identification of hazardous waste sites as environmental problems.

While odor perception and odor-related symptoms may signal exposure to toxicologically significant concentrations of hazardous materials, such is frequently not the case. For example, the common industrial sulfur gases (e.g., hydrogen sulfide, mercaptans, thiophenes) have odor thresholds orders of magnitude lower than levels known to cause symptoms by classical toxicologic or irritative mechanisms, yet are often associated with symptom reporting at levels barely exceeding the odor threshold (*11,12*). Such highly odorous compounds are found in a variety of industrial and hazardous waste materials. In neighborhoods surrounding the McColl site, for example, airborne levels of benzene and other volatile organics could not be distinguished from background levels in the Los Angeles basin, while odors (with which symptoms were associated) were traced to part per billion concentrations of some of the sulfur-containing compounds mentioned above (*4*).

Figure 5 illustrates several potential toxicologic and nontoxicologic mechanisms for explaining odor-related health effects near industrial/hazardous waste sources. Toxicologic health effects are indicated by line 1 (a broken line, signifying the rarity with which community exposures are documented at levels thought sufficient to cause acute or subacute symptoms by toxicologic mechanisms). Line 2 signifies those direct odor-mediated effects that do not involve cognitive or personality variables. These may include innate (biologically intrinsic) odor aversions (*13*), the exacerbation of underlying medical conditions (e.g., asthma or "morning sickness") by odors (*14*), and conditioned responses to odors after traumatic chemical overexposures (usually occurring in an occupational setting—so-called "behavioral sensitization") (*15*).

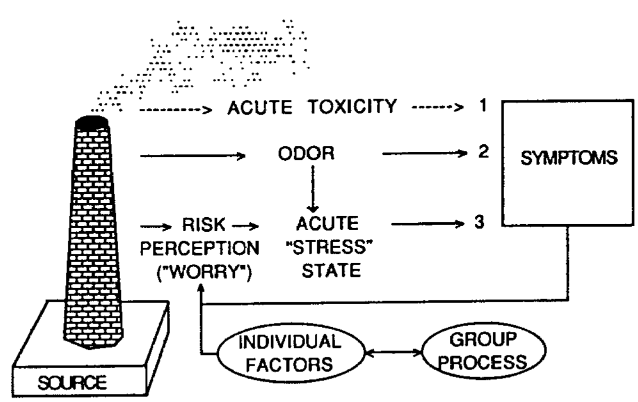

FIGURE 5. Model depicting potential mechanisms for the production of acute symptoms near industrial/hazardous waste facilities (see text for further explanation).

Line 3 in Figure 5 depicts the interaction of environmental odors with risk perception or worry. ("Interaction" in this context has both a pathophysiologic and an epidemiologic meaning.) Based upon our observation that odor and environmental worry are associated both independently and interactively with symptom reporting, we postulate that odors may serve as a sensory cue for the manifestation of autonomic or stress-related symptoms (e.g., headache and nausea) among individuals concerned about the quality of their neighborhood environment (*16*). Further, the observation that irritative symptoms (throat and eye) are elevated in a similar pattern with respect to these two variables might be interpreted as evidence that odor and worry heighten symptom perception or recall (i.e., result in recall bias).

Recall bias occurs when an adverse health outcome, the publicity surrounding an environmental issue, or another factor (such as odor perception) predisposes individuals to remember symptoms. Such bias is suspected when uniform elevation of symptoms with diverse etiologies is observed. To address this issue, questionnaire surveys can incorporate sham variables (i.e., symptoms not credibly related to exposures). Although no such variable was included in this pooled analysis, elevation of one sham variable (toothache) was observed in association with dumpsite proximity in two of the component studies (*5,6*), and with environmental worry in a related study (*3*). It should be noted that recall bias is said to occur even when genuine symptoms are being reported, if such symptoms are differentially recalled, depending upon exposure status (*17*).

In the present analysis, elimination of respondents who identified their environmental worry as resulting from personal or family illness helped ensure that worry was dealt with as an independent, not dependent, variable. In contrast, the possibility that reported frequencies of odor perception are biased by symptom occurrence (or even environmental worry) cannot be ruled out in this analysis. Thus, reporting of both dependent and independent variables may be susceptible to bias in studies such as these.

Future research on the relationship of symptoms to airborne emissions from hazardous waste sites should acknowledge the rapidly fluctuating nature of odor perception and the acute and reversible nature of odor-related symptoms. Such a goal could be met by combining real-time environmental monitoring with epidemiological data amenable to time-series analysis (e.g., use of daily symptom reporting logs by community residents). Use of real-time environmental monitoring data would have the additional advantage of addressing issues of bias in interpreting reported patterns of odor perception.

Further consideration of "environmental worry" near hazardous waste sites might explore situational factors known to influence risk perception. Such features as "involuntary" exposure, lack of perceived benefit, the "exotic" nature of the threat, and lack of community control over facility operations are precisely those shown (by factor analysis in opinion surveys) to be associated with heightened perception of technological risk (*18*). Risk perception may also be heightened if, when asked about potential health risks, public officials give answers which are (in the community's view) vague, contradictory, overly technical, or not timely. Communication dynamics between communities and public health agencies over environmental health issues have been explored elsewhere (*19,20*).

Conclusions

Data analyzed from three large epidemiologic studies point to a potential role of both environmental odors and environmental worry in the genesis of symptom complaints near hazardous waste sites. Scientific uncertainty regarding the chain of events involved in precipitating these symptoms would be reduced by *a*) attention to real-time monitoring of exposures (particularly to low levels of potent odorant compounds), *b*) symptom recording in a manner that reflects the rapid onset and self-limited course of many of these health complaints, and *c*) innovative approaches to identifying sources of bias in reporting.

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