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## Exposure to visible mould or dampness at home and sleep problems in children: Results from the LISApplus study

Carla M.T. Tiesler<sup>a,b</sup>, Elisabeth Thiering<sup>a,b</sup>, Christina Tischer<sup>a</sup>, Irina Lehmann<sup>c</sup>, Beate Schaaf<sup>d</sup>, Andrea von Berg<sup>e</sup>, Joachim Heinrich<sup>a,\*</sup><sup>a</sup> Helmholtz Zentrum München, German Research Center for Environmental Health, Institute of Epidemiology I, Ingolstaedter Landstrasse 1, 85764 Neuherberg, Germany<sup>b</sup> Ludwig-Maximilians-University of Munich, Dr. von Hauner Children's Hospital, Division of Metabolic Diseases and Nutritional Medicine, Lindwurmstr. 4, 80337 Munich, Germany<sup>c</sup> Helmholtz Centre for Environmental Research – UFZ, Department of Environmental Immunology, Permoserstraße 15, 04318 Leipzig, Germany<sup>d</sup> Medical Practice for Paediatrics, Luisenstr. 16, 53604 Bad Honnef, Germany<sup>e</sup> Marien-Hospital Wesel, Research Institute, Department of Paediatrics, Pastor-Janßen-Str. 8-38, 46483 Wesel, Germany

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## ABSTRACT

**Background:** Exposure to mould or dampness at home has been associated with adverse respiratory effects in all age groups. This exposure has also been related to insomnia in adults. We aimed to investigate the association between exposure to visible mould or dampness at home and sleep problems in children.

**Methods:** The study population consisted of 1719 10-year-old children from the German population-based birth cohort LISApplus with available data on current mould or dampness at home and sleep problems. The presence of visible mould or dampness at home was assessed by questionnaire. Parent-reported sleep problems of their child were analysed by four binary variables: presence of any sleep problems, problems to fall asleep, problems sleeping through the night and a 24 h sleep time of less than 9 h. Logistic regression models adjusted for study centre, sex, age and level of parental education were applied to examine the association between visible mould or dampness at home and sleep problems. Sensitivity analyses included a further adjustment for bedroom sharing and subgroup analyses in children without current allergic diseases.

**Results:** Thirteen percent of parents reported visible mould or dampness at home. We observed increased risks for all four sleep problem variables for children exposed to visible mould or dampness at home. Results were significant for any sleep problems (odds ratio (OR)=1.77 (95%-confidence interval (CI): 1.21–2.60), problems sleeping through the night (OR=2.52(1.27–5.00) and a short sleep time (OR=1.68(1.09–2.61)). While a further adjustment for bedroom sharing and the exclusion of children with asthma or eczema led to similar results, only the association with a short sleep time was still present in children without allergic rhinoconjunctivitis.

**Conclusion:** Our data suggests that visible mould or dampness at home might negatively influence sleep in children. The influence of allergic rhinoconjunctivitis on this association needs to be investigated in future studies.

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## 1. Introduction

Prevalence estimates of reported signs of dampness in buildings worldwide have a wide range, but the majority of studies

indicate that at least 20% of buildings are affected (National Research Council, 2004; WHO, 2009). In general, indoor humidity in buildings is increased by its residents by breathing or perspiration or by the use of water for showering, cooking or washing (National Research Council, 2004). Exchange of air by ventilation or by opening windows can reduce the humidity level. However, insufficient ventilation, inadequate building insulation or water damage such as water leakage or water-pipe bursts can lead to excess moisture in buildings and to a condensation of water on

Abbreviations: OR, odds ratio; CI, confidence interval; MVOC, microbial volatile organic compound

\* Corresponding author. Fax: +49 89 3187 3380.

E-mail address: [heinrich@helmholtz-muenchen.de](mailto:heinrich@helmholtz-muenchen.de) (J. Heinrich).

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surfaces such as floors or walls (National Research Council, 2004). These humid conditions favour the growth of many microbial species such as fungi or bacteria which release spores, cell fragments or microbial volatile organic compounds (MVOCs), which are related to a mould-related odour, into the air and have possible adverse health consequences for the inhabitants (National Research Council, 2004). Some of these components are potential allergens and living in homes with visible mould or dampness has been associated with current asthma, asthma development or exacerbation, respiratory infections, upper respiratory tract symptoms, wheeze, cough and dyspnoea in adults and children (Mendell et al., 2011; C. Tischer et al., 2011; C.G. Tischer et al., 2011; WHO, 2009). A recent study in children from 20 countries further supported an association of exposure to dampness at home and an increased risk for reported eczema (Weinmayr et al., 2013). Furthermore, living in homes with reported visible mould was associated with decreased cognitive function in children (Jedrychowski et al., 2011).

