Original Paper

Associations Between Indoor Musty Odors and Sleep Quality and Duration Among Older Adults: Longitudinal Study

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Abstract

Background: Indoor environmental air quality may influence sleep health among older adults. However, evidence on the association between indoor musty odors, a proxy for dampness- and mold-related exposures, and sleep outcomes remains limited. Susceptibility to environmental exposures may also vary by chronic lung disease status.

Objective: This study aimed to examine the associations of indoor musty odors with sleep quality and sleep duration among older adults and to explore these associations across subgroups defined by chronic lung disease status.

Methods: Data were drawn from 3 waves (2011-2018) of the Chinese Longitudinal Healthy Longevity Survey. Community-dwelling older adults aged ≥65 years without cognitive impairment or dementia were included. Self-reported sleep quality was categorized as good, fair, or poor, and sleep duration was categorized as short (<7 hours), normal (7-8 hours), or long (>8 hours). Generalized estimating equation models with a logit link and an exchangeable working correlation structure were applied. Stabilized inverse probability of attrition weights was used to account for attrition. Models were adjusted for sociodemographic, health-related, lifestyle, and residential environmental factors. Analyses were conducted overall and stratified by chronic lung disease status.

Results: A total of 5712 participants were included, contributing 10,449 observations across 3 survey waves. At baseline, participants had a mean age of 82.4 (SD 10.0) years; 39.8% (n=2271) were aged ≥85 years, 52.7% (n=3010) were male, and 12.8% (n=732) had chronic lung disease. Overall, 17.6% (n=1008) reported indoor musty odors; 24.6% (n=1404) and 11.4% (n=650) reported fair and poor sleep quality, respectively; and 32% (n=1829) and 27.9% (n=1591) reported short and long sleep durations, respectively. Exposure to indoor musty odors was associated with higher odds of fair sleep quality (odds ratio [OR] 1.19, 95% CI 1.04-1.36; *P*=.01) and poor sleep quality (OR 1.63, 95% CI 1.37-1.95; *P*<.001), as well as short sleep duration (OR 1.36, 95% CI 1.19-1.55; *P*<.001). These associations were statistically significant among individuals without chronic lung disease (*P*=.02, *P*<.001, and *P*<.001, respectively) but not among those with chronic lung disease (*P*=.20, *P*=.12, and *P*=.10, respectively).

Conclusions: Indoor musty odors were associated with adverse sleep outcomes among older adults, particularly among individuals without chronic lung disease. These findings highlight the importance of indoor air quality for sleep health and support interventions targeting dampness and mold in residential settings.

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KEYWORDS

indoor musty odors; sleep quality; sleep duration; indoor air quality; chronic lung disease

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Introduction

Sleep plays a critical role in health and well-being among older adults [1]. However, sleep disturbances are highly prevalent in this population and have been linked with a range of adverse health outcomes, including increased risk of diabetes, falls, functional disability, and dementia [2]. A meta-analysis of 52 studies reported that the pooled prevalence of poor sleep quality among older adults reached 50% (95% CI 45%-55%) [3]. Sleep duration is another important dimension of sleep health. The National Sleep Foundation recommends 7 to 8 hours of sleep for older adults [4]. One umbrella review indicated that, among short sleepers, each 1-hour reduction in sleep duration was associated with a 3% to 11% increased risk of all-cause mortality, coronary heart disease, osteoporosis, stroke, and diabetes [5]. In contrast, among long sleepers, each 1-hour increase in sleep duration was associated with a 7% to 17% higher risk of stroke mortality, coronary heart disease, stroke, and diabetes [5].

