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RESEARCH ARTICLE

Indoor mildew odour in old housing was associated with adult allergic symptoms, asthma, chronic bronchitis, vision, sleep and self-rated health: USA NHANES, 2005–2006

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Abstract A recent systematic review and meta-analysis has shown the effect of indoor mildew odour on allergic rhinitis risk, but its relation to other common chronic health outcomes in adults has not been investigated. Therefore, it was aimed to examine the relationship of indoor mildew odour and common health outcomes in adults in a national and population-based setting. Data was retrieved from the United States National Health and Nutrition Examination Surveys, 2005–2006, including the available information on demographics, housing characteristics, self-reported health conditions and urinary concentrations of environmental chemicals. *T* test, chi-squared test and survey-weighted logistic regression modelling were performed. Of all American adults (n= 4979), 744 (15.1 %) reported indoor mildew odour or musty smell in their households. People who reported indoor mildew odour or musty smell also reported poorer self-rated health, sleep complaints, chronic bronchitis, asthma attack, itchy rash, sneezing and poor vision. In addition, people who reported indoor mildew odour or musty smell also tended to reside in older housing that were built 20 years earlier. However, there were no significant statistical associations found between indoor mildew odour or musty smell and urinary concentrations of environmental chemicals, which was also found to be associated with old housing. People who lived in older housing with indoor mildew odour or musty smell tended to have chronic health problems. To protect occupants in old housing from chronic illnesses associated with indoor mildew odour, elimination of the odour sources should be explored in future research and therefore public health and housing programs.

Keywords Mildew odour · Self-rated health · Indoor environment · Allergy · Asthma · Sleep · Vision

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Introduction

There have been several studies investigating the effects of housing characteristics on human health and cardiovascular biomarkers (Jacobs et al. 2009; Shiue and Shiue 2013), in particular in children. In addition, the effect of indoor mildew odour, likely caused by low levels of chloroanisoles released from microbials, was found to increase the risk of allergic rhinitis (odds ratios 2.18, 95 % confidence interval 1.76–2.71) from a recent systematic review and meta-analysis (Jaakkola et al. 2013). Indoor mildew odour could come from different sources such as building materials, building indoor air quality, mould due to construction-based humidity problem, 2-methoxy-3,5-dimethylpyrazine released from wine cork, water-air transfer, misuse of bottles and so on and transfer to clothes and then onto human skin (Gunschera et al. 2004; Simpson et al. 2004; Diaz et al. 2005; Omür-Ozbek et al. 2011; Widén et al. 2005). Human beings could adapt to residential environments before sensing smell. It is known that house dust mite allergen, mould or fungi could release indoor mildew odour mostly affecting indoor air quality and human health problems such as asthma and lung disease symptoms (Senitkova 2014; Arbes et al. 2003; Taskar and Coultas 2008; Newman et al. 2004), but their relations to other common chronic health outcomes have not been investigated in large human samples. Therefore, it was aimed to examine

the relationship of indoor mildew odour and common chronic health outcomes in adults in a national and population-based setting. It was also assumed that the indoor mildew odour has been existing constantly.

Methods

Study sample

As described elsewhere (more details via: http://www.cdc.gov/nchs/nhanes.htm), the National Health and Nutrition Examination Surveys (NHANES) has been a national, population-based, multi-year, cross-sectional study to assess the health and nutritional status of adults and children in USA since the 1960s. Written informed consent was obtained from all participants by the NHANES researchers and nurses. Information on demographics, housing conditions (including indoor mildew odour/musty smell and built year) and self-reported health conditions including self-rated health, depression, allergic symptoms, sleep conditions, vision condition, body mass index, asthma attack, liver disorder and thyroid disorder that were occurred in the last 12 months was obtained by household interview using questionnaires (more details via http://wwwn.cdc.gov/nchs/nhanes/search/datapage.aspx?Component=Questionnaire&CycleBeginYear=2005). In the current analysis, the available and valid data on housing characteristics, self-reported health and urinary environmental chemicals in the 2005–2006 study cohort was retrieved. Data from later study cohorts were excluded because of the lack of sufficient information on either housing characteristics or health outcomes. Adults aged 20 and above were included for statistical analysis because they were the main age group of the questionnaire who were asked about chronic disease conditions. Exposure of indoor mildew odour was asked among participants, "In the past 12 months, has your home had a mildew odour or musty smell? (more details via http://wwwn.cdc.gov/nchs/nhanes/2005-2006/HOQ_D.htm)."

