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Indoor molds and lung function in healthy adults

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Summary

Background: Indoor mold exposure is common worldwide and constitutes an important health problem. There are very few studies assessing the relation between mold exposure and lung function levels among non-asthmatic adults. Our objective was to assess the relations between dampness and mold exposures at home and at work and lung function. In particular, we elaborated the importance of different exposure indicators.

Methods: In a population-based study, 269 non-asthmatic adults from South Finland answered a questionnaire on indoor dampness and mold exposures at home or at work and other factors potentially influencing lung function, and performed spirometry. Multiple linear regression model was applied to study the relations between exposures and spirometric lung function levels.

Results: In linear regression adjusting for confounding, FEV₁ level was reduced on average 200 ml related to mold odor at home (effect estimate −0.20, 95% CI −0.60 to 0.21) and FVC level was reduced on average 460 ml (−0.46, −0.95 to 0.03) respectively. Exposure to mold odor at home or at work or both was related to reduced FEV₁ (−0.15, −0.42 to 0.12) and FVC (−0.22, −0.55 to 0.11) levels. Women had on average 510 ml reduced FEV₁ levels (−0.51, −1.0 to 0.03) and 820 ml reduced FVC levels (−0.82, −1.4 to −0.20) related to mold odor exposure at home.

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Conclusions: Mold odor exposure was related to lower lung function levels among non-asthmatic adults, especially among women.

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Introduction

Indoor dampness and molds are common worldwide [1]. At least 20% of buildings in North America and Europe have one or more signs of dampness [2]. In cold climate the prevalence of water damage and dampness problems is estimated at 5%–30% and in moderate and warm climates at 10%–60% [3,4]. Thus, indoor dampness-related exposures constitute an important public health problem globally.

In a recent meta-analysis, the risk of developing asthma was significantly elevated in relation to dampness (effect estimate (EE) 1.33, 95% CI 1.12–1.56), visible mold (EE 1.29, 95% CI 1.04–1.60), and mold odor (EE 1.73, 95% CI 1.19–2.50), but not in relation to water damage (EE 1.12, 95% CI 0.98–1.27) [5]. Thus, the evidence indicated that dampness and molds in the home are determinants of asthma onset. Another meta-analysis provided evidence that dampness and mold problems increase the risk of allergic (AR) and non-allergic rhinitis: the largest risk was observed in relation to mold odor (rhinitis: 2.18 [95% CI, 1.76–2.71]; AR: 1.87 [95% CI, 0.95–3.68]). The risk related to visible mold was also consistently increased (rhinitis: 1.82 [95% CI, 1.56–2.12]; AR: 1.51 [95% CI, 1.39–1.64]; rhinoconjunctivitis: 1.66 [95% CI, 1.27–2.18]). In addition, exposure to dampness was related to increased risk of all types of rhinitis [6].

On the basis of the evidence on these adverse respiratory effects, lung function is a plausible target for adverse effects of dampness and mold problems. Our systematic literature search identified only four previous studies assessing the association between mold or dampness exposure and lung function levels in adults with no lung diseases [7–10]. All studies provided suggestive evidence of some reduction in lung function in individuals exposed to molds or dampness. One study presented some result separately for men and women [10]. Two of them focused on work exposure [7,8] and two on home exposure [9,10]. Our knowledge of the effect of mold and/or dampness on lung function among non-asthmatic adults is therefore limited.

Our objective was to assess the relations between dampness and mold exposures at home and at work and lung function among working aged adults without current or previous asthma. In particular, we elaborated the importance of different exposure indicators that have been found relevant in the studies on asthma and allergic rhinitis.

Methods

Study population

We conducted a population-based cross-sectional study of working aged non-asthmatic adults in a geographically

defined area in Finland. The study population served as controls in the Finnish Environment and Asthma Study (FEAS), a population-based study on incident asthma [11–19].

The study population was derived from a source population consisting of adults 21–63 years old living in the Pirkanmaa Hospital district, in South Finland identified from the national population registry, which has full coverage of the population. All together there were 1016 (response rate 67%) controls of which 299 performed spirometry. After excluding 21 people diagnosed with asthma, two who were over 64 years old, three without questionnaire data and 4 duplicates, the study population constituted 269 adults with spirometric lung functions and exposure data.