Sleep is influenced by indoor environmental conditions, such as air quality, noise, temperature, and lighting. The US Environmental Protection Agency estimates that Americans spend about 90% of their time indoors [6], highlighting the importance of indoor environments for health, especially for older adults who tend to spend a substantial proportion of their time indoors. Indoor environmental conditions related to dampness and mold have received increasing attention in recent years. Humid conditions favor the growth of microbial species, such as fungi and bacteria, which release spores, cell fragments, and microbial volatile organic compounds into the air [7]. These emissions are associated with musty odors and may contribute to sensory irritation, discomfort, or physiological stress responses, thereby potentially disrupting sleep. Prior studies have shown that children exposed to visible mold or dampness at home have a higher risk of sleep problems, including difficulty falling asleep, difficulty maintaining sleep, shorter sleep duration, and sleep-disordered breathing [8,9]. In addition, a study in Canada reported that visible mold in the house was significantly associated with a higher risk of sleep deprivation in the general population [10]. Despite the potential impact on health, evidence regarding the association between dampness-related exposures and sleep outcomes remains limited among older adults. Furthermore, even when research is conducted, visible mold may not fully capture indoor microbial exposure, particularly when mold growth occurs in hidden or less visible areas.

Indoor musty odors, often indicative of dampness and mold growth, are commonly used as a proxy for underlying biological exposures in residential environments [7]. A prior study conducted in China reported that approximately 13.6% of respondents experienced indoor musty odors in their homes during the past year [11]. To date, only a few studies have examined the relationship between indoor musty odors and sleep health. One study reported that adults aged ≥20 years exposed to indoor musty odors were more likely to report sleep complaints [12]. Another cross-sectional study primarily examined the association between residential proximity to major roadways and sleep quality and found that the association was stronger among participants reporting indoor musty odors [13]. Despite these findings, evidence on the direct association between indoor musty odors and sleep remains limited, particularly among older adults.

In addition, individual susceptibility to environmental exposures may vary by chronic lung disease status, reflecting differences in respiratory sensitivity, underlying symptom burden, and behavioral responses [14]. These differences may influence both exposure levels and physiological responses and may also mask the observable impact of environmental exposures, thereby potentially attenuating the associations between indoor environmental exposures and sleep outcomes in certain subgroups. Therefore, examining these associations across subgroups defined by chronic lung disease status may provide additional insights into population-specific patterns.

Therefore, this study aimed to examine the associations between indoor musty odors and sleep outcomes, including sleep quality and sleep duration, among older adults and to further explore these associations across subgroups defined by chronic lung disease status.

Methods

Data and Sample

The data used in this study were derived from the Chinese Longitudinal Healthy Longevity Survey (CLHLS), a national survey of older adults aged ≥65 years [15]. A multistage cluster random sampling method was adopted to recruit participants from 23 of 34 provinces in China, providing representative data to investigate determinants of longevity. The baseline survey was conducted in 1998, and the follow-up surveys were conducted in 2000, 2002, 2005, 2008 to 2009, 2011 to 2012, 2014, and 2017 to 2018 [15].

Because information on indoor musty odors was first collected in the 2011 wave of the CLHLS, participants were included from this wave and followed up in the 2014 and 2017 to 2018 waves. Participants were included in the analytic cohort if they were aged ≥65 years; were community dwelling; and had nonmissing data on indoor musty odors, sleep quality, and sleep duration at baseline. Individuals with self-reported dementia or cognitive impairment at baseline, identified using age- and education-adjusted cutoff scores on the Mini-Mental State Examination, were excluded to minimize potential reporting bias [16]. Reports of sleeping less than 2 hours or more than 16 hours each night were considered implausible and were coded as missing [17]. During follow-up, person-wave observations were excluded if participants were living in institutional care; had self-reported dementia or cognitive impairment; or had missing data on indoor musty odors, sleep quality, or sleep duration at that wave. Details of the sample selection process are provided in Figure S1 in Multimedia Appendix 1.

Measurements

Indoor Musty Odors

Indoor musty odors were measured by asking the participants, “Does your home often have a smell of musty odors?” The responses to this question were categorized as either “no” or

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"yes." Given the large-scale nature of this nationwide study, self-reported data were used as a practical and commonly accepted method for assessing environmental exposures. This approach has been validated in previous studies for evaluating indoor musty odors [11,12].

