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Health Problems Reported by Residents of a Neighborhood Contaminated by a Hazardous Waste Facility

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A symptom prevalence survey was conducted of a neighborhood exposed to airborne hazardous wastes. Residents' responses were compared to those of a nearby control population. The results revealed that the exposed group had more self-reported complaints referable to the respiratory system (wheezing, shortness of breath, chest discomfort, persistent colds, coughs), constitutional complaints (always fatigued, bowel dysfunction), and irregular heart beat. When the effect of a documented irritant source in a small portion of the control population was removed, the exposed group also complained more often of irritation of the eyes and nose. There was a biological gradient for several of these effects. Efforts to eliminate the influence of confounding and recall bias are discussed. The results suggest either that the general population reacts to chemicals at levels much lower than the available occupational literature would indicate or that the effects are more long lasting than previously thought.

Key words: **hazardous waste health effects, respiratory symptoms, prevalence study, neighborhood health surveys, recall bias**

INTRODUCTION

It is now a decade since Congress passed the Resource Conservation and Recovery Act (RCRA), of which subtitle C set forth the principles under which hazardous waste was to be regulated, and more than 7 years since the name of a Niagara neighborhood, Love Canal, became synonymous with the havoc that past disposal practices could wreak on a community [Solid Waste Disposal Act, 1976; Levine, 1982]. During that time remarkably little consensus has developed on the actual extent of hazard created by improper hazardous waste disposal despite widespread interest and concern [Phillips and Silbergeld, 1985; UAREP, 1985].

Epidemiological studies of waste sites are made inherently difficult by low statistical power associated with neighborhood-sized populations, poor measures of

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exposure, and lack of well-defined endpoints. Despite these formidable obstacles, some studies indicate that health effects are real and detectable [Harris and Highland, 1974; Budnick et al, 1974; Goldman et al, 1985). We report here a symptom prevalence survey of adults living in the neighborhood of an improperly managed hazardous waste facility. The results suggest that the minimum level of exposure at which adverse health effects occur may be lower than is currently believed.

BACKGROUND

From 1971 to 1977 a large volume of chemical wastes was handled on a five-acre site less than 400 feet from a residential neighborhood in Lowell, Massachusetts, an industrial city of 100,000 population near Boston. The operator of the facility processed a wide range of industrial wastes for the purpose of producing recycled material of commercial value (Table I). About 250,000 gallons of chemicals were received each month from some 100 clients. By 1974, financial problems had led to significant breaches of accepted waste management practices at the facility, causing neighborhood residents to complain of strong chemical odors. Some residents also reported various health problems that they associated with periods of increased odors from the plant site.

When operations at the firm finally ceased in 1977 because of bankruptcy, the full extent of the environmental problem was revealed to public health and environmental protection authorities. Extensive and repeated spills over grounds and equipment were evident, and corroded, split, and ruptured drums, sometimes stacked four high, were leaking onto the ground. There was evidence that materials were flowing onto adjacent properties on all sides of the site. Despite frozen ground and temperatures, foul chemical odors were evident everywhere [Fred C. Hart Assoc, 1978]. From that point, several years were required to remove all abandoned containers and bulk storage tanks from the property, a process that was finally completed in September of 1981.

It was estimated, however, that some 6,000 gallons of volatile organic contaminants remained from spilled materials in ground water or in the soil matrix [Perkins Jordan, 1982]. Odors continued to emanate from the site. Air monitoring studies during a 7-day period in August of 1982 by state and federal authorities, using

TABLE I. Chemicals and Waste Streams Handled by the Hazardous Waste Facility, 1971–1977*

Aqueous hydrocarbons (acetone, alcohol, methanol)	Methylene chloride
Aromatic hydrocarbons (not specified)	Mineral spirits
Benzene	Neutralization tanks containing pesticides and ammonia
Chlorinated and fluorinated hydrocarbons (not otherwise specified)	PCBs
Ethyl benzene	Pure hydrocarbon wastes (not specified)
Ethylene dichloride	Tetrachlorethylene
Fluoroboric acid	Tetrahydrofuran
Freon	Toluene
Fuel oil (#5)	Trichloroethylene
Hexane	Vanadium pentoxide
Latex wastes	Zinc solids
Methyl tetrahydrofuran	Waste glue
	1,1,1-Trichlorethane

*Sources: Fred C. Hart, Associates, 1978; Mitre Corporation, 1979.

photoionization detector/gas chromatographic (GC) and gaschromatographic/mass spectroscopy (GC/MS) methods, looked for a limited set of 13 priority chemicals.[1] These chemicals were those present in the soil in greatest concentrations, those that were particularly volatile, or those that were considered especially toxic. Only benzene, toluene, trichloroethylene, and tetrachloroethylene were detected in air in the surrounding residential neighborhood. Airborne levels were above the urban background but below the odor thresholds for these ubiquitous chemicals and nowhere exceeded 20 parts per billion (ppb) (toluene), usually measuring below 10 ppb [DEQE, 1982]. The precise causes of the odors from the site were never determined. Airborne levels were never measured for most agents found at the site (cf Table I). Because of continued concerns of residents that their health was being affected by conditions at the site, state officials requested a health study of the population living near the facility. In February–April 1983, we undertook a symptom prevalence survey of neighborhood residents to compare with a control population.

MATERIALS AND METHODS

Survey Methods

The study populations were defined by their physical relationship to the waste site. The "target" area included all households in blocks within 400 meters (¼ mile) of the site. On the basis of a field visit, we judged this radius to be sufficiently large to include an adequate population for study but not so large as to include residents without risk of exposure. The "control" area was a ring with innermost boundary at least 800 meters (½ mile) from the site and outermost boundary at most 1,200 meters (¾ mile) from the site. We excluded blocks that spanned the boundary of either area (Fig. 1).

