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Irritant Effects of Formaldehyde Exposure in Mobile Homes

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This paper reports the irritant effects associated with formaldehyde exposures in mobile homes. Week-long, integrated formaldehyde concentrations were measured using passive monitors in summer and winter while the mobile home residents continued their normal activities. Information on acute health problems, chronic respiratory/allergic illnesses, smoking behavior, demographic variables, and time spent at home was obtained on over 1000 individuals during the sampling period. Measured formaldehyde concentrations varied from under the limit of detection (0.01 ppm) to 0.46 ppm. Formaldehyde exposure was estimated for each individual by multiplying the concentration measured in his or her home by the time he or she spent at home. Irritant effects were found to be associated with formaldehyde exposure after controlling for age, sex, smoking status, and chronic illnesses using a logistic procedure. Some of the interaction terms found to be significant indicated that there were synergistic effects between formaldehyde exposure and chronic health problems.

Introduction

Acute health effects caused by low-level exposures to formaldehyde (HCHO) have been demonstrated in controlled studies of humans and animals and have also been observed in occupational and residential environments (*1*). Human subjects have experienced eye irritation at 0.5 ppm in an experimental chamber (*2*). Irritation effects in the upper respiratory tract begin at 0.1 ppm and become more common at 0.2 ppm (*3*). Symptoms in the lower airways such as cough, chest tightness, and wheeze are observed at higher levels (> 5 ppm), but may occur in the presence of fine particles at lower (0.07 ppm) concentrations (*4,5*). Electroencephalogram (EEG) changes have been found in human subjects exposed to 0.04 ppm of HCHO (*6*). Headache, nausea, vomiting, and diarrhea have been reported by people exposed to concentrations ranging from 0.02 to 4.15 ppm in residential environments (*7*). Neurobehavioral effects, such as headache, dizziness, nausea, memory loss, and sleeping problem were also observed among histology technicians exposed to concentrations between 0.2 and 1.9 ppm (*8*).

Approximately 1 to 7% of dermatologic patients show positive responses to patch tests with 2% HCHO (*9*). While it is clear that HCHO can produce hypersensitivity reactions by the dermal route, it is less certain that it can induce hypersensitivity reactions by inhalation (bronchial asthma). Occupational studies have shown that bronchial asthma is related to repeated exposure to HCHO at levels lower than 1 ppm, even though chamber studies have failed to produce asthma attacks in nonasthmatic people, or even on asthma patients at higher levels (*10,11*). The reason for the discrepancy between the occupational finding and the results of chamber studies is not known.

Since formaldahyde is an irritant chemical that also causes hypersensitivity reactions, it is possible that it might produce more symptoms among people with chronic respiratory illnesses and allergy problems. But aside from the investigations of asthma patients mentioned above, there are no systematic studies on HCHO's effects on people with chronic respiratory diseases or allergy problems.

HCHO is a widely used chemical. Billions of pounds of HCHO are produced in the United States annually, of which approximately one-half is used in the wood products industry. Plywood and particle board, commonly used in construction, are the major sources of HCHO in residential environments. Mobile homes, because of their air-tight structures, extensive use of pressed wood products, and relatively small volumes are more likely to have elevated HCHO concentrations than conventional homes. HCHO-related health complaints in mobile homes have been reported in several states (*12*), and several investigations have been carried out to study such complaints. A random sample of mobile homes has been investigated in only one study, namely, a pilot study of 65 noncomplaint mobile homes in Wisconsin. In that study, a positive relationship was found between HCHO concentration and eye irritation (*13*). However, due to the small sample size, only one of many potential confounders, age, was adjusted for in the statistical analysis.

In 1984–1985, the California State Indoor Air Quality Program carried out a random survey of HCHO in mobile homes. The major hypothesis to be tested was that irritant effects are positively

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associated with HCHO exposures. To test the hypothesis, the survey was designed to *a*) obtain the distribution of HCHO concentrations from randomly selected noncomplaint mobile homes, *b*) estimate HCHO exposures for residents of mobile homes using the concentration data and time activity patterns for occupants, and *c*) test the association between HCHO exposures and physical symptoms by controlling major potential confounders. The survey was also used to determine the important factors affecting HCHO concentrations. This paper addresses mainly the health effects of HCHO, while previous papers discussed other aspects of the study (*14–17*).