Sleep Quality and Sleep Duration

Sleep outcomes included sleep quality and sleep duration. Sleep quality was assessed using a single item, "How is your sleep quality now?" with responses recorded on a 5-point Likert scale. In this study, "very good" and "good" were classified as good, and "poor" and "very poor" were categorized as poor. The neutral response was considered fair [13]. Sleep duration was assessed using the question "How many hours do you usually sleep each day?" Information was provided by the participants or their close family members during face-to-face interviews. Sleep duration was initially treated as a continuous variable and categorized as short (<7 hours/day), normal (7-8 hours/day), or long (>8 hours/day), with 7 to 8 hours/day used as the reference range based on the National Sleep Foundation recommendation for older adults [4] and previous studies [18].

Covariates

On the basis of previous studies on sleep health [19,20], the following covariates were examined: sociodemographic, health-related, lifestyle, and residential environmental factors. Sociodemographic factors included age (65-84 or ≥85 years), gender (male or female), living area (urban or rural), marital status (married or others), literacy status (illiterate or literate), household income (at or above the median income or below the median income), and living alone (yes or no). Health-related factors included BMI, multimorbidity (yes or no), physical frailty (yes or no), and chronic lung disease (yes or no). BMI was calculated by dividing weight by the square of height (kg/m^2) and categorized according to the revised Asia-Pacific criteria proposed by the World Health Organization [21] into underweight (BMI<18.5 kg/m^2), normal weight (18.5kg/m^2≤BMI<23.0 kg/m^2), and overweight or obese (BMI≥23.0 kg/m^2). Multimorbidity was defined as the presence of 2 or more self-reported diseases, including hypertension, diabetes, heart disease, stroke, tuberculosis, cataract, glaucoma, cancer, gastric ulcer, Parkinson disease, arthritis, epilepsy, cholecystitis, blood disease, chronic nephritis, and hepatitis. Physical frailty was assessed using the frailty index (FI), with FI≥0.25 indicating physical frailty [22]. Chronic lung disease was assessed in the survey using a single self-reported question about the presence of any of the following conditions: bronchitis, emphysema, asthma, or pneumonia [23,24]. Lifestyle factors included current smoking (yes or no), current drinking (yes or no), and regular exercise (yes or no). Residential environmental factors included whether a respondent had their own bedroom (yes or no), their housing type (detached house or other), their cooking fuel type (solid fuel or other), and their exposure to secondhand smoke (yes or no). Cooking fuel type was categorized as solid if coal or coke, firewood or straw, or charcoal was used; otherwise, it was classified as other. Exposure to secondhand smoke was defined as having any co-residing household member who smoked more than 0 cigarettes per day inside the home.

Statistical Analysis

Descriptive statistics were used to summarize participants' baseline characteristics. Differences across sleep quality and sleep duration groups and by the presence of indoor musty odors were assessed using one-way ANOVA for continuous variables and χ^2 tests for categorical variables.

Given that the study population comprised older adults, a substantial proportion of participants experienced attrition during the study period due to death or loss to follow-up, which may be informative and introduce selection bias. To mitigate potential bias arising from informative attrition, stabilized inverse probability of attrition weights (IPAW) were constructed based on the probability of remaining under observation, conditional on indoor musty odors, sleep outcomes, and other covariates included in the analytic models [25].

Generalized estimating equations (GEEs) with a logit link and an exchangeable working correlation structure were used to account for within-subject correlation across repeated assessments [26,27]. As exposure and outcome were assessed concurrently at each visit, the estimated associations should be interpreted as repeated cross-sectional rather than strictly longitudinal effects. Although sleep quality and sleep duration were specified as 3-category outcomes, multinomial GEE models were not adopted because their combination with IPAW is not readily supported in standard R (R Foundation for Statistical Computing) implementations. Therefore, for sleep quality, 2 separate logistic IPAW-weighted GEE models were fitted to compare (1) fair vs good sleep quality and (2) poor vs good sleep quality. For sleep duration, another 2 logistic IPAW-weighted GEE models were fitted to compare (1) short vs normal sleep duration and (2) long vs normal sleep duration.