Field personnel established the sample frame with the use of lists of addresses on each block taken from the city directory. Each lister then went to her/his assigned target or control area and made additions or deletions according to what actually existed. Later, "found households" were added to the sample frame. These households were those uncovered by systematic questioning by field personnel but not included in the original listing because they were not visible as separate dwellings. For example, an "in-law apartment" without a separate address or mailbox constitutes a "found" household, as does an apartment whose entrance is at the rear of the house.

Using this method, we obtained a list of 605 households in the 34-block target area. We included all of these households in the sample. The 94-block control area contained approximately 2,800 households which we sampled randomly at a rate of 1 in 4 to yield 649 households.

Cost considerations led us to choose telephone interviewing insofar as possible. For each address we attempted to obtain a phone number. When this was not possible, field personnel visited the address to attempt in-person interviews.

We obtained 1049 interviews from 557 households in the target area (a response rate of 83.0%) and 948 interviews from 576 households in the control area (response

[1] 1,2 dichloroethane; chloroform; benzene; 1,1,2-trichloroethane; dichloromethane; 1,1,1-trichloroethane; 1,2-dichloropropane; tetrachloroethylene, 1,1,2,2-tetrachloroethane; trichloroethylene; toluene; 1,1,2-trichloro-1,2,2-trifluoroethane; 1,1-dichloroethane.

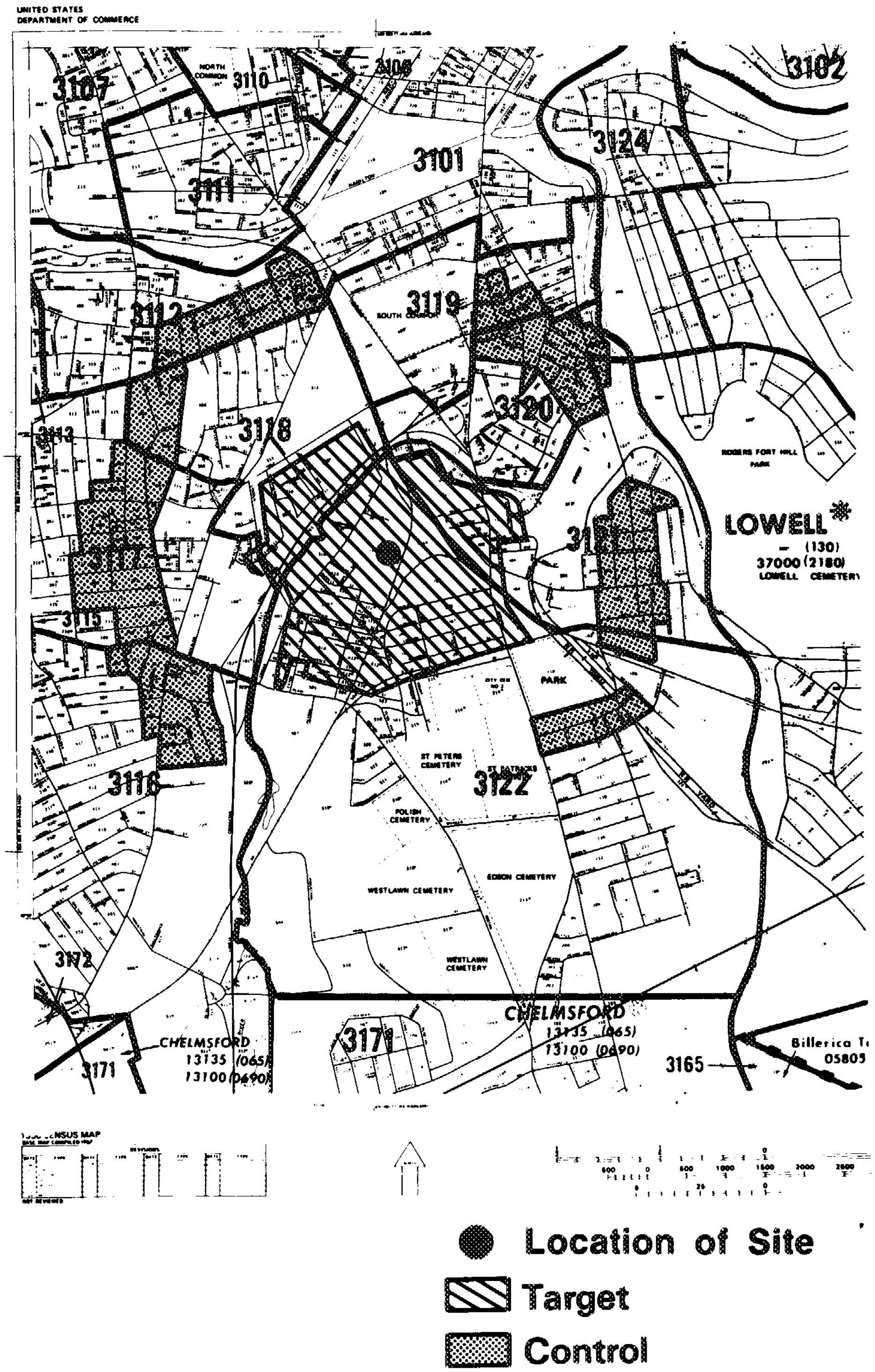

Fig. 1. Configuration of the target and control areas.