Blood pressure (BP) was measured three times for all examinees 8 years and older at the household interview (more details via http://www.cdc.gov/nchs/nhanes/nhanes2009-2010/BPX_F.htm). The standard measuring protocol can be found online (more details via http://www.cdc.gov/nchs/nhanes/nhanes20092010/BPX_F.htm#Protocol_and_Procedure). Participants with any of the following conditions on both arms were excluded from the examination according to the standard protocol: rashes, gauze dressings, casts, edema, paralysis, tubes, open sores or wounds, withered arms, a-v shunts and radical mastectomy or if BP cuff does not fit on the arm. The measurements were taken three times for each person, and in the present study, the second measurement was used in the analysis. People with ≥140 mmHg systolic and ≥90 mmHg diastolic pressures were classified as high BP.

Biomonitoring

Urine specimens were processed, stored and shipped to Division of Laboratory Sciences, National Center for Environmental Health, National Centers for Disease Control and Prevention, Atlanta, Georgia. The urinary concentrations of environmental chemicals were determined by inductively coupled plasma dynamic reaction cell mass spectroscopy (ICP-DRC-MS) or detected using online solid-phase extraction, isotope dilution and high-performance liquid chromatography separation, followed by electrospray ionization and tandem mass spectrometry on those aged 6 and above. Details of measuring steps and testing principles can be found in manuals online (more details via http://www.cdc.gov/nchs/data/nhanes/nhanes_05_06/lab.pdf and/or http://www.cdc.gov/nchs/nhanes/nhanes2005-2006/lab_methods_05_06.htm). In the current study, the urinary concentrations of environmental chemicals included mercury, heavy metals, arsenic, phthalates, bisphenols, parabens and pesticides. Since the urinary concentrations of environmental chemicals

Table 1 Characteristics of American adults aged 20 and above (n=4979)

	N (%)
Sex	
Male	2387 (47.9 %)
Female	2592 (52.1 %)
Age	47.5±18.2
20–39	1923 (40.0 %)
40–59	1486 (30.9 %)
60–79	1176 (24.5 %)
80+	224 (4.7 %)
Body mass index	28.8±6.7
0–18.5	79 (1.7 %)
18.5–25	1350 (28.9 %)
25–30	1604 (34.3 %)
30+	1646 (35.2 %)
Ethnicity	
Mexican American	1003 (20.1 %)
Other Hispanic	154 (3.1 %)
Non-Hispanic White	2495 (50.1 %)
Non-Hispanic Black	1123 (22.6 %)
Multi-race	204 (4.1 %)
Family poverty income ratio	
0–4	3822 (80.9 %)
5+	904 (19.1 %)
Serum continine (ng/mL)	58.3±125.2
Musty smell in the last 12 months	
Yes	744 (15.1 %)
No	4173 (84.9 %)

were highly right-skewed, they were all log transformed in the statistical modelling. Serum cotinine was detected to measure the prevalence and extent of tobacco use and exposure to environmental tobacco smoke (more details via http://wwwn.cdc.gov/nchs/nhanes/2005-2006/COT_D.htm). The measuring method was by using an isotope dilution-high-performance liquid chromatography/atmospheric pressure chemical ionization tandem mass spectrometry (ID HPLC-APCI MS/MS).

