SEMI-QUANTITATIVE MOLD EXPOSURE INDEX PREDICTS BUILDING-RELATED RESPIRATORY SYMPTOMS

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ABSTRACT
The National Institute for Occupational Safety and Health (NIOSH) investigated 13 college buildings to examine whether a semi-quantitative mold exposure index (EI) could efficiently predict work-related respiratory symptoms. We collected work-related symptom data and room locations/time fractions through questionnaires. Industrial hygienists classified rooms for factors including extent of water stain, visible mold, mold odor, and dampness. We estimated 323 individual EIs based on each factor or a combination of the factors weighted by time fraction in particular rooms. In logistic regression models adjusting for age, gender, job position, hire years, smoking, allergies, and use of latex gloves, we found a significant exposure-response relationship for wheeze (Odds Ratio(OR)=2.3) with stain-based EI. EI based on the combined factors showed significant exposure-response relationships for chest tightness (OR=2.2) and shortness of breath (OR=2.7). Our findings suggest that an observational semi-quantitative exposure index can support public health action to prevent risk of building-related respiratory disease.

INDEX TERMS
Mold, Semi-quantitative exposure index, Asthma, Respiratory symptoms.

INTRODUCTION
In response to indoor air quality complaints at six buildings and a library built in the 1970s, a college had solicited 14 environmental evaluations and conducted renovations over a period of twenty years. The complaints included possible building-related asthma, chronic sinusitis, and hypersensitivity pneumonitis, particularly in water-damaged buildings in two clusters in which interconnected buildings shared one long corridor. NIOSH conducted a health hazard evaluation to study the occupants and environments of the seven implicated buildings and six other college buildings built before or after the 1970s. In our epidemiologic study, we evaluated the utility of semi-quantitative exposure indices using observational measurements in predicting risk of respiratory symptoms in the college buildings.

METHODS
We conducted a self-administered questionnaire survey of college employees to obtain demographic characteristics, respiratory disease and symptom data, and the proportion of time spent in specific offices and classrooms during the fall semester. The response rate of the occupants of the 13 buildings was 71% (N=393). The only demographic difference between respondents and non-respondents was that non-respondents had a higher proportion of males (56% versus 44%). For exposure-response modeling, we used data on 323 full-time employees who provided complete information on where and how much time they had worked. We examined seven work-related respiratory symptoms reported to have occurred in

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the previous 12 months: wheeze, chest tightness, shortness of breath, attack of cough, nasal symptoms, sinus symptoms, and throat irritation. We defined work-related symptoms as those that got better away from work or for which more medication was used on workdays than on other days.

We evaluated 721 rooms in the 13 buildings. In the 12 buildings (1970s buildings, the library, and the old buildings) except for the new 1990s building, we inspected all 669 accessible offices and classrooms. In the new building built in 1990s, we randomly selected 25% of classrooms and offices on each floor for evaluation. Using an environmental evaluation sheet to record observed indices of possible mold exposure, pairs of trained industrial hygienists recorded floor type, measured temperature, relative humidity, and square footage of the room, and classified seven areas of each room for water stains, visible mold, mold odor, and signs of moisture. The seven areas were ceiling, walls, windows, floor, HVAC, heating and/or cooling pipes, and furniture. To check the validity of observations among industrial hygiene teams, the two teams cross-evaluated eight rooms. Percentage agreement for each measurement ranged from 63% to 100%.

We defined water stain as blisters, rust, stain, or discoloration that might indicate water intrusion. We graded water stain on a scale of 0-3, using “1” if water stains covered less than 5% of the evaluated area; “2” if water stains covered 5 to 30 %; and “3” if coverage was greater than 30%. We computed an average water stain score for the room using the grades for the seven areas within a room. We evaluated visible mold by presence of visible mold growth on any area. We graded current moisture as “damp” if wet building material existed and “wet” if unintended standing water or water on building material existed within a room. We graded mold odor on a scale from no to slight to strong.