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rate of 79.1%). Of these, 808 were done by telephone and 1189 by personal interview in the respondents' households. We employed identical procedures for the target and control groups and conducted interviews concurrently in the two areas over a 6-week period. We employed trained interviewers, each of whom had a minimum of three to 5 days' instruction in general interviewing techniques. All of the interviewers, regardless of experience, received one additional day of training specifically for this study. Field interviewers worked at least one 6-h shift on the telephone so supervisors could monitor their interviewing. Completed interviews were reviewed as they were returned to the office. Each field interviewer had at least weekly contact with a supervisor, and a supervisor was always present during phone shifts. At least one interview was monitored for each shift worked by an interviewer and two additional completed interviews were carefully reviewed each shift for every interviewer. Specific areas of interviewing technique were noted and immediate feedback given by the supervisor. We recontacted 10% of the sample to ensure that they had been interviewed.

We attempted to interview every person older than 18 within every household in the sample. We asked each individual about his or her own health, residential, occupational, and avocational history, opinions about the quality of the air and water, and demographic data.

The literature on effects of the volatile contaminants at the site helped guide the choice of health outcomes that we assessed (cf Proctor and Hughes, [1978]). We also considered neighborhood concerns in selecting these health outcomes. Skin irritations and rashes, eye and nose irritation, headaches, upper respiratory infections, asthma, and high prevalence of cancer had been reported in an informal survey of the neighborhood by a community group a year earlier. Some of these complaints were plausible results of exposure to the chemicals in question while others were less obviously related.

Exposure Variables

We defined the exposed population initially as those individuals whose residence was within 400 meters of the waste site. The main criterion for selection of the control population was that they not be affected by the site. Crude modelling of airborne pollutant behavior indicated that a distance of 800 meters would provide ample separation from the site and yet would yield a residential area sufficiently similar for comparison purposes.[2]

Because it was unclear how far any site-associated influence might extend within the target area itself, we measured the linear distance of each residence to the center of the site on a map and used this distance to construct a second exposure variable. All portions of the control were at essentially "infinite" distance regarding exposures, so we used the reciprocal of the distance as a variable. This led to larger positive numbers for closer target households and zero values for control households.

Meteorologic data indicated that prevailing winds came from southwest and northwest. However, when the target area was divided into quadrants, too few

[2]Assuming neutral air (C stability) and light winds (2 m/s) blowing in a single direction 40% of the time, the 30-day average at .8 km is more than 99% attenuated compared to the property line of the site [Turner, 1970].

residents were included in any single subarea to analyze. We have therefore combined all quadrants into a single target area.

Statistical Methods

We compared target and control areas on both crude and adjusted prevalence rates. Crude rates were compared through the chi-square test of independence [Colton, 1974]. This procedure assumes that each respondent constitutes an independent response. Since the data collection was on a household basis and there may exist some correlation between responses from the same household, this procedure could have exaggerated significance levels. To account for this sampling procedure, we performed weighted t tests, in which we treated the household as the unit of analysis [Goodnight, 1982].

We then used multiple logistic regression to compare prevalence rates between areas, with adjustment for background factors of age, sex, education, marital status, smoking history, length of residence, type of dwelling, and occupational exposure [Schlesselman, 1982]. Income was highly correlated with many of these variables and since there were a number of missing values for this variable, it was not used in the regression in order to minimize multicollinearity and to incude the maximum number in the analysis. Both areas were more than 90% white, so ethnicity varied too little to include as a variable. Our measure of drinking habits was rather crude and it did not differ much in the two areas; hence, we eliminated it in the regression model.

We have represented age (and in some analyses, distance) as a continuous variable and all other factors as categorical variables.

RESULTS

Table II shows the characteristics of the target and control groups in our sample. The groups were similar in sex, marital status, employment status, and prevalence of specific occupational exposures. The target area had more single-family units and multiple-adult households while the control area had more apartments. There were more long-term residents in the target area with 40% at their current address since 1970 versus 30% in the comparison group. Target area residents were also slightly older. Both groups had a similar proportion of employed adults; however, of those not working, the proportion retired was greater in the target area than in the control area, while the proportion laid-off was greater in the control area. Although both areas were 90% white, the target area had more blacks in the nonwhite group while the control area had more Hispanics. These findings suggest that the control area had more newcomers than the target area, a characterization consistent with the further finding that the control area, relative to the target, had a greater proportion of households with income under $15,000 (53 vs 45%) and more adults with less than an eighth-grade education (23 vs 17%). The overall picture was of a target neighborhood somewhat older, more stable, marginally better educated, and slightly higher in income than the control area.

In comparison of smoking habits, target area adults had significantly more current smokers than their control counterparts (47 vs 41%). We found no differences in the occupational or avocational exposures of the two groups.

Table III presents a comparison between target and control areas for self-reported symptoms within the previous 6 months and for medical conditions about which the respondent was told by his or her doctor or other health-care provider. In this crude comparison, a greater proportion of target area residents reported respiratory symptoms, heart problems, and constitutional complaints (always fatigued or tired and bowel disorders). There were no significant differences in other gastrointestinal symptoms or problems and none referable to the nervous system. There was more frequent medical history of anemia and other blood problems. An analysis accounting for within-household correlation of variables confirmed the results from the chi-square analysis.

We used multiple logistic regression analysis to control for population differences in sex, age, marital status, education, type of dwelling, exposure to hazards at work, and smoking habits. Table IV shows that all variables previously significant at the $p = .05$ level remained so after taking into account potential confounders. Table IV also presents odds ratios calculated from the univariate and the multiple logistic regression analyses. The two analyses yielded similar odds ratios. We did not adjust for within-household correlation in the multivariate analysis because the adjustment in the univariate case changed the p value very little.

During the analysis of the results, we learned that two factories in the northeast quadrant of the control area were emitting high volumes of dimethylformamide, xylene, and toluene into the immediate neighborhood. With the elimination of that quadrant of the control area, the "history-of-blood-problems" variables no longer achieved statistical significance. The analysis revealed, however, that irritation of the eyes and nose was more prevalent in the target area compared to the "nonfactory" control areas. No other variables were affected.