It has been suggested that living in damp or mouldy home environments might also be associated with sleep problems. In a cross-sectional study among adults in England, subjects living in damp buildings were more likely to report sleep problems (Packer et al., 1994). In a study by Janson et al. in about 40-year-old Northern Europeans, the prevalence of insomnia was higher among individuals who were living in damp buildings (Janson et al., 2005). However, whether a similar association could already be observed in children has, to our knowledge, not yet been investigated. Thus, this study aimed to investigate the association between reported current visible mould or dampness at home and sleep problems in 10-year-old children.

## 2. Methods

### 2.1. Study population

The study population of the current study consists of children from an ongoing German population-based birth cohort study, the study of influence of life-style factors on the development of the immune system and allergies in East and West Germany plus the influence of traffic emissions and genetics (LISApplus). Between end of 1997 and beginning of 1999, 3097 healthy, full-term neonates born in four German cities (Munich, Leipzig, Wesel and Bad Honnef) were recruited in the study. Descriptions of screening and exclusion criteria can be found in previous publications (Heinrich et al., 2002; Zutavern et al., 2006). Children were followed at ages of 0.5, 1, 1.5, 2, 4, 6 and 10 years. The LISApplus study was conducted in accordance with the Declaration of Helsinki, was approved by the local ethics committees and written consent was obtained from the parents of all study participants.

At the age of 10 years, questionnaires administered to the parents included questions about visible mould or dampness at home and sleep problems of their child. Out of the 3097 children originally recruited at birth, 1761 (56.9%) participated at the 10-year follow-up. Of these, 1721 had information on sleep duration or sleep problems. After exclusion of two children without information on visible mould or dampness at home, the study population consisted of 1719 children.

### 2.2. Exposure definition

Current exposure to visible mould at home was based on parent's report of any damp spots or visible mould (a) in child's room and (b) in the rest of the apartment (apart from mould on food and apart from mould in the cellar). An exposure was defined to be present if visible mould was reported at either of the two

locations. Children with no visible mould at both locations served as control group. A "yes" answer to the question "Would you consider your apartment/house as being damp?" was defined as living in a damp home.

Two binary variables were defined to analyse the presence of any mould at home (somewhere vs. nowhere at home) or dampness at home (yes vs. no). A further variable combines both exposures: any visible mould at home or dampness at home vs. no visible mould and no damp home.

### 2.3. Sleep problem outcome variables

Current information on sleep problems of the 10-year-old children was assessed by questionnaire administered to the parents. Average sleep time (hours) of the child during 24 h was categorised into less than vs. equal to or more than 9 h. Presence of any sleep problems was defined based on the question "Does your child suffer from sleep problems?". In case of a "yes" answer, the type of sleep problems (problems to fall asleep or problems sleeping through the night) was further assessed. Three binary variables were defined to analyse the presence of any sleep problems, having problems to fall asleep and having problems sleeping through the night.

### 2.4. Statistical analysis

Logistic regression models were used to examine the association between an exposure to visible mould or dampness at home and sleep problems in children. Results are presented as odds ratios (OR) with corresponding 95% confidence intervals (CI) and *p* values. For univariate analyses, chi-squared tests were used. Statistical significance was defined according to the conventional two-sided alpha level of 5%. Adjusted models included study centre (Munich, Leipzig, Bad Honnef or Wesel), sex and age at 10-year follow-up. Furthermore, parental education level was based on the duration of education defined as the highest level of both parents (both parents with less than 10 years of schooling as 'low', at least one parent with 10 years of schooling as 'medium' and at least one parent with more than 10 years of schooling as 'high'). Two sensitivity analyses were conducted. The first investigated the influence of bedroom sharing (no, with one other person, with more than one other person). Second, the influence of the presence of current allergic diseases on the association between mould or dampness exposure and sleep problems was analysed by excluding children with current asthma, current eczema or current allergic rhinoconjunctivitis, respectively. Current asthma was defined as the presence of at least two out of the following three conditions: (1) any doctor-diagnosis of asthma up to the age of 10 years, (2) wheezing in the previous 12 months and (3) taking asthma medication in the previous 12 months. Children with at most one of these conditions served as control group. Current eczema was defined as the presence of at least two out of the following three conditions: (1) any doctor-diagnosis of eczema up to the age of 10 years, (2) an itchy rash that was coming and going for at least 6 months in the previous 12 months and (3) taking eczema medication in the previous 12 months. Children with at most one of these conditions served as control group. Current allergic rhinoconjunctivitis was defined as (1) any doctor-diagnosis of allergic rhinitis or hayfever up to the age of 10 years and (2) itchy-watery eyes and a runny or blocked nose in the absence of a cold in the previous 12 months. The control group for this definition consisted of children who never reported such a doctor diagnosis and who did not have any current eye or nose symptoms.