We estimated occupants’ average exposure to each environmental factor or to a combination of factors to examine the association of the exposure with work-related respiratory symptoms. The exposure was computed by the following equation:

$$\text{Exposure index for person j} = \sum_{i=1}^{k} (E_i \times TF_{ij}) \qquad (1)$$

where i = refers to the rooms; E_i = exposure factor (0 versus 1 or continuous value) or combined exposure index of all environmental factors for room i; TF_{ij} = estimated time fraction spent in room i during the fall semester, and TF_{ij} sums to 1.0.

Estimated personal exposure to each factor was either dichotomized as “no” versus “any exposure” or treated as a continuous variable for average water stain score. In estimating personal exposure level for the occupants who spent some time fraction in rooms that were not evaluated within the new 1990s building, a zero value was assigned to the exposure for that time fraction. We formulated two combined exposure indices using less weight (0.5) for mold odor and moisture condition and either visible mold or water stain, and more weight (1.0) for either visible mold or water stain (See footnote to Table 2).

We computed mean values of average water stain score by building group. We used generalized linear regression models to examine the association of average water stain score with other environmental factors and to obtain least squares means of average water stain score (SAS 8.0, PROC GLM). We examined the association of personal exposure level with upper and lower respiratory symptoms with multivariate logistic regression models, adjusting for age, gender, smoking, job position, the year of hire, presence of allergies, and use of latex gloves, and computed adjusted odds ratios and 95% confidence intervals (SAS 8.0, PROC LOGISTIC). We used Somers' D statistics of rank correlation to compare the predictive ability between the model with water-stain based exposure index and the models with combined index (SAS 8.0, PROC LOGISTIC).

RESULTS

Table 1 shows the distribution of each scored factor by building category. Only one of 52 rooms in the new building had visible mold, and no room had mold odor, dampness or wetness; the mean of the average water stain score was 0.08. The mean of the average water stain score was higher in buildings with history of water damage, and more than 98 % of the rooms in those buildings had water stains. In a preliminary analysis employing multivariate models, buildings with a history of water damage had significantly higher average water stain scores (least squares mean (LSMean)=0.81) than did those without a history of water damage (LSMean=0.44, $p < 0.0001$), controlling for fixed effects of room type, floor, industrial hygiene team, temperature, and relative humidity. In a logistic regression model controlling for room type, reported water-damaged buildings showed a significantly higher odds of visible mold (OR=11.4; 95% Confidence Interval (CI)=4.0-31.9), and of mold odor (OR=4.5, 95% CI=1.1-19.3). The multivariate models also showed that the 221 classrooms had significantly (p-values < 0.02) higher water stain score, prevalence of visible mold, and of mold odor than the 500 offices.

Table 1. Distribution of Measurements for Rooms in Buildings

Building Category	No. of Rooms	Average Water Stain		Any Visible Mold N (%)	Any Mold Odor		Moisture Condition	
		Contin-uous (SD)	Any N (%)		Strong N (%)	Slight N (%)	Wet N (%)	Water N (%)
Buildings with history of water damage								
	558	0.80(0.5)	549(98)	109(20)	7 (1)	23(4)	4(1)	4(1)
Other buildings								
	163	0.38(0.4)	122(80)	4(3)	0(0)	2(1)	0(0)	0(0)
Total	721	0.71(0.5)	671(93)	113(16)	7(1)	25(4)	4(1)	4(1)

Each visual and olfactory measurement was significantly correlated with the others. All rooms with mold odor, visible mold, or damp or wet material showed significantly (p-values < 0.005) higher mean levels (means = 0.99, 1.18, 1.20, respectively) of average water stain score than those without them (means = 0.69, 0.62, 0.70, respectively). The difference of mean value of water stain level between two categories (yes versus no) was biggest for visible mold. The odds of mold odor in rooms with visible mold was 4.0 times higher (95% CI=1.9-8.4) than in rooms without visible mold.