Exposure assessment

Exposure was assessed based on questionnaire information on indoor water damage, damp stains and other marks of structural dampness, visible mold, and mold odor, both at home and at work [11,20–22]. For water damage, damp stains, and visible mold, we asked information about their occurrence during the past year, 1–3 years before, or >3 years ago. For mold odor, we asked about occurrence during the past 12 months and inquired if such odor appeared almost daily, 1–3 days a week, 1–3 days a month, <1 day a month, or never.

Measurement methods

Questionnaire

The self-administered questionnaire has been described in detail elsewhere [11–19].

Lung function measurements

We conducted a baseline spirometry with a pneumotachograph spirometer connected to a computer using a disposable flow transducer (Medikro 905; Medikro Ltd., Kuopio, Finland). Measurements were conducted according to the standards of the American Thoracic Society [23]. We judged the presence of obstruction using the reference values derived from the Finnish population [24].

Statistical methods

Our outcome of interest was spirometric lung function at baseline, i.e. FEV₁ and forced vital capacity (FVC) measured before the bronchodilation test. We applied multiple linear regression to estimate the relations between the dampness and mold exposure indicators and the lung function levels. First, we adjusted for three core covariates: age, sex and height. We built the full model by

Table 1 Characteristics of the study population ($N = 269$).

Characteristic		Men ($N = 122$)		Women ($N = 147$)		Total ($N = 269$)	
		<i>n</i>	%	<i>N</i>	%	<i>n</i>	%
Age (years)	21–29	7	5.8	21	14.3	28	10.4
	30–39	22	18.0	36	24.3	58	21.6
	40–49	32	26.2	47	32.0	79	29.4
	50–59	42	34.4	34	23.1	76	28.2
	60–64	19	15.6	9	6.1	28	10.4
Education	No vocational schooling	16	13.1	22	15.0	38	14.1
	Vocational course	14	11.5	16	10.9	30	11.1
	Vocational institution	37	30.3	34	23.1	71	26.4
	College-level education	36	29.5	47	32.0	83	30.9
	University or corresponding	19	15.6	28	19.0	47	17.5
Smoking	No	49	40.1	91	62.0	140	52.0
	Ex	44	36.1	28	19.0	72	26.8
	Current	29	23.8	28	19.0	57	21.2
SHS in the workplace							
	Yes	23	18.9	9	6.1	32	11.9
SHS at home							
	Yes	5	4.1	5	3.4	10	3.7

SHS = second hand smoking.

adding into the model current and previous smoking, exposure to second-hand smoking, and education as an indicator of socio-economic status, in addition to the three core covariates. We have previously described the variables for smoking [25] and second-hand smoking in detail [13]. We fitted a model with four exposure indicators (i.e. water damage, dampness, visible mold, each at any time, and mold odor in the last 12 months) at home and the corresponding four exposure indicators at work, so altogether eight exposure indicators. We also fitted a model including these four exposure indicators describing exposure at home and/or at work combined. In both analyses the reference category consisted of those with no dampness or mold exposure at home or at work. We estimated the relations of interest separately for men and women. Exposure to mold odor in the past 12 months was further categorized into no mold odor exposure, low exposure (reported mold odor 1–3 times a month or less frequently), and high exposure (reported mold odor 1–3 times a week or daily). The model assessing potential exposure-response relation included indicator variables for low and high exposure. The analysis was performed with SAS statistical software package (SAS, version 9.3, SAS Institute, Cary, NC).

Results

Characteristics of the study population and exposures

The characteristics of the study population of non-asthmatics are displayed according to gender in Table 1. Of the 269 adults, 122 were men (45.4%) and 147 women (54.6%). Table 2 shows dampness and mold exposures of the study population. A total of 126 subjects (46.8%) reported the presence of at least one of the exposure indicators

either at work or home. The most common exposure indicator was dampness at home (24.2%, $n = 65$), followed by dampness at work (18.2%, $n = 49$) and water damage at home (16.0%, $n = 43$). Of these 65 (24.2%) individuals reported some exposure at work and 86 (32.0%) at home. The prevalence of exposure was similar between men and women: 8.8% ($N = 13$) of women and 7.3% ($n = 9$) of men had exposure to mold odor at home.

Dampness and mold exposures and lung function

In the analyses adjusting for all covariates and including eight exposure variables for home and work dampness or mold, FEV₁ level was reduced on average 200 ml related to mold odor at home (effect estimate -0.20 , 95% CI -0.60 to 0.21) and FVC level was reduced on average 460 ml (-0.46 , -0.95 to 0.03) respectively (Table 3). These did not reach statistical significance, although the upper confidence limit for effect estimate of FVC level was close to 0. In the four exposure variable model, exposure to mold odor at home or at work or both was related to reduced FEV₁ (-0.15 , -0.42 to 0.12) and FVC (-0.22 , -0.55 to 0.11) levels.