Methods

An age-stratified random sampling scheme was used in this survey for the selection of mobile homes. A list of randomly selected mobile homes with approximately 60% of the homes manufactured after 1980 was provided by the California Department of Housing and Community Development. A total of 2203 letters were mailed to recruit participants. Forty-four percent of the recipients responded positively to the request, and the age distribution of their residences was similar to that of the original list. The survey consisted of two phases. The summer phase was carried out during July and August, 1984, and the winter phase during February and March, 1985. A total of 663 mobile homes with 1394 residents completed the summer phase and 523 homes with 1096 residents finished the winter phase of the survey. A detailed description of the study design can be found in a previous publication (*14*).

The large sample size of the participants (over 1000 individuals) allowed for control of potential confounders such as age, sex, smoking status, and time spent at home without the loss of statistical power. It also allowed the investigation of the effects of HCHO on people with chronic respiratory illnesses and allergy problems.

This survey was carried out by mail, although approximately 20% of the residences were visited in the summer, and an additional 14% were visited in the winter. Passive HCHO monitors, along with a cover letter, instructions, logging forms, a questionnaire, and a return envelope were mailed to the participants. They were instructed to uncap the monitors and put one in the kitchen and one in the master bedroom. After 7 days of exposure, monitors and completed questionnaire were mailed back. The residents carried out their normal daily activities during the monitoring period. HCHO concentrations were measured using the chromatrophic acid method.

The survey questionnaire consisted of questions on housing characteristics, household activities, and occupant information. It was filled out by an adult in each participating household. Occupant information was obtained for all residents. It included personal data, presence or absence of 6 respiratory/allergy diseases, and 16 physical symptoms. Personal data requested were name, age, sex, occupation, smoking status, and the average number of hours spent at home per day during the 1-week monitoring period. Individual exposure was obtained by multiplying the average HCHO concentration by the time spent in the mobile home. The 6 chronic conditions were asthma, hay fever, emphysema, rashes, chronic bronchitis, and allergies. The 16 symptoms were asthma attacks, wheezing or difficult breathing, chest pain, stinging or burning skin, burning or tearing eyes, sore throat, running nose, cough, rashes, headache, sleeping problems, dizziness, nausea or vomiting, unusual fatigue or drowsiness, abdominal pain, and diarrhea. Occurrences of these symptoms were reported for the 2 weeks prior to the end of the monitoring period.

Variables related with symptoms were first identified using univariate analyses. The effects of HCHO on symptoms were then evaluated using logistic regression to control potential confounders.

Results

HCHO concentrations measured in this study varied from below the limit of detection (0.01 ppm) to 0.46 ppm. Since no significant differences were found between the kitchen and bedroom measurements, the two values were averaged to represent the whole-house concentration. The mean of the whole-house HCHO concentrations of all monitored mobile homes was 0.089 ppm in the summer and 0.088 ppm in the winter. The weekly HCHO exposure for each individual was obtained by multiplying the whole-house concentration by the total number of hours spent at home during the monitoring week. Weekly HCHO exposures varied from 0 (several residents did not stay at home during the sampling week) to 53.4 ppm-hr in the summer and from 0 to 40.9 ppm-hr in the winter. The average exposures were 9.8 ppm-hr and 9.9 ppm-hr, respectively.

Based on the returned questionnaires, there were 1394 individuals included in the summer phase and 1096 individuals included in the winter phase of the study. The characteristics of the participants are shown in Table 1. Fifty-three percent were females and 47% were males. One-third were 65 years of age or older, and one-quarter were smokers. Thirty-three percent reported having chronic respiratory disease and/or allergy problems.