Adjusted odds ratios and 95% confidence intervals of respiratory symptoms for exposure indices are shown in Table 2. When the EI based on average water stain score alone was treated as a continuous variable in multivariate models adjusting for gender, age, smoking, job position, the year of hire, presence of allergic disease, and use of latex gloves, a significant exposure-response relationship was found for work-related wheeze (OR = 2.3; 95% confidence interval = 1.15-4.54), implying that the odds of work-related wheeze increased 2.3-fold as the water stain exposure index increased by unity. The exposure indices based on water stains or visible mold appeared to strongly predict work-related respiratory symptoms compared to the other two factors. Any exposure to visible mold was significantly associated with work-related wheeze, chest tightness, and shortness of breath, and nasal and sinus symptoms in multivariate models, with about 1.7 to 2.6-fold risk. Any exposure to mold odor significantly increased odds of throat irritation by 2.3 times.

Significant exposure-response relationships were also seen for the two continuous exposure indices based on combinations of the four binary factors for work-related chest tightness, shortness of breath, nasal symptoms and sinus symptoms. The two continuous exposure indices better predicted risk of work-related nasal and sinus symptoms than the continuous index based on the single factor model using average water stain (Somers' D statistics: 0.40, 0.40 versus 0.37; 0.33, 0.34 versus 0.31, respectively). However, the predictive ability of the water stain based model was better for risk of wheeze and throat irritation than either combination index model. The combination index models and the water-stain index model similarly predicted risk of chest tightness, shortness of breath, and attack of cough. The two combination indices predicted risk of work-related shortness of breath better than for any other lower respiratory symptoms (Somers' D statistics: 0.50 for shortness of breath versus smaller than 0.42 for other symptoms).

Table 2. Adjusted* Odds Ratios (95% Confidence Interval) of Respiratory Symptoms for Exposure Index of Each Factor and of Linear Combination of the Factors

Work-Related Respiratory Symptoms	Average water stain		Any visible mold	Any mold odor	Any wet material or standing water	Combination† (continuous variable)	
	Contin-uous variable	Any stain				Model1	Model2
Wheeze	2.3 (1.2-4.5)	2.6 (0.7-9.2)	2.0 (1.1-3.7)	1.1 (0.6-2.4)	1.2 (0.3-4.5)	1.8 (0.9-3.5)	1.7 (0.9-3.4)
Chest tightness	1.9 (0.9-3.8)	1.9 (0.5-6.9)	2.6 (1.3-4.9)	1.01 (0.5-2.3)	1.0 (0.2-4.2)	1.8 (0.9-3.8)	2.2 (1.1-4.6)
Shortness of Breath	1.7 (0.8-3.6)	6.3 (0.7-14)	2.6 (1.3-5.1)	1.5 (0.7-3.2)	3.3 (0.9-12)	2.7 (1.2-6.1)	2.5 (1.2-5.4)
Cough	1.3 (0.6-2.6)	3.2 (0.8-47)	1.5 (0.8-2.8)	1.7 (0.8-3.6)	1.0 (0.2-4.5)	1.5 (0.7-3.2)	1.7 (0.8-3.6)
Nasal	1.5 (0.8-2.8)	4.4 (1.2-15)	1.7 (1.0-3.0)	1.1 (0.6-2.1)	1.7 (0.5-6.0)	2.4 (1.3-4.6)	2.5 (1.3-4.7)
Sinus	1.6 (0.9-2.9)	3.8 (1.1-18)	2.0 (1.2-3.4)	1.3 (0.7-2.5)	0.8 (0.2-2.9)	1.8 (1.0-3.4)	2.2 (1.2-4.1)
Throat irritation	2.4 (1.3-4.4)	2.0 (0.7-5.6)	1.3 (0.7-2.1)	2.3 (1.2-4.3)	1.5 (0.4-5.1)	1.6 (0.9-3.0)	1.5 (0.8-2.8)

* Adjusted for age, gender, smoking, job position, the year of hire, allergies, and latex gloves in logistic regression models.