We also performed similar analyses separately for men and women. Strongest association was found among women between home exposure and lung function levels. They had on average 510 ml reduced FEV₁ levels (-0.51 , -1.0 to 0.03) and 820 ml reduced FVC levels (-0.82 , -1.4 to -0.20) related to mold odor exposure at home (Tables 4 and 5).

Discussion

The main finding of our population-based study of working aged adults is that mold odor at home or at work or both was related to a reduced lung function levels. FEV₁ was on

Table 2 Distribution of exposure indicators, Finnish Environment and Asthma Study (FEAS) 1997–2000 ($n = 269$).

Exposure indicator	All (N)	%	Men (N = 122)	%	Women (N = 147)	%
Workplace						
Water damage						
No	235	87.4	106	86.9	129	87.8
Yes, during past 12 months	20	7.4	12	9.9	8	5.4
Yes, 1–3 years ago	8	3.0	2	1.6	6	4.1
Yes, >3 years ago	6	2.2	2	1.6	4	2.7
Yes, any time	34	12.6	16	13.1	18	12.2
Dampness						
No	220	81.8	97	79.5	123	83.7
Yes, during past 12 months	37	13.7	17	13.9	20	13.6
Yes, 1–3 years ago	4	1.5	3	2.5	1	0.7
Yes, >3 years ago	8	3.0	5	4.1	3	2.0
Yes, any time	49	18.2	25	20.5	24	16.3
Visible mold						
No	258	95.9	117	95.9	141	95.9
Yes, during past 12 months	8	3.0	3	2.5	5	3.4
Yes, 1–3 years ago	3	1.1	2	1.6	1	0.7
Yes, >3 years ago	0	0	0	0	0	0
Yes, any time	11	4.1	5	4.1	6	4.1
Mold odor (in the past 12 months)						
No	249	92.6	114	93.5	135	91.8
Yes, almost daily	11	4.1	5	4.1	6	4.0
Yes, 1–3 days a week	3	1.1	1	0.8	2	1.4
Yes, 1–3 days a month	2	0.7	0	0	2	1.4
Yes, less often	4	1.5	2	1.6	2	1.4
Any exposure ^a	20	7.4	8	6.5	12	8.2
Any exposure in the workplace^b						
No	204	75.8	91	74.6	113	76.9
Yes	65	24.2	31	25.4	34	23.1
Home						
Water damage^c						
No	225	84.0	103	84.5	122	83.5
Yes, during past 12 months	8	3.0	2	1.6	6	4.1
Yes, 1–3 years ago	11	4.1	2	1.6	9	6.2
Yes, >3 years ago	24	8.9	15	12.3	9	6.2
Yes, any time	43	16.0	19	15.5	24	16.5
Dampness^c						
No	203	75.8	93	76.2	110	75.3
Yes, during past 12 months	29	10.8	13	10.7	16	11.0
Yes, 1–3 years ago	14	5.2	5	4.1	9	6.2
Yes, >3 years ago	22	8.2	11	9.0	11	7.5
Yes, any time	65	24.2	29	23.8	36	24.7
Visible mold						
No	249	92.6	115	94.3	134	91.2
Yes, during past 12 months	8	3.0	3	2.5	5	3.4
Yes, 1–3 years ago	6	2.2	2	1.6	4	2.7
Yes, >3 years ago	6	2.2	2	1.6	4	2.7
Yes, any time	20	7.4	7	5.7	13	8.8
Mold odor (in the past 12 months)						
No	247	91.8	113	92.7	134	91.2
Yes, almost daily	6	2.2	2	1.6	4	2.7
Yes, 1–3 days a week	1	0.4	1	0.8	0	0
Yes, 1–3 days a month	5	1.9	2	1.6	3	2.0
Yes, less often	10	3.7	4	3.3	6	4.1
Any exposure ^a	22	8.2	9	7.3	13	8.8

(continued on next page)

Table 2 (continued)

Exposure indicator	All (N)	%	Men (N = 122)	%	Women (N = 147)	%
Any exposure at home^b						
No	183	68.0	84	68.9	99	67.3
Yes	86	32.0	38	31.1	48	32.7
Any exposure at home or work^b						
No	143	53.2	66	54.1	77	52.4
Yes	126	46.8	56	45.9	70	47.6

^a Exposure to mold odor at any frequency (almost daily, 1–3 days a week, 1–3 days a month, less often).