All statistical analyses were carried out using the statistical software R (version 3.0.2, <http://www.r-project.org/>; R Development Core Team, 2009).

### 3. Results

Table 1 shows the characteristics of the study population and prevalence of sleep problems. Thirteen percent of the parents reported that their child suffered from any sleep problems. From these 230 children, 203 were reported to have problems to fall asleep, 50 have problems sleeping through the night and 28 have both sleep problems. Median sleep time was 10 h with a range from 6 h to 12 h. The prevalence of a short sleep duration (< 9 h/24 h) was 23.5% among children with any sleep problems compared to 7.3% without such problems ( $p < 0.0001$ ).

Of the 1719 children in the study population, 1615 had information on visible mould at home, 1711 had information on perceived dampness of the home and 1612 had information on both exposures. The prevalence of visible mould at home was 12.1% (196 out of 1615). Living in a damp home was reported by 2.4% (41 out of 1711) of the parents. Of the 1612 children with full information on mould exposure and on dampness at home, 13.0% (210 out of 1612) were exposed to at least one of the two exposures. More detailed, 164 (10.2%) children were living in a home with visible mould but without perceived dampness and 27 (1.7%) were living in a damp home with visible mould.

Compared to the LISApplus population at baseline, this study population differs significantly with respect to parental level of education ( $p < 0.001$ ). Families with lower levels of education were more likely to be lost to follow-up. In the study population, the parental level of education was neither associated with sleep problems nor with mould/dampness exposure at home.

Table 2 shows the association between exposure to visible mould or dampness at home and sleep problems in children. Children exposed to visible mould or dampness at home were observed to have increased risks for all four sleep problem variables. The effect estimates remained similar after adjustment for study centre, child's sex and age and parental level of education. Results were significant for any sleep problems (OR=1.77 (CI:1.21–2.60)), problems sleeping through the night (OR=2.52 (CI:1.27–5.00)) and a short sleep time (OR=1.68 (CI:1.09–2.61)).

When the exposures were regarded separately, an exposure to visible mould was associated with a higher risk for any sleep problems (OR=1.67(CI:1.13–2.48)), problems sleeping through the night (OR=2.11(1.02–4.37)) and a short sleep time (OR=1.76 (CI=1.13–2.75)). Compared to children whose parents did not report to live in a damp home, children living in such a home showed a higher risk for having any sleep problems (OR=2.57 (CI:1.26–5.24)), especially for having problems sleeping through the night (OR=4.29 (CI:1.43–12.85)).

The results of the first sensitivity analysis about the influence of bedroom sharing are also shown in Table 2. The percentage of children showing sleep problems was not significantly higher among children who share their bedroom with more than one person compared to children sleeping alone. However, the percentage of children living in mould exposed or damp homes was significantly higher ( $p < 0.0001$ ) among children who share their bedroom (with more than one person: 24.2%, with one person: 20.9%) compared to children who sleep alone (11.3%). After further adjustment for bedroom sharing, the results on the association between visible mould or dampness and sleep problems were similar.