Table V presents results of analyses that assessed the influence of distance from the site as an independent variable. We found proximity to the site significantly related to four other outcomes not previously related to residence in the target area. This suggests that for these effects (chest pains, shortness of breath, easy bruising/bleeding, headaches) the distance variable differentiated between persons in the target area who were nearer to, as opposed to more distant from, the site. A histogram of distance from the site for each household in the target area (not shown) revealed three natural groupings which we designated as "near," "middle," and "far." The households in the "far" area were approximately twice as far from the site as those in the "near" area. Figure 2 shows the distance gradient in prevalence for areas close to the site compared to other areas. The increase in odds ratios (Table IV compared to Table III) most likely reflects differential effects in the most proximate as opposed to more distant sections of the target area.

An examination of the "other symptoms" category did not reveal any pattern of specific medical conditions that differed markedly between the two areas. The same lack of pattern occurred with the "heart disease" category. Small numbers prevented further specification of these categories.

DISCUSSION

The results of this study demonstrate that residents living near a source of airborne chemical contamination report more respiratory symptoms (wheezing, cough, persistent colds), more sensation of irregular heart beat and medical history of heart trouble, more constitutional complaints (always fatigued or tired, bowel dysfunction), and a more frequent medical history of anemia and other blood disorders compared

TABLE II. Characteristics of Target and Control Populations

	Target (%)	Control (%)	p[a]
Housing	(N = 513)	(N = 502)	< .0001
Single-family house	50.6	30.8	
2-, 3-Family house	38.2	38.6	
Apartment/flat	11.2	30.6	
Number of adults in house			<.01
1	22.0	29.9	
2	52.4	48.2	
3	13.8	14.7	
4+	11.8	7.2	
Sex (adults, 18 and over)	(N = 1,049)[b]	(N = 948)[b]	NS
Male	48.0	47.9	
Female	52.0	52.1	
Marital status			NS
Married	58.7	54.6	
Widowed	6.9	7.2	
Separated	3.2	4.0	
Divorced	6.8	6.9	
Never married	24.4	27.3	
Years at current address			<.001
Since 1970	40.8	30.5	
Age (adults, 18–)			.01
18–19	6.6	4.2	
20–29	29.3	33.5	
30–39	19.0	20.5	
40–49	15.4	12.1	
50–59	11.6	14.4	
60–69	11.4	9.4	
70–79	5.1	4.4	
80–89	1.5	1.5	
Currently employed	62.9	60.2	NS
Not working			.02
Unemployed	13.7	14.5	
Laid-off	7.0	13.4	
Retired	31.2	22.6	
Medical leave	3.6	3.0	
Disabled	10.1	11.3	
Homemaker	28.3	31.4	
Student	5.9	3.5	
No response	.3	.3	
Ethnicity			.0001
White	92.0	90.4	
Black	4.7	1.3	
Hispanic	2.3	6.4	
Native American	.6	.6	
Asian	.5	1.3	
Family income ($)[c]			.01
–5,000	8.1	8.6	
5,000–10,000	17.9	20.5	
10,000–15,000	19.4	23.5	
15,000–20,000	14.8	11.8	
20,000–25,000	19.8	16.7	
25,000–30,000	7.2	9.2	
30,000+	9.7	12.8	

(continued)

TABLE II. Characte

Education
–8th grade
1–3 Years high scho
High school diploma
1–3 years college
College diploma
Graduate school
Current smokers
Quitting rate of ever-
Drinking frequency/m
Nondrinkers
1–5/month
6–10/month
11–20/month
21+/month
Number of daily drin
0
1–2
3–6
7+
Occupational exposur
Ever exposed to
Smoke, fumes vapo
Don't know
Pesticides or herbic
Don't know
Irritants to eyes or
Don't know
Asbestos
Don't Know
Beryllium
Don't know
Radiation
Don't know
Sandblasting, silica,
rockcrushing, rock
Don't know
Solvents/degreasers
perc or trichloroet
Don't know
Lead
Don't know
Mercury, cadmium,
Don't know

[a]χ^2 test, 2-tailed; NS
[b]Maximum N. Actual
[c] Total N = 1,777. T
values).
[d]Percentage not expos

TABLE II. Characteristics of Target and Control Populations (continued)

	Target (%)	Control (%)	p[a]
Education			.003
-8th grade	17.0	22.5	
1-3 Years high school	27.4	25.1	
High school diploma	40.4	34.6	
1-3 years college	11.4	11.9	
College diploma	2.6	4.4	
Graduate school	1.2	1.6	
Current smokers	46.7	40.9	.0001
Quitting rate of ever-smokers	70.3	71.1	NS
Drinking frequency/month			
Nondrinkers	32.4	33.8	.02
1-5/month	34.4	30.4	
6-10/month	13.8	11.9	
11-20/month	8.1	8.0	
21+/month	11.4	15.9	
Number of daily drinks			NS
0	32.3	33.7	
1-2	29.9	31.5	
3-6	31.8	27.3	
7+	6.0	7.5	
Occupational exposures[d]			NS
Ever exposed to			
Smoke, fumes vapors	41.1	40.6	
Don't know	.6	.4	
Pesticides or herbicides	4.7	5.4	
Don't know	1.1	1.0	
Irritants to eyes or nose	22.8	24.0	
Don't know	.2	.1	
Asbestos	8.7	8.1	
Don't Know	2.0	3.2	
Beryllium	1.2	.8	
Don't know	7.1	8.1	
Radiation	2.4	4.5	
Don't know	2.4	4.7	
Sandblasting, silica, rockcrushing, rockdrilling, talc	11.3	9.8	
Don't know	.4	.7	
Solvents/degreasers, such as perc or trichloroethylene	20.1	16.7	
Don't know	1.4	2.1	
Lead	6.9	6.1	
Don't know	.6	.1	
Mercury, cadmium, arsenic	2.3	2.7	
Don't know	1.0	2.1	

[a] χ^2 test, 2-tailed; NS means $p > .05$.
[b] Maximum N. Actual N varies slightly from item to item because of occasional missing data.
[c] Total N = 1,777. This item had significantly more missing data points than other items (220 missing values).
[d] Percentage not exposed to each agent has been omitted for clarity.