Statistical analysis

In the first step, correlations of indoor mildew odour or musty smell with self-reported health conditions were investigated by using survey-weighted logistic or multinomial regression modelling, depending on the study outcome variables being binary or categorical. Covariates including age, sex, body mass index (BMI), family poverty income ratio (PIR; more details via http://wwwn.cdc.gov/nchs/nhanes/2005-2006/DEMO_D.htm#INDFMPIR) and serum cotinine levels were adjusted. In the second step, the relationship of indoor mildew odour or musty smell and the occupants' urinary concentrations of environmental chemicals was assessed by using *t* test. In the third step, the association of the housing built year and indoor mildew odour or musty smell was examined to study whether indoor mildew odour or musty smell tended to occur in old housing. Survey design and sample weights were applied in the statistical modelling (more details via http://www.cdc.gov/Nchs/tutorials/environmental/orientation/sample_design/index.htm). Effects were reported in ORs or relative risk ratios (RRRs), depending on the type of outcome variables (binary or categorical), and 95 % CI, with $P<0.05$ considered statistically significant. Statistical software STATA version 12.0 (StataCorp, College Station, Texas, USA) was used to perform all the analyses. Since this study is only a secondary data analysis by extracting data from the NHANES website, no further ethics approval was required.

Table 2 Associations of indoor mildew odour/musty smell and self-reported current chronic diseases

	With musty smell (n=744)	Without musty smell (n=4173)	OR or RRR	P value
General health				
Good	231 (31.0 %)	1491 (35.7 %)	1.00	
Fair	415 (55.8 %)	2046 (49.0 %)	1.34 (1.11–1.63)	0.005
Poor	28 (3.8 %)	106 (2.5 %)	1.60 (0.79–3.23)	0.178
Depression	75 (10.1 %)	248 (5.9 %)	1.22 (10.82–1.81)	0.305
No	417 (56.0 %)	2022 (48.5 %)	1.00	
Allergic symptoms				
Itchy rash	98 (13.2 %)	347 (8.3 %)	1.88 (1.50–2.36)	<0.001
No	645 (86.7 %)	3824 (91.6 %)	1.00	
Sneezing	284 (38.2 %)	1282 (30.7 %)	1.36 (1.11–1.65)	0.005
No	460 (61.8 %)	2890 (69.3 %)	1.00	
Sleep disorders	56 (7.5 %)	286 (6.9 %)	0.99 (0.74–1.32)	0.923
No	688 (92.5 %)	3882 (93.0 %)	1.00	
Sleep complaints	218 (29.3 %)	859 (20.6 %)	1.37 (1.07–1.75)	0.016
No	526 (70.7 %)	3306 (79.2 %)	1.00	
Vision				
Good	562 (75.5 %)	3444 (82.5 %)	1.00	
Fair	139 (18.7 %)	571 (13.7 %)	1.67 (1.20–2.32)	0.005
Poor	42 (5.6 %)	152 (3.6 %)	2.10 (1.27–3.46)	0.006
High blood pressure	18 (2.4 %)	141 (3.4 %)	0.57 (0.31–1.07)	0.077
No	495 (66.5 %)	2635 (63.1 %)	1.00	
Chronic bronchitis	30 (4.0 %)	111 (2.7 %)	1.76 (1.09–2.84)	0.023
No	680 (91.4 %)	3935 (94.3 %)	1.00	
Liver disorders	17 (2.3 %)	71 (1.7 %)	2.07 (1.24–3.45)	0.009
No	710 (95.4 %)	4037 (96.7 %)	1.00	
Asthma	45 (6.0 %)	145 (3.5 %)	2.22 (1.23–4.02)	0.011
No	622 (83.6 %)	3645 (87.3 %)	1.00	

Adjusted for age, sex, BMI, PIR and serum cotinine

Table 3 Associations of mildew odour/indoor musty smell and environmental chemicals (unit μg/L)