The second sensitivity analysis (Table 3) aimed to investigate whether the current allergic disease status of the children has an influence on the association between visible mould or dampness at home and sleep problems. Children with current asthma did not have a significantly different prevalence of sleep problems compared to children without this allergic disease. Similar results were observed for current eczema and current allergic rhinoconjunctivitis. Moreover, the percentage of children with current asthma,

**Table 1**

Characteristics of the study population of 10-year-old children originating from the LISApplus study (N=1719).

	n/N> (%) <sup>a</sup> or mean (sd)	
<b>Sex</b>		
Female	831/1719	(48.3)
Male	888/1719	(51.7)
<b>Study centre</b>		
Munich	905/1719	(52.6)
Leipzig	434/1719	(25.2)
Bad Honnef	201/1719	(11.7)
Wesel	179/1719	(10.4)
<b>Age</b>		
Years	10.1	(0.24)
<b>Parental level of education<sup>b</sup></b>		
Low	64/1707	(3.7)
Medium	410/1707	(24.0)
High	1233/1707	(72.2)
<b>Bedroom sharing</b>		
No	1367/1669	(81.9)
With one other person	266/1669	(15.9)
With more than one other person	36/1669	(2.2)
<b>Current asthma</b>		
No	1632/1713	(95.3)
Yes	81/1713	(4.7)
<b>Current eczema</b>		
No	1607/1709	(94.0)
Yes	102/1709	(6.0)
<b>Current allergic rhinoconjunctivitis</b>		
No	1474/1632	(90.3)
Yes	158/1632	(9.7)
<b>Any sleep problems</b>		
No	1481/1711	(86.6)
Yes	230/1711	(13.4)
<b>Problems to fall asleep</b>		
No	1503/1706	(88.1)
Yes	203/1706	(11.9)
<b>Problems sleeping through the night</b>		
No	1656/1706	(97.1)
Yes	50/1706	(2.9)
<b>Sleep time &lt; 9 h</b>		
No	1550/1713	(90.5)
Yes	163/1713	(9.5)

<sup>a</sup> Number of children in each category (n) out of all children for which information on the variable is available (N) and corresponding percentage (%), N may be different from 1719 due to missing data.

<sup>b</sup> Definition based on highest parental educational level: both parents with less than 10 years of schooling (low), at least one parent with 10 years of schooling (medium), at least one parent with more than 10 years of schooling (high).

current eczema or current allergic rhinoconjunctivitis, respectively, was not significantly different among children with current mould or dampness exposure at home compared to children without this exposure. The analyses in the subgroup of children without current asthma revealed similar results compared to the entire study population. The exclusion of children with current eczema also resulted in similar effect estimates. While the association between mould or dampness exposure and a short sleep time was also present in the group of children without current allergic rhinoconjunctivitis, the associations with any sleep problems and with problems sleeping through the night were attenuated and not significant anymore.

### 4. Discussion

The results of the present study suggest that living in a damp or mouldy home may be related to sleep problems in children. Adverse effects were observed for any sleep problems, problems maintaining sleep and for a short sleep time. Similar results were

**Table 2**  
Association between current exposure to visible mould or dampness at home and sleep problems.

	Crude OR (95%-CI)	Adjusted I <sup>a</sup> OR (95%-CI)	Adjusted II <sup>b</sup> OR (95%-CI)
<b>Visible mould at home</b>			
Any sleep problems (214/1598) <sup>c</sup>	1.61 (1.09–2.37)	1.67 (1.13–2.48)	1.70 (1.13–2.54)
Problems to fall asleep (189/1593)	1.43 (0.94–2.18)	1.47 (0.96–2.26)	1.50 (0.97–2.33)
Problems sleeping through the night (46/1593)	2.02 (0.99–4.13)	2.11 (1.02–4.37)	1.91 (0.89–4.13)
Sleep time < 9 h (154/1597)	1.69 (1.09–2.62)	1.76 (1.13–2.75)	1.67 (1.06–2.65)
<b>Damp home</b>			
Any sleep problems (227/1692)	2.43 (1.20–4.92)	2.57 (1.26–5.24)	2.59 (1.26–5.31)
Problems to fall asleep (201/1687)	1.32 (0.55–3.18)	1.37 (0.57–3.33)	1.39 (0.57–3.40)
Problems sleeping through the night (49/1687)	3.90 (1.33–11.40)	4.29 (1.43–12.85)	4.30 (1.41–13.13)
Sleep time < 9 h (161/1693)	0.75 (0.23–2.45)	0.71 (0.21–2.34)	0.69 (0.21–2.28)
<b>Visible mould/dampness at home</b>			
Any sleep problems (214/1596)	1.70 (1.16–2.47)	1.77 (1.21–2.60)	1.80 (1.22–2.66)
Problems to fall asleep (189/1591)	1.42 (0.94–2.15)	1.48 (0.97–2.23)	1.50 (0.98–2.30)
Problems sleeping through the night (46/1591)	2.38 (1.21–4.66)	2.52 (1.27–5.00)	2.36 (1.15–4.84)
Sleep time < 9 h (153/1594)	1.63 (1.06–2.51)	1.68 (1.09–2.61)	1.60 (1.02–2.51)

<sup>a</sup> Adjusted for study centre, sex, child's age, parental education level.