Both unadjusted and fully adjusted models were estimated. The fully adjusted models included the covariates described above and survey wave (modeled as dummy variables). Analyses were conducted both overall and stratified by chronic lung disease status, and interaction terms were included to assess effect modification by chronic lung disease status. Adjusted odds ratios (ORs) and 95% CIs were reported. Following previous CLHLS studies [28,29], sampling weights were not applied in the regression models because age, gender, and urban or rural residence, which were used to construct the CLHLS sampling weights, were included as covariates in the adjusted models. Applying sampling weights under these conditions may inflate SEs and reduce precision [30].

Given that alternative thresholds for short sleep have been used among older Chinese adults [31], we conducted a sensitivity analysis defining short sleep as <6 hours/day, with 6 to 8 hours/day as the reference category and >8 hours/day as long sleep.

Missing values among covariates were handled using multiple imputation by chained equations. Multicollinearity was assessed using the variance inflation factor (VIF), with VIF>4 indicating potential multicollinearity [32]. All statistical analyses were performed using RStudio (version 2025.09.0; Posit PBC), and a 2-sided P<.05 was considered statistically significant.

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Ethical Considerations

The CLHLS was approved by the Biomedical Ethics Committee of Peking University (IRB00001052-13074). Written informed consent was obtained from all participants or their legal representatives. The present study was a secondary analysis of deidentified data, and participant privacy and confidentiality were maintained throughout the study.

Results

Sample Characteristics

A total of 5712 participants were included at baseline, contributing 10,449 observations across 3 survey waves. At baseline, the mean age of participants was 82.4 (SD 10.0) years; 39.8% (n=2271) were aged ≥85 years, 52.7% (n=3010) were male, 19% (n=1087) lived alone, 12.8% (n=732) had chronic lung disease, and 17.6% (n=1008) reported indoor musty odors. Regarding sleep outcomes, 64% (n=3658), 24.6% (n=1404), and 11.4% (n=650) of participants reported good, fair, and poor sleep quality, respectively. The mean sleep duration was 7.56 (SD 2.13) hours, with 40.1% (n=2292), 32% (n=1829), and 27.9% (n=1591) reporting normal, short, and long sleep duration, respectively. Table 1 presents the baseline characteristics of the study participants according to sleep quality and sleep duration.

Participants exposed to indoor musty odors were more likely to report poor sleep quality and short sleep duration than those not exposed (P<.001). Most covariates differed across sleep quality and sleep duration categories, except for living area, having one's own bedroom, housing type, and cooking fuel type. Baseline characteristics according to the presence of indoor musty odors are presented in Table S1 in Multimedia Appendix 1.

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Table 1. Distribution of sleep quality and sleep duration according to baseline characteristics (N=5712)[a].