	Musty smell household (n=744)	Non-musty smell household (n=4173)	P value
Metals			
Barium	2.19±3.19	2.28±4.01	0.766
Beryllium	0.05±0	0.05±0	0.411
Cadmium	0.41±0.48	0.42±0.45	0.832
Cobalt	0.56±0.87	0.60±1.64	0.774
Caesium	5.37±3.46	5.84±4.39	0.132
Molybdenum	59.38±58.37	59.78±51.90	0.917
Lead	0.82±0.80	0.98±1.29	0.082
Platinum	3.36±47.25	0.42±13.23	0.065
Antimony	0.10±0.12	0.11±0.19	0.401
Thallium	0.19±0.14	0.19±0.13	0.843
Tungsten	0.15±0.39	0.15±0.31	0.944
Uranium	0.01±0.01	0.01±0.03	0.204
Mercury	0.91±1.47	0.89±1.34	0.809
Arsenic			
Total arsenic	18.47±41.08	25.54±73.58	0.167
Arsenous acid	0.86±0.08	0.90±0.67	0.421
Arsenic acid	0.76±0.24	0.76±0.46	0.878
Arsenobetaine	9.68±30.72	14.28±59.34	0.261
Arsenocholine	0.47±0.58	0.45±0.21	0.272
Dimethylarsonic acid	4.97±4.72	6.07±10.08	0.114
Monomethylarsonic acid	0.89±0.44	1.00±1.24	0.184
Trimethylarsine oxide	0.71±0	0.72±0.23	0.423
Bisphenols			
Bisphenol A	4.34±8.45	3.71±13.53	0.508
Triclosan	0.86±0.08	0.90±0.67	0.190
4-tert-Octyl phenol	0.15±0.04	0.21±1.97	0.637
Benzophenone-3	218.20±1542.35	297.11±1408.81	0.451
Parabens			
Methyl paraben	293.16±566.69	279.93±758.41	0.805
Ethyl paraben	13.65±45.79	14.76±55.39	0.779
Propyl paraben	64.89±145.10	78.31±261.17	0.459
Butyl paraben	4.46±15.41	5.14±21.46	0.655
Phthalates			
Mono(carboxynonyl) phthalate	6.88±21.20	5.94±25.70	0.608
Mono(carboxyoctyl) phthalate	27.63±223.76	14.67±56.30	0.079
Mono-2-ethyl-5-carboxypentyl phthalate	6.88±21.20	6.88±21.20	
Mono-n-butyl phthalate	35.74±42.43	41.77±281.75	0.752
Mono-ethyl phthalate	486.80±1348.39	459.11±1164.00	0.751
Mono-(3-carboxypropyl) phthalate	4.97±18.51	4.05±13.20	0.369
Mono-cyclohexyl Phthalate	0.49±0.55	0.48±0.95	0.928
Mono-(2-ethyl-5-hydroxyhexyl)	78.76±203.80	76.70±278.26	0.917
Mono-(2-ethyl)-hexyl phthalate	11.51±30.77	11.16±62.15	0.935
Mono-n-methyl phthalat	3.21±9.50	4.78±30.37	0.448
Mono-isononyl phthalate	2.26±9.42	1.86±7.37	0.479
Mono-(2-ethyl-5-oxohexyl)	49.79±130.50	47.23±176.20	0.837
Mono-n-octyl phthalate	1.34±0.38	1.34±0.44	0.808
Mono-benzyl phthalate	21.50±48.48	28.54±465.96	0.823
Mono-isobutyl pthalate	13.09±27.51	21.76±410.47	0.755

Table 3 (continued)

	Musty smell household (n=744)	Non-musty smell household (n=4173)	P value
Pesticides			
2,5-Dichlorophenol	296.30±1504.21	187.96±990.33	0.172
o-Phenyl phenol	0.17±0.44	0.21±1.23	0.670
2,4-Dichlorophenol	10.33±52.01	5.56±25.50	0.035
2,4,5-Trichlorophenol	0.18±0.45	0.15±0.28	0.185
2,4,6-Trichlorophenol	0.70±1.27	0.71±2.99	0.957

Results

Of all American adults (n=10,348) in the 2005–2006 study cohort, 48.1 % were adults (n=4979) aged 20 and above. Seven hundred forty-four (15.1 %) people reported indoor mildew odour or musty smell in their households in the last 12 months. Table 1 shows the demographic characteristics of the included participants. In Table 2, it presents associations between indoor mildew odour or musty smell and self-reported health status. After full adjustment, it was observed that people who reported indoor mildew odour or musty smell also reported poorer self-rated health, sleep complaints, chronic bronchitis, asthma attack, itchy rash, sneezing and poor vision. However, there were no statistically significant associations shown between indoor mildew odour or musty smell and urinary concentrations of environmental chemicals (see Table 3).

On the other hand, in older housing, there tends to have stronger indoor mildew odour or musty smell (see Table 4). In particular, housing that was built before 1940 had the highest likelihood to have indoor mildew odour or musty smell (OR 5.27, 95 % CI 3.50–7.92, P<0.001), compared to those that were built in 1990 or after.