<sup>b</sup> Model adjusted I further adjusted for bedroom sharing.

<sup>c</sup> Number of cases (*n*) out of all (*N*) samples used for model adjusted I.

**Table 3**  
Association between current exposure to visible mould/dampness at home and sleep problems (only in children without specific current allergic diseases).

	Crude OR (95%-CI)	Adjusted <sup>a</sup> OR (95%-CI)
<b>Without current asthma</b>		
Any sleep problems (200/1514) <sup>b</sup>	1.65 (1.12–2.45)	1.71 (1.15–2.55)
Problems to fall asleep (176/1509)	1.41 (0.92–2.17)	1.45 (0.94–2.23)
Problems sleeping through the night (43/1509)	2.08 (1.01–4.28)	2.18 (1.05–4.54)
Sleep time < 9 h (140/1513)	1.71 (1.09–2.68)	1.77 (1.13–2.80)
<b>Without current eczema</b>		
Any sleep problems (193/1493)	1.63 (1.09–2.42)	1.70 (1.14–2.54)
Problems to fall asleep (172/1489)	1.35 (0.87–2.09)	1.40 (0.90–2.17)
Problems sleeping through the night (41/1489)	2.17 (1.05–4.48)	2.28 (1.09–4.76)
Sleep time < 9 h (140/1492)	1.76 (1.13–2.75)	1.83 (1.16–2.86)
<b>Without current allergic rhinitis</b>		
Any sleep problems (180/1373)	1.33 (0.86–2.05)	1.36 (0.88–2.11)
Problems to fall asleep (160/1368)	1.08 (0.67–1.74)	1.10 (0.68–1.79)
Problems sleeping through the night (36/1368)	1.97 (0.88–4.39)	2.03 (0.91–4.57)
Sleep time < 9 h (128/1373)	1.70 (1.07–2.72)	1.76 (1.09–2.82)

<sup>a</sup> Adjusted for study centre, sex, child's age, parental education level.

<sup>b</sup> Number of cases (*n*) out of all (*N*) samples used for adjusted model.

observed after additional adjustment for bedroom sharing, in the subgroup of non-asthmatic children and in children without eczema. Only the result for sleep problems was still present in the subgroup of children without allergic rhinoconjunctivitis.

#### 4.1. Results from previous studies

A previous study by Packer et al. investigated the association between living in damp housing and adult health in a cross-sectional study among 2353 adults in England (Packer et al., 1994). Sleep problems were assessed by one of six dimensions of a questionnaire assessing perceived ill health. Taking into account the sex, age and social class of the subjects, the authors observed that subjects living in damp buildings showed a significantly higher prevalence of self-reported sleep problems compared to subjects living in dry housing (Packer et al., 1994).

A second study was conducted by Janson et al. (2005) in about 16,000 40-year-old Northern Europeans with a cross-sectional design. Three specific sleep problems, i.e. difficulties inducing sleep, difficulties maintaining sleep and early morning awakenings were defined based on a 7-item sleep questionnaire. Insomnia was

defined as at least one of the three aforementioned problems. Living in damp buildings was related to a higher risk for insomnia and also for all three sleep problems regarded separately. The association also withstood adjustment for respiratory diseases (Janson et al., 2005). Furthermore, Sahlberg et al. (2012) reported an association between dampness and indoor moulds and a higher incidence of mucosal, skin or general symptoms of sick building syndrome in 452 adults from Uppsala, Sweden followed for 10 years. Apart from headache, sensation of catching a cold and nausea, the symptoms categorised as “general symptoms” include an item about tiredness (Sahlberg et al., 2012).

In a further study by Sahlberg et al. (2013) the concentrations of airborne moulds and bacteria as well as MVOCs, plasticisers and formaldehyde were assessed. Buildings with a history of dampness showed significantly higher levels of total bacteria, total moulds, viable moulds, 3-methylfuran and ethyl-isobutyrate. For current dampness, higher levels of 2-ethyl-1-hexanol and 2-methylfuran were observed compared to dry buildings. However, the compounds observed in higher levels in damp homes were not the same ones that showed an adverse effect on symptoms of the sick building syndrome (Sahlberg et al., 2013).