Variables	Sleep quality				Sleep duration			
	Good	Fair	Poor	*P* value	Normal	Short	Long	*P* value
Participants, n (%)	3658 (64)	1404 (24.6)	650 (11.4)	—[b]	2292 (40.1)	1829 (32)	1591 (27.9)	—[b]
Indoor musty odors, n (%)				<.001				<.001
Yes (n=1008)	564 (56)	284 (28.2)	160 (15.8)		347 (34.4)	406 (40.3)	255 (25.3)	
No (n=4704)	3094 (65.8)	1120 (23.8)	490 (10.4)		1945 (41.3)	1423 (30.3)	1336 (28.4)	
Age (y), mean (SD)	82.3 (10.1)	82.8 (10.1)	82.3 (9.3)	.02	80.7 (9.7)	82.4 (9.7)	84.9 (10.2)	.03
65-84 (n=3441)	2209 (64.2)	831 (24.1)	401 (11.7)		1532 (44.5)	1124 (32.7)	785 (22.8)	
≥85 (n=2271)	1449 (63.8)	573 (25.2)	249 (11)		760 (33.5)	705 (31)	806 (35.5)	
Gender, n (%)				<.001				<.001
Male (n=3010)	2057 (68.3)	685 (22.8)	268 (8.9)		1291 (42.9)	845 (28.1)	874 (29)	
Female (n=2702)	1601 (59.3)	719 (26.6)	382 (14.1)		1001 (37.1)	984 (36.4)	717 (26.5)	
Living area, n (%)				.28				.20
Urban (n=2803)	1808 (64.5)	665 (23.7)	330 (11.8)		1157 (41.3)	886 (31.6)	760 (27.1)	
Rural (n=2909)	1850 (63.6)	739 (25.4)	320 (11)		1135 (39)	943 (32.4)	831 (28.6)	
Marital status, n (%)				.01				<.001
Married (n=2767)	1826 (66)	649 (23.5)	292 (10.5)		1248 (45.1)	834 (30.1)	685 (24.8)	
Others (n=2945)	1832 (62.2)	755 (25.6)	358 (12.2)		1044 (35.4)	995 (33.8)	906 (30.8)	
Literacy status, n (%)				<.001				<.001
Illiterate (n=2805)	1717 (61.2)	745 (26.6)	343 (12.2)		1035 (36.9)	953 (34)	817 (29.1)	
Literate (n=2907)	1941 (66.8)	659 (22.6)	307 (10.6)		1257 (43.3)	876 (30.1)	774 (26.6)	
Living alone, n (%)				.09				<.001
Yes (n=1087)	668 (61.5)	278 (25.5)	141 (13)		420 (38.6)	407 (37.5)	260 (23.9)	
No (n=4625)	2990 (64.6)	1126 (24.4)	509 (11)		1872 (40.5)	1422 (30.7)	1331 (28.8)	
Household income[c], n (%)				.001				<.001
Below the median income (n=2893)	1785 (61.7)	746 (25.8)	362 (12.5)		1115 (38.5)	1001 (34.6)	777 (26.9)	
At or above the median income (n=2819)	1873 (66.4)	658 (23.4)	288 (10.2)		1177 (41.8)	828 (29.3)	814 (28.9)	
BMI, n (%)				<.001				<.001
Normal (n=2657)	1709 (64.3)	653 (24.6)	295 (11.1)		1048 (39.4)	852 (32.1)	757 (28.5)	
Underweight (n=1198)	678 (56.6)	347 (29)	173 (14.4)		411 (34.3)	433 (36.2)	354 (29.5)	
Overweight or obese (n=1857)	1271 (68.4)	404 (21.8)	182 (9.8)		833 (44.9)	544 (29.3)	480 (25.8)	
Multimorbidity, n (%)				<.001				<.001
Yes (n=1378)	755 (54.8)	393 (28.5)	230 (16.7)		529 (38.4)	510 (37)	339 (24.6)	
No (n=4334)	2903 (67)	1011 (23.3)	420 (9.7)		1763 (40.7)	1319 (30.4)	1252 (28.9)	
Physical frailty, n (%)				<.001				.003
Yes (n=299)	135 (45.2)	88 (29.4)	76 (25.4)		99 (33.1)	122 (40.8)	78 (26.1)	
No (n=5413)	3523 (65.1)	1316 (24.3)	574 (10.6)		2193 (40.5)	1707 (31.5)	1513 (28)	
Chronic lung disease, n (%)				<.001				<.001
Yes (n=732)	412 (56.3)	195 (26.6)	125 (17.1)		249 (34)	285 (38.9)	198 (27.1)	
No (n=4980)	3246 (65.2)	1209 (24.3)	525 (10.5)		2043 (41)	1544 (31)	1393 (28)	