† Model 1: any water stain + (0.5×visible mold) + (0.5×mold odor) + (0.5×presence of wet material or standing water); Model 2: (0.5×any water stain) + visible mold + (0.5×mold odor) + (0.5×presence of wet material or standing water).

DISCUSSION

Our study provides strong evidence that work-related upper and lower respiratory symptoms were significantly associated with semi-quantitative exposure indices created from visual and olfactory observations or their combination. Harverinen and colleagues (Haverinen, *et al*., 2001) reported that a three-level classification for water-damaged residential buildings, using both the amount of moisture damage and its severity, better predicted health symptoms than two-level classifications. Our classification for water stains is a four-level classification based on the percentage area of seven different locations that we averaged for the room level. These scales, weighted for the time fraction spent in particular rooms, resulted in a continuous variable for modeling exposure-response relationships. The water stain- or visible mold-based exposure indices were sensitive surrogates of exposure in predicting building-related respiratory symptoms as single factors reflecting possible microbial exposure. However, using information on all factors in a combined exposure index better predicted nasal and sinus symptoms compared with water stain-based continuous exposure index.

In occupational health studies, the presence of an exposure-response relationship suggests that an exposure index is a marker for the causative exposure. In this study, the exposure indices related to water damage and mold growth are markers for likely bioaerosols causing upper and lower respiratory symptoms that were temporally related to building occupancy. Although the specific microbial cause(s) remains unknown, a robust body of knowledge exists to support the association of moisture incursion in residences with respiratory disease and risk of asthma and respiratory symptoms (Dales, *et al*., 1991; Brunekreef, 1992; Andriessen, *et al*., 1998; Haverinen, *et al*., 2001). Our study adds to the evidence that the same risks occur in non-residential water-damaged buildings (Li, *et al*., 1997; Wan and Li, 1999; Savilahti, *et al*., 2000; Jarvis and Morey, 2001). Self-reported moldy odor has been shown to be associated with total culturable fungi in dust samples, and visible mold growth in homes has been associated with higher levels of *Aspergillus* spp. and *Penicillium* spp. than in those without visible mold (Dales, *et al*., 1997). Garrett et al. also reported similar association between airborne fungal spore level and mold odor, visible mold growth and water damage in Australian residential environments (Garrett, *et al*., 1998).

Our findings have some limitations. First, underestimation of exposure would result if past remediation removed visual evidence of prior water incursion despite hidden reservoirs of microbial agents. Second, some degree of disagreement among classifying industrial hygienists may limit the repeatability and reliability of the exposure index. Third, we may have misclassified exposure to occupants of the 1990s building by assigning zero exposure to rooms that had not been evaluated for mold and dampness. All of these limitations of the visual and olfactory approach result in possible misclassification of a room occupant's exposure level. However, any misclassification is likely equivalent in both directions because the trained industrial hygienists who evaluated room environments did not know the health status of room occupants. This random misclassification of exposure would tend to bias the measure of association toward the null. In the absence of misclassification, we might obtain stronger associations between indices of dampness and mold exposure and respiratory health outcomes.

The strength of the observational approach is its efficiency in time and expense, in comparison to traditional sampling methods for bioaerosols. Sampling for culturable fungi or spore counts with short-term grab samples has limited reliability because the temporal and spatial variability of airborne fungi is large (Macher, 1999). Thus, misclassification of exposure with bioaerosol sampling is unavoidable at a feasible expense, which may explain the usual absence of association between building-related symptoms and traditional bioaerosol measures.

CONCLUSION AND IMPLICATIONS

Our semi-quantitative mold exposure index, based on visual and olfactory observation, was associated with building-related symptoms that may reflect asthma, hypersensitivity pneumonitis, and nasal/sinus disease. From a public health perspective, these observational findings justify action to control water damage with attention to hidden reservoirs of bioaerosols, in order to prevent building-related respiratory disease.

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