The symptoms reported in this survey were found to be statistically significantly related with gender, age, smoking status, and presence of chronic respiratory/allergy problems. As can be seen in Tables 2 and 3, the percentage of people having various symptoms was generally higher for females, smokers, and persons with chronic respiratory/allergy problems. However, the reported symptoms did not vary linearly with age. When the prevalence of the 16 symptoms was compared among three age groups (5–19, 20–64, 65+), reported symptoms did not always increase with age. For eight symptoms in the summer and six symptoms in the winter, highest prevalence rates were found among the people between the age of 20 and 64 years.

Age, gender and smoking status are usually controlled in epidemiologic studies as potential confounders to evaluate the relationships between health effects and exposures. However, in this study, the close association between the reported symptoms and the presence of chronic respiratory/allergy conditions made it neccessary that these conditions be controlled as well. The strong association is indicated in Tables 2 and 3. Prevalence rates of symptoms among the people with chronic diseases are higher than those among females or smokers. Furthermore, all the differences between the people with and without chronic conditions (except for the symptom of nausea in the summer) are statistically significant.

Due to the nonlinear relationship between age and symptoms, the procedure of linear logistic regression was carried out on the

Table 1. Characteristics of participants in the California HCHO study.

Parameter	No. of participants (%) Summer	Winter
Gender		
Male	645 (46.5)	518 (47.4)
Female	743 (53.5)	575 (52.6)
Age		
≤ 4	46 (3.4)	39 (3.6)
5–19	135 (9.8)	90 (8.3)
20–64	739 (53.9)	587 (54.0)
≥ 65	452 (32.9)	371 (34.1)
Smoking		
Yes	372 (26.9)	256 (23.4)
No	1011 (73.1)	836 (76.6)
Respiratory/allergy conditions		
Yes	464 (33.3)	356 (33.5)
No	928 (66.7)	707 (66.5)
Allergy		
Yes	297 (21.3)	209 (19.7)
No	1095 (78.7)	854 (80.3)
Asthma		
Yes	59 (4.2)	53 (5.0)
No	1333 (95.8)	1010 (95.0)
Chronic bronchitis		
Yes	71 (5.1)	77 (7.2)
No	1321 (94.9)	986 (92.8)
Emphysema		
Yes	42 (3.0)	34 (3.2)
No	1350 (97.0)	1029 (96.8)
Hayfever		
Yes	175 (12.6)	115 (10.8)
No	1217 (87.4)	948 (89.2)
Rashes		
Yes	86 (6.2)	51 (4.8)
No	1306 (93.8)	1012 (95.2)
HCHO concentration		
< 0.05 ppm	429 (30.8)	220 (20.4)
0.05–0.1 ppm	552 (39.7)	535 (49.6)
> 0.1 ppm	411 (29.5)	323 (30.0)
HCHO exposures, ppm-hr		
< 7.0	631 (46.7)	406 (39.6)
7.0–12.0	357 (26.4)	337 (32.9)
> 12.0	364 (26.9)	282 (27.5)

Table 2. Percentage of participants with symptoms by gender, smoking status, and respiratory/allergy diseases in summer phase.

Symptom	Gender Female	Male	Smoker Yes	No	Respiratory/allergy Yes	No
Abdominal pain	7.0	2.8*	5.1	5.0	9.1	3.0*
Asthma attack	0.8	0.9	0.3	1.1	2.6	0.0*
Burning eyes	16.2	11.5*	17.0	13.0	25.9	8.1*
Burning skin	3.9	2.2	4.0	2.8	6.9	1.2*
Chest pain	5.8	3.1*	5.4	4.3	6.7	3.5*
Cough	19.8	14.3*	25.9	14.1*	28.5	11.5*
Diarrhea	9.7	6.5*	10.5	7.4	12.5	6.0*
Dizziness	8.1	4.0*	5.4	6.5	8.6	5.0*
Fatigue	15.2	11.2*	15.6	12.6	19.8	10.0*
Headache	26.2	14.9*	24.3	19.8	32.3	15.1*
Nausea	5.8	2.6*	4.3	4.4	5.6	3.7
Sleeping problems	19.4	12.7*	17.8	15.6	24.4	12.2*
Rashes	5.5	3.4	4.9	4.4	12.3	0.7*
Running nose	19.4	16.1	19.1	17.4	29.7	11.9*
Sore throat	11.7	7.1*	10.0	9.4	15.7	6.5*
Wheezing	8.1	7.0	11.3	6.2*	16.4	3.1*