To the best of our knowledge, no study on the association between living in damp homes or in homes with visible mould and sleep problems in children has been published so far.

In our study, the prevalence of difficulties falling asleep was higher than that for difficulties maintaining sleep (11.9% vs. 2.9%). This has also been observed in a study on sleep problems of about 10-year-old German children which used similar questions to assess these problems (Fricke-Oerkermann et al., 2007). Parent-reported prevalences were 6.1% (22.4%) for often (sometimes) having sleep onset problems whereas only 2.6% (10.8%) of children were reported to often (sometimes) have difficulties maintaining sleep (Fricke-Oerkermann et al., 2007). The average sleep duration of the children in our study is comparable to the recommended sleep duration of about 10 h (Heussler, 2005; Howard and Wong, 2001), whereas it was observed that both the observed and also the recommended sleep durations tend to show a decreasing trend within the last century (Matricciani et al., 2012).

Concerning factors influencing sleep problems, no association with sharing a bedroom with other people has been observed in two other studies (Lehmkuhl et al., 2008; Stein et al., 2001). In our study, we also did not observe a significant difference of sleep problem prevalence with regard to bedroom sharing, only a tendency towards an adverse effect which might be related to the problem that it could take some time until everyone in the room is quiet and asleep. Furthermore, we observed a significant relationship between bedroom sharing and living in a home with visible mould or dampness. We thought that sleeping together with other people in the same room might also be related to a higher relative level of humidity in this room and thus a higher risk for mould. Thus, we decided to adjust the models for bedroom sharing. The results, however, remained stable.

Allergic diseases such as asthma, eczema or allergic rhinitis can adversely influence sleep in children (Koinis-Mitchell et al., 2012). Nighttime symptoms of asthma due to e.g. inadequate treatment or pathophysiological mechanisms of increased inflammation during nighttime could lead to disrupted sleep (Koinis-Mitchell et al., 2012). Jernelov et al. reported that the risk for being overtired in adolescence was increased for children with asthma (Jernelov et al., 2013). The sleep of children with eczema might be affected by an itchy rash (Camfferman et al., 2010; Koinis-Mitchell et al., 2012). Children with allergic rhinitis can suffer from sleep-disordered breathing or snoring which might be due to aggravated nasal congestion during nighttime resulting from the lying position (Koinis-Mitchell et al., 2012).

Furthermore, an exposure to mould or dampness at home has been associated with an increased risk for allergic diseases in children (Mendell et al., 2011; C. Tischer et al., 2011; Weinmayr et al., 2013). Thus, as allergic diseases can have negative effects on sleep and indoor mould or dampness exposure is associated with allergic diseases, we have investigated the association among children without current allergic diseases. The results obtained after exclusion of asthmatic children or of children with eczema were similar. The exclusion of children with allergic rhinoconjunctivitis led to similar results for a short sleep time and even if the associations with any sleep problems and problems sleeping through the night did not reach statistical significance anymore, the ORs were still increased.

The results of this sensitivity analysis suggest that the observed adverse relationship between mould or dampness exposure at home and sleep problems might partly be explained by symptoms of allergic rhinoconjunctivitis and that lower respiratory tract symptoms or skin symptoms only play a minor role. Unfortunately, due to the small number of children with current allergic diseases, separate analyses in this subgroup or in the subgroups with a specific allergic disease were not feasible.

#### 4.2. Potential biological mechanisms for the relationship

An explanation of the observed relationship between exposure to visible mould or dampness at home and sleep problems in children is not straightforward. Several suggestions have been made by Janson et al. (2005) to explain the respective relationship in an adult population. First, the authors mentioned the possibility that  $\beta$ -1,3-glucan which can stem from fungal cell walls may play a role as an exposure to this compound has been associated with fatigue. A second explanation includes MVOCs. These are metabolic products of fungi and bacteria (Korpi et al., 2009). An exposure to higher indoor levels of several MVOCs, among which was 3-methylfuran, at home has been associated with any symptoms of the sick building syndrome (Sahlberg et al., 2013). In the same study, the authors observed that indoor concentrations of total bacteria, total moulds as well as of three MVOCs (2-ethyl-1-hexanol, 3-methylfuran and ethyl-isobutyrate) were significantly higher in buildings with reported history of dampness. However, only a single MVOC, 3-methylfuran, was associated with both, any sick building syndrome symptoms and with history of dampness status. Furthermore, Schleibinger et al. compared levels of several MVOCs in homes with and without mould growth and observed that only levels of two MVOCs (2-methyl-1-butanol and 1-octen-3-ol) differed significantly, however only by a small difference and that mould status of a building only explains 10% of these levels (Schleibinger et al., 2008). The authors concluded that the concentrations of these two MVOCs in homes should not be considered as a sensitive or specific marker for determining mould in buildings due to other factors influencing indoor MVOC concentrations (Schleibinger et al., 2008).