Discussion

Previous research

Epidemiological studies have shown an association between indoor environment including mould and dampness and asthma and other respiratory disease, although mostly among children. However, exposure to mildew was only defined by its physical presence but not by the smell. Smell could come from mould, dampness, building materials or chemicals. There were also few studies looking into mildew odour specifically (Bonner et al. 2006). In addition, previous research showed how mildew could be associated with loss of sleep in children with asthma (Mitchell et al. 1996). The present study not only shows the associations in the sleep and respiratory health mentioned above but additionally reveals the associations in self-rated health and vision problems as well. While smelly housing could have higher levels of pesticides, such as 2,4-dichlorophenol, this might be due to domestic pesticide use or the occupational exposure (Kintz et al. 1992). Old housing was previously found being related to levels of environmental chemicals (Shiue and Bramley 2015) and is now found being associated with indoor mildew odour or musty smell in the current analysis. However, no significant associations between indoor mildew odour or musty smell and levels of environmental chemicals were observed, suggesting different contaminating sources for human health.

Environmental odour could be unpleasant and annoying for human beings and even animals such as fish that tend to avoid water streams with alarm scents (Palm and Powell 2010). In the worst scenario, odour could impact human behaviours leading to negative living experience throughout life (Knaapila and Tuorila 2013). Some research has also shown the correlation of odour on depression, although the study sample was rather small (Naudin et al. 2012). In the present study, depression was not associated with indoor mildew odour or musty smell. Odour was also found to increase

Table 4 Associations between housing built year and indoor musty smell

	Musty smell (n=744)	Non-musty smell (n=4173)	OR	P value
Built year				
1990 to present	64 (6.3 %)	957 (93.5 %)	1.00	n/a
1978–1989	104 (14.0 %)	639 (86.0 %)	3.04 (1.61–5.77)	0.002
1960–1977	127 (17.4 %)	604 (82.6 %)	3.97 (2.23–7.09)	<0.001
1950–1959	80 (17.4 %)	381 (82.7 %)	3.84 (2.31–6.37)	<0.001
1940–1949	73 (23.2 %)	242 (76.8 %)	4.97 (2.73–9.05)	<0.001
Before 1940	108 (19.8 %)	437 (80.2 %)	5.27 (3.50–7.92)	<0.001

attention towards a congruent visual object and possibly visually induced emotion, compared to a non-odour condition among health volunteers (Seo et al. 2010; Walla and Deecke 2010). These results support the finding of the present study that there is an association between indoor mildew odour or musty smell and vision conditions.

Strengths and limitations

The present study has a few strengths. First, to my knowledge, this is the first study to document the associations of indoor mildew odour or musty smell and adult chronic health conditions and urinary concentrations of environmental chemicals using a very large study sample representative of the general population. Second, the relationship of housing built year and indoor mildew odour or musty smell was also explored. However, there are also study limitations that cannot be ignored. First, indoor mildew odour or musty smell was only self-reported. This means that only the human-detectable indoor mildew odour or musty smell was reported, although the detectable level might vary according to different levels of tolerance among the occupants. The exact exposure duration of indoor mildew odour or musty smell, unfortunately, could not be examined in the current limited dataset, either. Second, the specific types of indoor mildew odour or musty smell from different sources mentioned in the previous section could not be identified. Third, as the maximum age in the present study cohort was 85, it is not possible to assess the effect of indoor mildew odour or musty smell on the health status specifically for the very old aged 80 and above, being more vulnerable to environmental exposures than other age groups. Therefore, future studies keeping the strengths and overcoming the abovementioned limitations with a longitudinal or experimental approach would be suggested.

Conclusion

People who reported indoor mildew odour or musty smell also reported poorer health outcomes including general health condition, itchy rash, sneezing, vision problem, sleep complaints, chronic bronchitis and asthma. Moreover, older housing that were built 20 years earlier tended to have indoor mildew odour or musty smell while the strongest association was found in housing that were built 70 years earlier. These observations would suggest the need for closer monitoring of environmental chemicals in old housing and the consideration of more frequent housing renovation in order to remove indoor mildew odour or musty smell for the long-term health benefits of occupants.

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Conflict of interest None.

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