*Significant result from χ^2 test with p-value less than 0.05.

age group with the largest sample size (age 20–64). In addition to the independent variables of gender, smoking status, chronic respiratory/allergy diseases, and HCHO exposure, an interaction term of HCHO exposure and chronic diseases was also included in the logistic model. The logistic model can be expressed as the following function:

Table 3. Percentage of participants with symptoms by gender, smoking status, and respiratory/allergy diseases in winter phase.

Symptom	Gender Female	Male	Smoker Yes	No	Respiratory/allergy Yes	No
Abdominal pain	4.5	2.0*	4.0	3.1	5.3	2.3*
Asthma attack	1.6	1.0	0.4	1.6	3.9	0.0*
Burning eyes	14.8	10.8	13.3	12.8	22.2	8.2*
Burning skin	2.5	2.2	3.2	2.1	3.7	1.7*
Chest pain	6.1	3.2*	7.2	4.0*	9.0	2.6*
Cough	24.6	21.2	31.7	20.2*	34.8	17.0*
Diarrhea	6.4	3.4*	6.4	4.6	8.7	3.1*
Dizziness	7.3	4.0*	5.2	5.9	8.4	4.4*
Fatigue	11.2	6.6*	14.1	7.5*	12.1	7.5*
Headache	25.5	14.4*	24.1	19.1	33.4	13.6*
Nausea	5.9	1.8*	3.2	4.1	7.6	2.1*
Sleeping problems	16.6	10.0*	12.9	13.4	21.1	9.6*
Rashes	3.4	5.0	4.4	4.1	9.3	1.6*
Running nose	22.5	20.6	24.1	20.7	30.6	17.0*
Sore throat	14.1	11.4	11.7	13.1	17.7	10.3*
Wheezing	7.8	6.4	11.2	5.9*	16.6	2.4*

*Significant result from χ^2 test with p-value less than 0.05.

$$\ln(P/(1-P)) = a + b_1X_1 + b_2X_2 + b_3X_3 + b_4X_4 + cX_3X_4$$

where P = the probability of having a given symptom; X_1 = gender; X_2 = smoking status; X_3 = chronic respiratory/allergy disease status; X_4 = HCHO exposure; and X_3X_4 = chronic disease × HCHO exposure.

The results of the logistic regression on 16 symptoms for both seasons are shown in Table 4. As can be seen from this table, complaints of burning/tearing eyes, stinging/burning skin, fatigue, and sleeping problems in the summer and burning/tearing eyes, chest pain, dizziness, sleeping problems, and sore throat in the winter were significantly associated with HCHO exposure after all the important potential confounders were controlled. HCHO acted sometimes independently and sometimes jointly with chronic diseases (as an interaction term) to affect the irritant effects. The fact that some interaction terms reached the 0.05 significance level indicates a high probability that there were synergistic effects between HCHO exposure and chronic diseases.

Since burning/tearing eyes were associated with HCHO exposure for both seasons, an attempt was made to establish the relationship between HCHO exposures and percentages of people with eye symptoms by dividing subjects into three ranges of exposure. The exposure-response relationship is shown in Figure 1. For the three ranges of HCHO exposure, the percentage of people with burning/tearing eyes in the summer increased from 13.3% (<7.0 ppm-hr) to 17.1% (7.0–12.0 ppm-hr) and then to 21.4% (>12.0 ppm-hr). In the winter, the increases are from 10.8 to 14.7% and then to 20.6%.