A further explanation mentioned by Janson et al. refers to the impairment of sleep by unpleasant smells which are related to a humid environment (Janson et al., 2005). Some MVOCs have a musty or mouldy smell (Korpi et al., 2009). Furthermore, humidity and dampness in buildings might cause chemical degradation of building materials which itself is related to an emission of volatile organic compounds as for example the degradation of polyvinyl chloride floorings which is related to an emission of 2-ethyl-1-hexanol (WHO, 2009).

Finally, Janson et al. (2005) refer to the possibility that exposure to visible mould or dampness might impair sleep via swollen nasal airways which would be supported by the results of the sensitivity analysis in children without allergic rhinoconjunctivitis where the associations were attenuated partly to nonsignificance.

#### 4.3. Strengths and limitations

A strength of this study is the possibility to investigate the association between mould or dampness at home and sleep problems at an early age. Children have a much more consistent and homogenous daily routine than adults. Potential influential factors that certain adults may experience (i.e. nightshift work) are thus unlikely to be relevant in studies on children. Furthermore, we were able to account for the influence of several potential confounding variables, especially the prospectively collected information about allergic diseases.

However, this study has also some limitations.

The first limitation is related to the assessment of the outcome. Sleep problems were assessed by three dichotomous questions assessing the mere presence of any sleep problem and the type of these problems (problems initiating or maintaining sleep). No information about the severity or frequency (problem occurring every night, only sometimes or never) of these problems was collected. Therefore, we were not able to separately analyse the association in children with no or mild symptoms compared to those with more severe sleep problems. Furthermore, the study

could have been complemented by an objective measurement of sleep parameters for example by actigraphy. This approach, however, was not feasible for the present study.

Moreover, sleep problems of the children were reported by the parents. This might lead to a misclassification of the outcome. However, compared to self-reports, parental reports rather tend to underestimate the extent of the sleep problems (Fricke-Oerker-mann et al., 2007). This would then lead to an underestimation of the effect estimates.

Another limitation is related to exposure misclassification. Unfortunately, we did not have information on the severity of mould exposure (total affected area). Moreover, a misclassification is also possible when the area affected by mould growth is not visible when occurring behind furniture.

A further limitation refers to attrition bias which is a common problem of longitudinal studies. Families with a lower level of parental education were less likely to continue participation in the study up to the 10-year follow-up. However, as neither sleep problems nor mould/dampness exposure were significantly associated with parental level of education in the study population, we think that a major bias by attrition is unlikely.

Finally, this is a cross-sectional analysis and no conclusions on causality can be based on our results. We are also not able to rule out the possibility of residual confounding.

## 5. Conclusion

Our data suggests that visible mould or dampness at home might negatively influence sleep in children. The influence of allergic rhinoconjunctivitis on this association needs to be investigated in future studies.

## Conflict of interest

The authors of this paper declare that they have no potential conflicts of interest to disclose. The authors have indicated that they have no financial relationships relevant to this article to disclose.

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## Ethical approval

The LISApplus study was approved by the local ethics committees.