^b Exposure to at least one of the following: water damage, dampness, visible mold or mold odor.

^c 'Do not know' was answered by 1 woman.

average 200 ml lower (effect estimate -0.20 , 95% CI -0.60 to 0.21) and FVC on average 460 ml lower (-0.46 , -0.95 to 0.03) in those exposed compared to those without exposure. Among women the corresponding reduction was more pronounced with an average 510 ml reduction in FEV₁ levels (-0.51 , -1.0 to 0.031) and 820 ml in FVC levels (-0.82 , -1.4 to -0.20), reaching statistical significance.

Validity of results

Questionnaire-based exposure information may include some misclassification. Several studies have compared the occupant reported presence of indoor dampness and/or mold problems with findings in building inspections or measurements of fungi in indoor dust, as reviewed by Jaakkola and Jaakkola [26]. Most of the studies have shown relatively good agreement between these methods of exposure assessment. In general it has been found that subjects tend to underestimate dampness/mold problems at home compared to inspection or dust mold measurements, and this trend has been observed among both in asthmatics

and in healthy subjects. Nondifferential misclassification of exposure is likely to lead to some underestimation of the true effect related to indoor mold problems. On the other hand, dust measurements and inspection usually reflect just one point in time, while occupant report may reflect better long term exposures that are more relevant to health effects. Reponen et al. reported that air concentrations of endotoxin and β -D-glucan were consistently higher in homes with moldy odor [27]. Our outcome of interest was objectively measured lung function level which is not sensitive to bias. We were able to adjust for a number of potential confounders including sex, age, height, education, smoking and exposure to secondhand smoke, in regression analysis to eliminate these factors as potential explanations for our results.

Synthesis with the previous knowledge

We conducted a systematic literature search and found only four previous papers assessing the associations between dampness or mold exposures and lung function levels in

Table 3 Exposure to dampness and mold and lung function ($n = 269$).

Exposure indicators	FEV ₁ ^a (l)		FVC ^a (l)	
	Effect estimate	95% CI	Effect estimate	95% CI
8 exposure indicators in the model				
Home				
Water damage	0.009	-0.25 to 0.27	0.04	-0.27 to 0.36
Dampness	0.004	-0.19 to 0.20	-0.01	-0.25 to 0.22
Visible mold	-0.15	-1.12 to 0.81	0.17	-1.00 to 1.33
Mold odor	-0.20	-0.60 to 0.21	-0.46	-0.95 to 0.03
Work				
Water damage	-0.18	-0.55 to 0.19	-0.20	-0.65 to 0.24
Dampness	-0.13	-0.36 to 0.10	-0.14	-0.42 to 0.13
Visible mold	0.42	-0.47 to 1.30	1.00	-0.06 to 2.07
Mold odor	0.01	-0.33 to 0.36	0.10	-0.31 to 0.52
4 exposure indicators in the model				
Home or work or both				
Water damage	-0.07	-0.29 to 0.14	-0.07	-0.33 to 0.19
Dampness	-0.08	-0.24 to 0.07	-0.10	-0.29 to 0.09
Visible mold	0.08	-0.55 to 0.71	0.52	-0.25 to 1.29
Mold odor	-0.15	-0.42 to 0.12	-0.22	-0.55 to 0.11

^a Adjusted for age, sex, height, education, smoking (current, ex), and second hand smoke exposure.

Table 4 Exposure to dampness and mold and FEV₁ and FVC in men (*n* = 122) and women (*N* = 147).