Discussion

Because this study was a random survey, which covered the entire State of California and included mobile homes of all ages, the average measured HCHO concentrations were expected to be lower than those from surveys of homes where occupants

Table 4. Variables significantly related with health symptoms for the participants between 20 and 64 years of age.[a]

Symptom	Significant independent variables	
	Summer (n = 726)	Winter (n = 544)
Abdominal pain	Gender	—
Asthma attack	—	—
Burning eyes	Gender, HCHO, chronic	HCHO, chronic
Burning skin	HCHO, smoker, chronic	—
Chest pain	Gender	HCHO, smoker, chronic
Cough	Smoker	Smoker, chronic
Diarrhea	—	—
Dizziness	Gender	Gender, HCHO
Fatigue	HCHO*chronic[b]	Smoker
Headache	Gender	Gender
Nausea	Gender	Gender
Sleeping problems	Gender, HCHO*chronic[b]	Gender, HCHO
Rashes	Chronic	—
Running nose	Chronic	—
Sore throat	Gender, chronic	HCHO*chronic
Wheezing	Smoker, chronic	Smoker

[a]The variables listed in this table are those entered into the linear logistic regression function with p-values less than 0.05.
[b]HCHO*chronic indicates an interaction between these two variables.

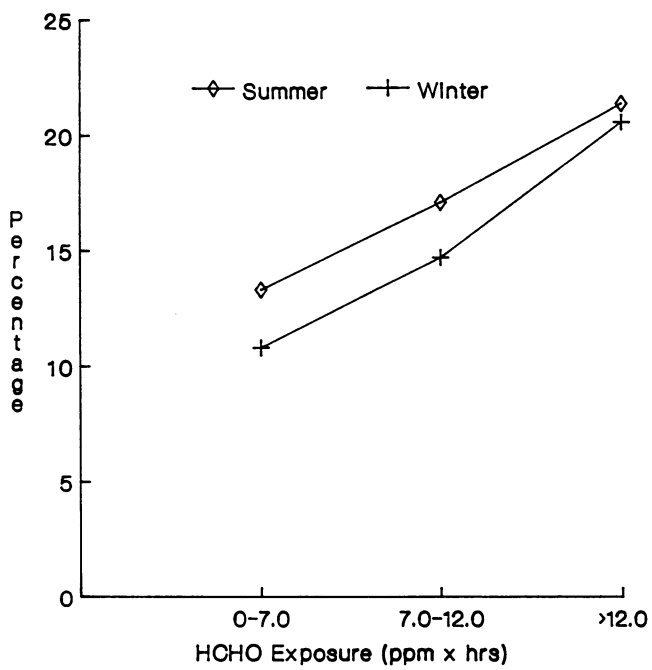

FIGURE 1. Percentage of participants between 20 and 64 years having burning/tearing eyes by three ranges of HCHO exposures.

complained of symptoms. For these noncomplaint participants chronically exposed to relatively low levels of HCHO, positive associations were found between week-long average HCHO exposures and irritant effects. Both in the winter phase and summer phase, several irritant symptoms were related to HCHO exposures when the potential confounders of age, gender, smoking status, and status of chronic respiratory/allergy problems were controlled. This indicates that HCHO-related irritant symptoms exist among residents of mobile homes who have not formally complained to government agencies, suggesting that effects occur at lower HCHO levels than previously thought.

Another significant finding of this study was the synergistic effect between HCHO exposure and chronic respiratory/allergy problems. For persons with such chronic health problems, the prevalence rates of irritant symptoms were generally higher than for those without chronic problems. Further, for some symptoms, these rates were even higher than would be expected if the effects of HCHO exposure and chronic health problem were only additive.

A positive exposure-response association was observed in this study for burning/tearing eyes over the exposure ranges studied. Further, responses were found at exposure levels as low as 7 ppm-hr. For a person who spends 60% of the time inside his or her own home, a weekly HCHO exposure of 7 ppm-hr can be translated into a weekly average HCHO concentration of 0.07 ppm. It is not uncommon to find HCHO concentrations at this level in mobile homes (*14*). The fact that approximately 10,000 mobile homes are sold annually in California alone implies that the affected population may be substantial.

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