TABLE III. Association With the Target Area, Univariate Comparisons

Outcome (N = 1,997)[b]	Target (%) (N = 1,049)	Control (%) (N = 948)	Prevalence ratio: target/control	p[a]
Respiratory symptoms/problems				
Wheezing, tightness in chest	27.4	20.6	1.33	.0005
Cough, more than 2 weeks	25.6	18.8	1.36	.0004
Persistent colds	11.8	7.6	1.55	.002
Shortness of breath	24.5	21.5		NS
Lung problems, told by doctor	15.3	13.3		NS
Cardiovascular symptoms/problems				
Irregular heart beat	14.9	11.4	1.31	.03
Chest pains	19.4	17.6		NS
Heart trouble, told by doctor	16.3	11.9	1.37	.006
Gastrointestinal symptoms/problems				
Nausea/vomiting	17.8	15.4		NS
Unusual color to urine	5.9	5.3		NS
Digestive problems, told by doctor	15.8	15.3		NS
Liver problems, told by doctor	5.9	4.9		NS
Blood symptoms/problems				
Easy bruising, bleeding	10.9	8.7		NS
Swollen glands	10.2	10.3		NS
Anemia, told by doctor	14.7	11.1	1.32	.02
Other blood problems, told by doctor	6.5	4.2	1.55	.03
Skin/mucous membranes				
Rash, skin irritation	15.6	13.2		NS
Irritation, burning of eyes and nose	24.0	21.3		NS
Acne	11.0	9.9		NS
Skin disease/allergy, told by doctor	14.5	15.0		NS
Constitutional				
Always fatigued or tired	37.9	32.7	1.16	.02
Bowel complaints (diarrhea/constipation)	29.5	23.0	1.28	.0013
Loss of 10 lb. without dieting	7.0	7.0		NS
Comparative health				NS
Better	23.6	24.2		
Same	65.6	66.2		
Worse	10.9	9.6		
Overall health				NS
Excellent	21.4	21.9		
Good	51.8	52.5		
Fair	21.3	21.1		
Poor	5.2	4.5		
Nervous system				
Dizziness	18.2	16.5		NS
Unconsciousness/blackouts	2.5	2.3		NS
Numbness in fingers, toes	23.6	20.9		NS
Nervousness	30.5	33.7		NS
Headaches	11.3	9.5		NS
Neurologic problems, told by doctor	9.6	11.4		NS
Other				
Kidney problems, told by doctor	11.9	10.0		NS
Cancer, told by doctor	3.6	2.1		NS

(continued)

TABLE III. Association With the Target Area, Univariate Comparisons (continued)

Outcome (N = 1,997[b])	Target(%) (N = 1,049)	Control (%) (N = 948)	Prevalence ratio: target/control	p[a]
Other problems, told by doctor	22.1	16.0	1.38	.0007
Hospitalized since June 1982	11.3	10.1		NS
Seen doctor, last 2 months	33.1	31.1		NS

[a]Continuity adjusted χ^2, 2-tailed; NS means $p > .05$.
[b]Maximum N, which may vary from item to item because of missing values.

TABLE IV. Control of Confounding by Multiple Logistic Regression Analysis*

	Coefficient of target/control variable[a] (SE)	P	Odds ratio*[b] Univariate	Odds ratio*[b] Adjusted
Wheezing/tightness in chest	−.296 (.113)	.009	1.45	1.34
Cough	−.348 (.115)	.003	1.49	1.42
Persistent colds	−.476 (.162)	.003	1.63	1.61
Irregular heartbeat	−.290 (.141)	.04	1.36	1.34
Heart trouble, told by doctor	−.392 (.140)	.005	1.44	1.48
Anemia, told by doctor[c]	−.299 (.150)	.05	1.38	1.35
Other blood problems, told by doctor[c]	−.448 (.216)	.04	1.49	1.57
Irritation, eyes/nose[d]	−.263 (.130)	.04		1.30
Always feeling fatigued	−.255 (.100)	.01	1.26	1.29
Bowel complaints, diarrhea/constipation	−.321 (.108)	.005	1.40	1.38
Other problems, told by doctor	−.419 (.122)	.0006	1.49	1.52

*Regression model: Dependent variables consisted of target/control, sex, age, marital status, current exposure to work hazard, education, housing type, current smoker, former smoker.
[a]Target area coded "zero," control area coded "one." A negative coefficient for this variable indicates a higher prevalence in the target area compared to the control.
[b]Univariate odds ratio based on overall rates presented in Table II. Adjusted odds ratio based on logistic regression, adjusting for possible confounding variables.
[c]Fail to be significant when northeast quadrant eliminated from control (see text).
[d]Northeast quadrant of the control area not included in comparison (see text).