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## References

- Camfferman, D., Kennedy, J.D., Gold, M., Martin, A.J., Lushington, K., 2010. Eczema and sleep and its relationship to daytime functioning in children. *Sleep Med. Rev.* 14, 359–369.
- Fricke-Oerker-mann, L., Pluck, J., Schredl, M., et al., 2007. Prevalence and course of sleep problems in childhood. *Sleep* 30, 1371–1377.
- Heinrich, J., Bolte, G., Holscher, B., et al., 2002. Allergens and endotoxin on mothers' mattresses and total immunoglobulin E in cord blood of neonates. *Eur. Respir. J.* 20, 617–623.
- Heussler, H.S., 2005. 9. Common causes of sleep disruption and daytime sleepiness: childhood sleep disorders II. *Med. J. Aust.* 182, 484–489.
- Howard, B.J., Wong, J., 2001. Sleep disorders. *Pediatr. Rev.* 22, 327–342.
- Janson, C., Norback, D., Omenaas, E., et al., 2005. Insomnia is more common among subjects living in damp buildings. *Occup. Environ. Med.* 62, 113–118.
- Jedrychowski, W., Mauger, U., Perera, F., et al., 2011. Cognitive function of 6-year old children exposed to mold-contaminated homes in early postnatal period. Prospective birth cohort study in Poland. *Physiol. Behav.* 104, 989–995.
- Jernelov, S., Lekander, M., Almqvist, C., Axelsson, J., Larsson, H., 2013. Development of atopic disease and disturbed sleep in childhood and adolescence – a longitudinal population-based study. *Clin. Exp. Allergy* 43, 552–559.
- Koinis-Mitchell, D., Craig, T., Esteban, C.A., Klein, R.B., 2012. Sleep and allergic disease: a summary of the literature and future directions for research. *J. Allergy Clin. Immunol.* 130, 1275–1281.
- Korpi, A., Jarnberg, J., Pasanen, A.L., 2009. Microbial volatile organic compounds. *Crit. Rev. Toxicol.* 39, 139–193.
- Lehmkuhl, G., Fricke-Oerker-mann, L., Wiater, A., Mitschke, A., 2008. Sleep disorders in children beginning school: their causes and effects. *Dtsch. Arztebl. Int.* 105, 809–814.
- Matricciani, L.A., Olds, T.S., Blunden, S., Rigney, G., Williams, M.T., 2012. Never enough sleep: a brief history of sleep recommendations for children. *Pediatrics* 129, 548–556.
- Mendell, M.J., Mirer, A.G., Cheung, K., Tong, M., Douwes, J., 2011. Respiratory and allergic health effects of dampness, mold, and dampness-related agents: a review of the epidemiologic evidence. *Environ. Health Perspect.* 119, 748–756.
- National Research Council, 2004. *Damp Indoor Spaces and Health*. The National Academies Press, Washington, DC.
- Packer, C.N., Stewart-Brown, S., Fowle, S.E., 1994. Damp housing and adult health: results from a lifestyle study in Worcester, England. *J. Epidemiol. Community Health* 48, 555–559.
- R Development Core Team, 2009. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing, Vienna, Austria.
- Sahlberg, B., Gunnbjörnsdóttir, M., Soon, A., et al., 2013. Airborne molds and bacteria, microbial volatile organic compounds (MVOC), plasticizers and formaldehyde in dwellings in three North European cities in relation to sick building syndrome (SBS). *Sci. Total Environ.* 444, 433–440.
- Sahlberg, B., Norback, D., Wieslander, G., Gislason, T., Janson, C., 2012. Onset of mucosal, dermal, and general symptoms in relation to biomarkers and exposures in the dwelling: a cohort study from 1992 to 2002. *Indoor Air* 22, 331–338.
- Schleibinger, H., Laussmann, D., Bornehag, C.G., Eis, D., Rueden, H., 2008. Microbial volatile organic compounds in the air of moldy and mold-free indoor environments. *Indoor Air* 18, 113–124.
- Stein, M.A., Mendelsohn, J., Obermeyer, W.H., Amromin, J., Benca, R., 2001. Sleep and behavior problems in school-aged children. *Pediatrics* 107, E60.

- Tischer, C., Chen, C.M., Heinrich, J., 2011. Association between domestic mould and mould components, and asthma and allergy in children: a systematic review. *Eur. Respir. J.* 38, 812–824.
- Tischer, C.G., Hohmann, C., Thiering, E., et al., 2011. Meta-analysis of mould and dampness exposure on asthma and allergy in eight European birth cohorts: an ENRIECO initiative. *Allergy* 66, 1570–1579.
- Weinmayr, G., Gehring, U., Genuneit, J., et al., 2013. Dampness and moulds in relation to respiratory and allergic symptoms in children: results from Phase Two of the International Study of Asthma and Allergies in Childhood (ISAAC Phase Two). *Clin. Exp. Allergy* 43, 762–774.
- WHO, 2009. WHO Guidelines for Indoor Air Quality: Dampness and Mould, Regional Office for Europe.
- Zutavern, A., Brockow, I., Schaaf, B., et al., 2006. Timing of solid food introduction in relation to atopic dermatitis and atopic sensitization: results from a prospective birth cohort study. *Pediatrics* 117, 401–411.