Exposure indicator	FEV ₁ ^a (l)		FVC ^a (l)	
	Effect estimate	95% CI	Effect estimate	95% CI
Men (8 indicators)				
At home				
Water damage	−0.03	−0.52 to 0.46	0.24	−0.36 to 0.83
Dampness	−0.09	−0.43 to 0.26	−0.02	−0.44 to 0.40
Visible mold	—		—	
Mold odor	0.03	−0.62 to 0.69	−0.09	−0.89 to 0.70
At work				
Water damage	−0.64	−1.72 to 0.44	−0.22	−1.54 to 1.09
Dampness	−0.15	−0.53 to 0.23	−0.29	−0.76 to 0.18
Visible mold	0.38	−0.69 to 1.44	0.97	−0.33 to 2.28
Mold odor	0.02	−0.54 to 0.57	0.08	−0.60 to 0.76
Men (4 indicators)				
At home or at work or both				
Water damage	−0.15	−0.59 to 0.30	0.14	−0.40 to 0.69
Dampness	−0.19	−0.47 to 0.09	−0.21	−0.56 to 0.13
Visible mold	0.35	−0.70 to 1.40	0.95	−0.34 to 2.24
Mold odor	−0.06	−0.50 to 0.39	−0.09	−0.63 to 0.46
Women (8 indicators)				
At home				
Water damage	−0.005	−0.30 to 0.29	−0.15	−0.49 to 0.18
Dampness	0.04	−0.21 to 0.28	−0.016	−0.30 to 0.27
Visible mold	−0.34	−1.20 to 0.52	0.09	−0.90 to 1.10
Mold odor	−0.51	−1.04 to 0.03	−0.82	−1.44 to −0.20
At work				
Water damage	−0.07	−0.42 to 0.27	−0.17	−0.58 to 0.23
Dampness	−0.14	−0.43 to 0.14	−0.01	−0.35 to 0.32
Visible mold	—		—	
Mold odor	−0.05	−0.49 to 0.39	0.10	−0.41 to 0.61
Women (4 indicators)				
At home or at work or both				
Water damage	−0.03	−0.25 to 0.20	−0.16	−0.42 to 0.11
Dampness	−0.04	−0.23 to 0.15	−0.02	−0.24 to 0.21
Visible mold	−0.39	−1.21 to 0.44	0.10	−0.86 to 1.07
Mold odor	−0.23	−0.58 to 0.11	−0.27	−0.67 to 0.14

^a Adjusted for age, height, education, smoking (current, ex), and second hand smoke exposure.

adults with no lung diseases [7–10]. In some of these studies individuals reported musty odor but none of those assessed separately an association between mold odor and lung function levels. All four studies presented some evidence of a reduction in lung function levels due to exposure to mold or dampness. Consistently with the present results, the ECRHS study found an association mainly among women [10]. In a previous study of 40 mold-exposed cases and 40 age and sex matched controls, 60% of cases and 0% of controls had abnormal lung function test results [7]. In a Finnish case–control study, the baseline FVC and FEV₁% predicted were significantly lower among the mold-exposed subjects when compared with the other groups (*p* = 0.046 and *p* = 0.004, respectively) [8]. In a cohort study of 6443 patients, after excluding the asthmatic patients, there was an association among women between lung function decline and reported water damage in the last 12 months (*n* = 2989: additional decline in FEV₁ −2.89 ml; 95% CI −5.36 to −0.41 ml), and with dampness score

>0 (additional decline −3.00 ml; 95% CI −5.00 to −0.99 ml) when comparing to those with a dampness score = 0. There were no similar associations seen among non-asthmatic men [10]. In a case–control study of 105 mold-exposed cases and 202 non-exposed controls there was a significantly lower FVC and FEV₁ levels among cases [9].

Conclusions

Our results provide evidence that exposure to mold odor is related to lower lung function levels among non-asthmatic adults, especially among women.

Conflict of interest statement

None declared.

Table 5 Low and high exposure to mold odor at home or at work or both and lung function.

Exposure to mold odor	FEV ₁ (l)		FVC (l)	
	Effect estimate	95% CI	Effect estimate	95% CI
At home or at work^a (n = 269)				
Low	−0.14	−0.35 to 0.07	−0.12	−0.37 to 0.14
High	−0.01	−0.22 to 0.19	−0.05	−0.30 to 0.20
Any exposure to water damage, dampness, visible mold at home or at work or both	0.05	−0.06 to 0.17	0.03	−0.11 to 0.16
Men^b (n = 122)				
Low	−0.16	−0.55 to 0.23	−0.06	−0.55 to 0.42
High	−0.08	−0.47 to 0.30	−0.12	−0.59 to 0.36
Any exposure to water damage, dampness, visible mold at home or at work or both	0.05	−0.15 to 0.25	0.03	−0.21 to 0.28
Women^b (n = 147)				
Low	−0.08	−0.32 to 0.16	−0.08	−0.36 to 0.20
High	0.06	−0.18 to 0.30	0.02	−0.25 to 0.30
Any exposure to water damage, dampness, visible mold at home or at work or both	0.03	−0.10 to 0.16	−0.01	−0.16 to 0.14

^a Adjusted for age, sex, height, education, smoking (current, ex), and second hand smoke exposure.

^b Adjusted for age, height, education, smoking (current, ex), and second hand smoke exposure.

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