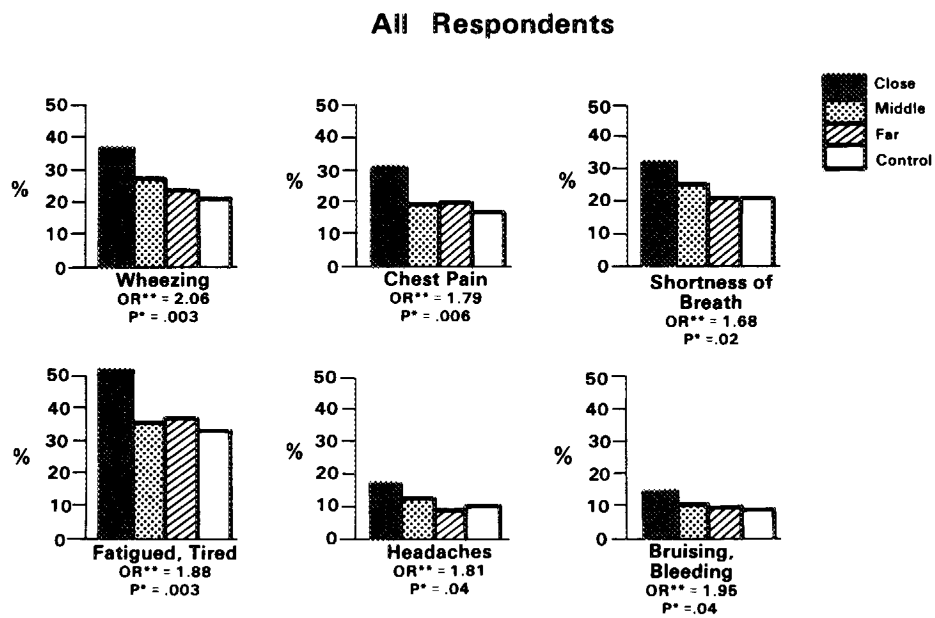
with a control group further from the source. Reports of eye and nose irritation also seemed to be associated with the site when the presence of an irritant source affecting part of the control population was taken into account. Use of distance from the site as a measure of exposure showed that within the target area itself, complaints of wheezing, chest pains, shortness of breath, fatigue and tiredness, easy bruising/bleeding, and headaches were most frequent in residents who lived closest to the site (Fig. 2). These differences could not be explained by differences in demographic make-up, occupational experiences, or various lifestyle characteristics of residents in the respective areas. Before one reaches a conclusion that these differences are site-related, one must consider a number of study limitations and potential biases.

Given the strict quality control used by the survey team, interviewer bias seems highly unlikely. The same interviewers worked in both target and control areas and response rates were high (80%) in both areas. Further, the degree of cooperation, as

TABLE V. Percentages of Respondents Reporting Symptoms by Distance From Site

Outcome	Control	Far	Middle	Close	P[a]	Odds ratio[b]
Wheezing	21%	23%	27%	37%	.003	2.06
Chest pain	17	19	18	29	.006	1.79
Shortness of breath	21	21	25	32	.02	1.68
Fatigued, tired	33	37	36	51	.003	1.88
Bruising, bleeding	9	10	11	14	.04	1.95
Headaches	10	8	12	17	.04	1.81
N[c]	919	355	555	127		

[a]P-value associated with the distance variable in multiple logistic regression (model same as Table III).
[b]Odds ratio comparing risk of those close to the site to that of the controls (see text).
[c]Total N slightly lower than given in Table I due to missing values.



*Distance variable in multiple logistic regressions.
**Risk of those close to the site compared to controls.

Fig. 2. Histograms of complaint by distance from site.

noted by the interviewer after each interview, was very similar in both groups. A combination of phone and in-person interviews is an acceptable survey research practice if the same set of questions is used for both types of interview, as was done in this study [Mangione et al, 1982; Thornberry, 1976; Siemiatycki, 1979].

The most serious potential problem in the study is recall bias: respondents may have given special importance to certain symptoms in the target area, or "differential forgetting" may have occurred in the control area. For example, a respondent who believed his headache resulted from his breathing chemicals in the air of his neighborhood may remember his headaches better than someone for whom a headache is just another minor annoyance in life. One would expect such recall bias to increase with proximity to the site just as one would expect a biological effect to increase. We recognize, however, that people who believe their headaches result from their breathing of chemicals may very well be correct.

The suspicion that recall bias is operating is raised by the dramatic "pan-symptom" effect shown in Table III. Even when differences do not reach significance, we see an overwhelming trend of higher prevalence in the target group. However, the univariate comparison is confounded by age and smoking which could account from some of this. (These and other differences are taken into account in the logistic regressions of Table IV.) Another indication of recall bias was revealed when we compared respondents who answered "Yes" to whether they believed the air or water in their neighborhoods made them ill. Such a belief could produce bias if there were more such people in the target area as compared to the control. Table VI presents representative results for a few outcomes (other outcomes are similar). Table VI shows that there is a much higher symptom prevalence in people who believed the air or water in their neighborhood made them ill. This held for both control and target areas. While this could be interpreted as strong evidence of recall bias, a true biological effect could also have brought respondents to the conclusion that the air or water was responsible for their feelings of ill health.

A better test for recall bias is to assess the effect of the site variable on those individuals who did *not* believe the air or water made them ill. We maintain that these individuals are less likely to be subject to site-associated recall bias. Multiple logistic regressions for only those respondents answering "No" to both questions about air and water showed that "bowel complaints" and "cough" were the only outcomes still significant under these conditions (data not shown). We note that passing this test is some evidence against recall bias for these outcomes, but that failing to pass it merely means that we are not helped in deciding between the alternatives of biological effect and recall bias. In another use of these responses, we looked for a biological gradient with distance, as in Figure 2, but now involving only those respondents who answered "No" to whether they believed the air in their neighborhood made them ill. Figure 3 shows that six symptoms still exhibit a biological gradient although only three achieved statistical significance, possibly because of the reduced sample sizes. These results suggest that recall bias alone does not account for the findings of the study.

The presence of a community organization working on site clean-up was another factor that could possibly bias responses. No references to any environmental purpose

TABLE VI. Opinions on Air and Water and Outcomes for Target and Control Groups

	Opinion as to whether water causes illness			
	Control area		Target area	
Outcome	Yes (%) (N = 71)	No (%) (N = 835)	Yes (%) (N = 89)	No (%) (N = 921)
Wheezing	43.7	18.0	49.4	24.6
Chest pain	39.3	16.9	40.9	15.1
Nausea/vomiting	32.4	13.8	37.1	15.9
	Opinion as to whether air causes illness			
	(N = 33)	(N = 875)	(N = 126)	(N= 887)
Wheezing	66.7	18.3	56.3	23.2
Chest pain	48.5	15.8	35.7	16.8
Nausea/vomiting	24.2	14.9	29.4	16.1

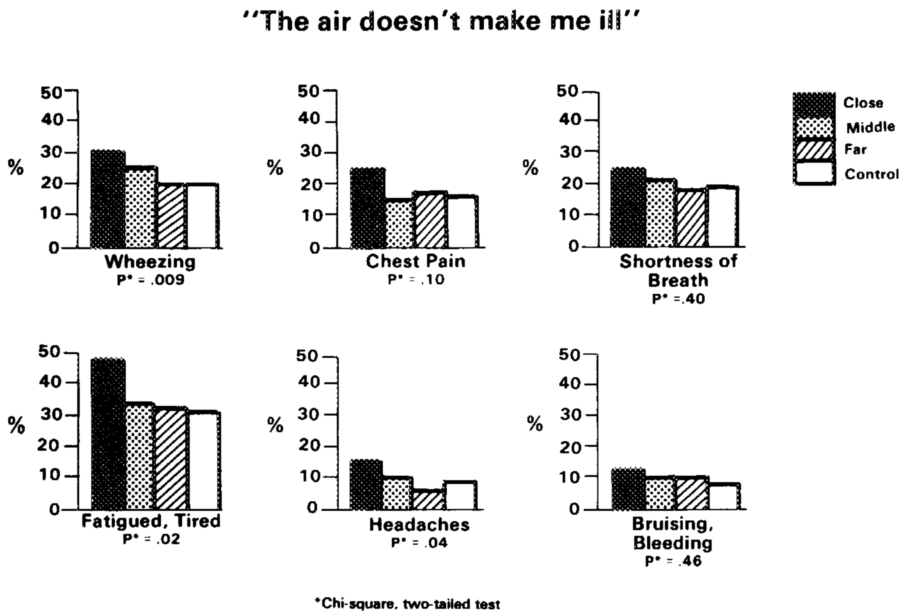


Fig. 3. Histogram of complaints of those least likely to be subject to recall bias (see text).

were made in the interview, respondents being told only that a state agency was interested in the health of people in Lowell and factors in their lives that affected their health. Although the waste site was not mentioned, some respondents spontaneously referred to the site or mentioned the community group that organized around the issue of the site. Using "awareness" as an independent variable in the logistic regressions failed to alter the set of variables that were significant before controlling for "awareness." While this suggests that bias introduced by exaggerated reporting is not the explanation for the results, this depends on the extent to which "awareness" is an adequate indicator of such bias. Alternatively, the community group also engendered some negative reactions in the neighborhood, so this kind of bias can operate in either direction. In any event, "awareness" could also be the result of "reverse causation," ie, actual site-associated illness causing awareness of the site and concern with it.

Eight of eleven outcomes passed at least one of these tests for lack of recall bias: headaches, wheezing/tightness in the chest, bowel complaints, cough, fatigue, persistent colds, heart problems, and "other" medical disorders. Three outcomes, irregular heart beat, medical history of anemia, and history of other blood problems failed both tests and may be considered suspect.

We note that there are also a number of factors that might work against detection of an association between symptoms and area of residence. As in any cross-sectional design, we could interview only current residents. Numerous respondents in the target area described neighbors who had become ill and decided to move away from the site area. Moreover, although we conducted the survey from February to April 1983 and inquired only about recent symptoms so as to mitigate the effects of recall bias, it is known that the worst site conditions occurred in the years 1974 to 1979. Conditions were also alleged to be worse during the summer months while this survey was conducted in late winter. Exposures among residents varied widely, depending on the amount of time spent in the neighborhood on an average day, movement within the area, and relative amount of time spent indoors versus outdoors. The lack of specificity in our measures of exposure reduced the study's ability to detect differences. Finally, we had scant information available on chemical exposure in the control neighborhood. Any substantial exposure to chemicals among control residents would tend to obscure differences due to the site. The masking of the irritant effects of the site by factories located in one quadrant of the control area exemplifies this phenomenon.

No independent verification of outcomes was done. It was neither feasible to obtain releases and check medical records of 3,000 respondents nor possible to perform clinical tests, even on a restricted subset of respondents. This is a problem common to large-scale symptom prevalence surveys. Moreover, self-reported health outcomes are generally not subject to verification, even in principle. Most involve complaints such as headaches, dizziness, or fatigue, for which objective findings rarely exist. The decision to see a doctor for these complaints (and hence generate a medical record) is influenced by many factors other than the complaint itself. And in the last analysis, such care-seeking behavior results in a documentation of a self-reported illness with no more objective foundation than that obtained by survey methods.

We also note that the perception or self-report of ill health is an objective fact on its own of some significance and requires no verification. Insofar as a difference in prevalence of self-reported symptoms is not an artifact of bias, the perception of symptoms, whether or not there is a documented physiological basis, has an adverse impact on the quality of life of a community.

The reason for the results remains to be explained. The higher prevalence of respiratory symptoms and headaches is consistent with the known effects of some of the volatile chemicals at the site, but the relevant occupational health literature indicates that these symptoms appear only after exposures that are very much higher than those measured by our concurrent air monitoring, in some cases three orders of magnitude higher [Proctor and Hughes, 1978]. Occupational groups, however, represent a selected portion of the population in that they are a nonrepresentative sample with regard to age and sex and are sufficiently healthy to be employed. Furthermore, we reason that individuals especially bothered by specific chemical exposures do not stay long in workplaces where they occur (the "tolerant worker effect"). Studies of the resulting tolerant and healthy occupational groups may thus underestimate exposure effects in the general population which comprises the very old, the very young, the chronically ill, and an unknown number of the very sensitive.

A second possibility is that the higher symptom prevalence seen near the waste site could be residual effects from heavier past exposures. If this is so, the effects appear to be more lasting than formerly thought.

Finally, there may have been other airborne contaminants present that were not measured but were responsible for the symptoms. The odors perceptible at the site are not associated with any of the measured chemicals. However, many agents are perceptible at extremely low levels and sources of odor are rarely identified by the usual air-monitoring methods. Few studies have looked at the effects of odorants *per* *se* as a cause of symptoms. Virtually all odorants have some irritant effect as well. Olfactory sensation is mediated by the olfactory nerve (cranial nerve I) while irritant effects are mediated by the trigeminal nerve (cranial nerve V). Alvarie and Luo [1986] have noted that trigeminal stimulation affects more organ systems than does any other peripheral receptor. One study of symptom prevalence in residents living near odor-producing petroleum refineries showed an inconsistent relationship between respondents bothered by odors and symptoms of dizziness, nausea and vomiting, and burning/irritation of the eyes and nose. Chest pain showed an inverse trend with odor annoyance. There was no significant relation of odor perception and responses to the British Medical Research Council's questionnaire on respiratory symptoms [Deane and Sanders, 1978]. The relative roles of olfaction, irritation responses, and other effects in producing the kinds of symptoms seen in this report are yet to be clarified.

CONCLUSION

The results of this study raise the possibility that exposure to relatively low levels of airborne chemicals may have increased the prevalence of respiratory and constitutional symptoms in adults in the affected neighborhood. Further studies are needed to confirm the suspicion that members of the general population react to chemical exposures at levels that are considerably lower than those anticipated from existing data derived in the occupational environment. This has important implications for risk assessment and the setting of environmental standards.

The focus of public concern about the health effects of hazardous wastes has centered on serious but low-prevalence diseases such as cancer. Such endpoints are extremely difficult to study by epidemiologic methods because of the low statistical power associated with small sample sizes. This study suggests that a population exposed to contamination of the environment by chemicals may exhibit an increase in the frequency of many common medical complaints. Not only are such outcomes more amenable to study because of their higher prevalence, they may have considerable importance because of their impact on the efficiency, well-being, comfort, and productivity of a community.

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REFERENCES

Alarie Y, Luo JE (1986): Sensory Irritation by Airborne Chemicals: A Basis to Establish Acceptable Levels of Exposure. In Barrow CS (ed): "Toxicology of the Nasal Passages." Washington: Hemisphere, pp 91–122.

Budnick LD, Sokal DC, Falk H, Logue JN, Fox JM (1984): Cancer and birth defects near the Drake Superfund Site, Pennsylvania. Arch Env Health 39:409–413.

Colton T (1974): "Statistics In Medicine." Boston: Little Brown.

Deane M, Sanders G (1978): Annoyance and health reactions to odor from refineries and other industries in Carson, California, 1972. Environ Res 15:119–132.

Department of Environmental Quality Engineering [DEQE] (1982): "Preliminary Evaluation of the Silresim Air Monitoring Study, Lowell, Massachusetts." Boston, Division of Air Quality Control.

Fred C. Hart Associates, Inc. (1978): "Final Report: Analysis of Hazardous Waste Management Incident in Lowell, Massachusetts." USEPA, Office of Solid Waste Contract No. 68-01-3897, New York, New York.

Goldman LR, Paigen B, Magnant MM, Highland JH (1985): Low birthweight, prematurity and birth defects in children living near the hazardous waste site, Love Canal. Haz Waste 2:209–224.

Goodnight JH (1982): TTEST. In: "SAS User's Guide: Statistics, 1982 Ed. Gary, NC: SAS Institute.

Harris R, Highland J (1984): Adverse health effects at a Tennessee hazardous waste disposal site. Haz Waste 1:183–204.

Levine AG (1982): "Love Canal: Science, Politics, and People." Lexington: Lexington Books.

Mangione TN, Hingson R, Barrett J (1982): Collecting sensitive data: a comparison of three survey strategies. Sociolog Meth Res 10:337–346.

Mitre Corporation (1979): "Hazardous Waste Cleanup: Silresim Site in Lowell, Massachusetts." Summary Report, October 1969, Bedford, MA.

Perkins Jordan, Inc. (1982): "Silresim Chemical Corporation Site, Lowell, Massachusetts, Remedial Action Study." Prepared for DEQE, Commonwealth of Massachusetts, 27 April 1982, Reading, Massachusetts.

Philips AM, Silbergeld, EK (1985): Health effects studies of exposure from hazardous waste sites—where are we today? Editorial, Am J Ind Med 8:1–7.

Proctor NH, Hughes JP (1978): "Chemical Hazards of the Workplace." Philadelphia: J. B. Lippincott.

Schlesselman JJ (1982): "Case Control Studies." New York: Oxford University Press.

Siemiatycki J (1979): A comparison of mail, telephone and home interview strategies for household health surveys. AJPH 69:238–245.

Solid Waste Disposal Act, as amended by the Resource Conservation and Recovery Act of 1976, 42:USC, 6905.

Thornberry OT (1976): An evaluation of three strategies for the collection of data from households. Ph.D. dissertation. Brown University.

Turner DB (1970): "Workbook of Atmospheric Dispersion Estimates." Washington: USEPA.

Universities Associated for Research and Education in Pathology [UAREP] (1985): "Health aspects of the disposal of waste chemicals." Bethesda, MD, UAREP.