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Variables	Sleep quality				Sleep duration			
	Good	Fair	Poor	*P* value	Normal	Short	Long	*P* value
Current smoking[d], n (%)				<.001				.005
Yes (n=1216)	845 (69.5)	258 (21.2)	113 (9.3)		524 (43.1)	344 (28.3)	348 (28.6)	
No (n=4496)	2813 (62.6)	1146 (25.5)	537 (11.9)		1768 (39.3)	1485 (33)	1243 (27.7)	
Current drinking[e], n (%)				<.001				.02
Yes (n=1106)	813 (73.5)	187 (16.9)	106 (9.6)		461 (41.7)	314 (28.4)	331 (29.9)	
No (n=4606)	2845 (61.8)	1217 (26.4)	544 (11.8)		1831 (39.8)	1515 (32.9)	1260 (27.3)	
Regular exercise[f], n (%)				<.001				.04
Yes (n=2315)	1561 (67.4)	503 (21.7)	251 (10.9)		971 (41.9)	703 (30.4)	641 (27.7)	
No (n=3397)	2097 (61.7)	901 (26.5)	399 (11.8)		1321 (38.9)	1126 (33.1)	950 (28)	
Own bedroom, n (%)				.12				.91
Yes (n=5410)	3480 (64.3)	1323 (24.5)	607 (11.2)		2174 (40.2)	1732 (32)	1504 (27.8)	
No (n=302)	178 (59)	81 (26.8)	43 (14.2)		118 (39.1)	97 (32.1)	87 (28.8)	
Housing type, n (%)				.33				.13
Detached house (n=3743)	2416 (64.5)	917 (24.5)	410 (11)		1484 (39.6)	1184 (31.6)	1075 (28.7)	
Others (n=1969)	1242 (63.1)	487 (24.7)	240 (12.2)		808 (41)	645 (32.8)	516 (26.2)	
Cooking fuel type, n (%)				.10				.88
Solid fuel (n=2767)	1742 (63)	715 (25.8)	310 (11.2)		1101 (39.8)	891 (32.2)	775 (28)	
Others (n=2945)	1916 (65.1)	689 (23.4)	340 (11.5)		1191 (40.4)	938 (31.9)	816 (27.7)	
Exposure to secondhand smoke, n (%)				.21				<.001
Yes (n=1634)	1034 (63.3)	395 (24.2)	205 (12.5)		615 (37.6)	477 (29.2)	542 (33.2)	
No (n=4078)	2624 (64.4)	1009 (24.7)	445 (10.9)		1677 (41.1)	1352 (33.2)	1049 (25.7)	

[a]For categorical variables, percentages were calculated using the total number of participants in each category as the denominator (row percentages).

[b]*P* value columns indicate that *P* values are reported for each variable overall and are not repeated for individual categories.

[c]For household income, participants with household incomes below the median for their respective living areas (east, central, and west) were classified as "below the median income," whereas those with incomes at or above the median were classified as "at or above the median income."

[d]Current smoking was assessed using the question "Do you smoke at the present?" and was classified as "yes" or "no."

[e]Current drinking was assessed using the question "Do you drink alcohol at the present?" and was classified as "yes" or "no."

[f]Regular exercise was assessed using the question "Do you do exercises regularly at present?" and was classified as "yes" or "no."

Associations Between Indoor Musty Odors and Sleep Outcomes

Table 2 and Figure 1 present the associations between indoor musty odors and sleep outcomes among older adults. In the fully adjusted model (10,449 person-wave observations), exposure to indoor musty odors was significantly associated with higher odds of fair sleep quality (OR 1.19, 95% CI 1.04-1.36; *P*=.01) and poor sleep quality (OR 1.63, 95% CI 1.37-1.95; *P*<.001), compared with good sleep quality. Exposure was also associated with a higher likelihood of short sleep duration (OR 1.36, 95% CI 1.19-1.55; *P*<.001), whereas no significant association was observed for long sleep duration (OR 1.04, 95% CI 0.89-1.21; *P*=.66), compared with optimal sleep duration. Full model results are presented in Table S2 in Multimedia Appendix 1.

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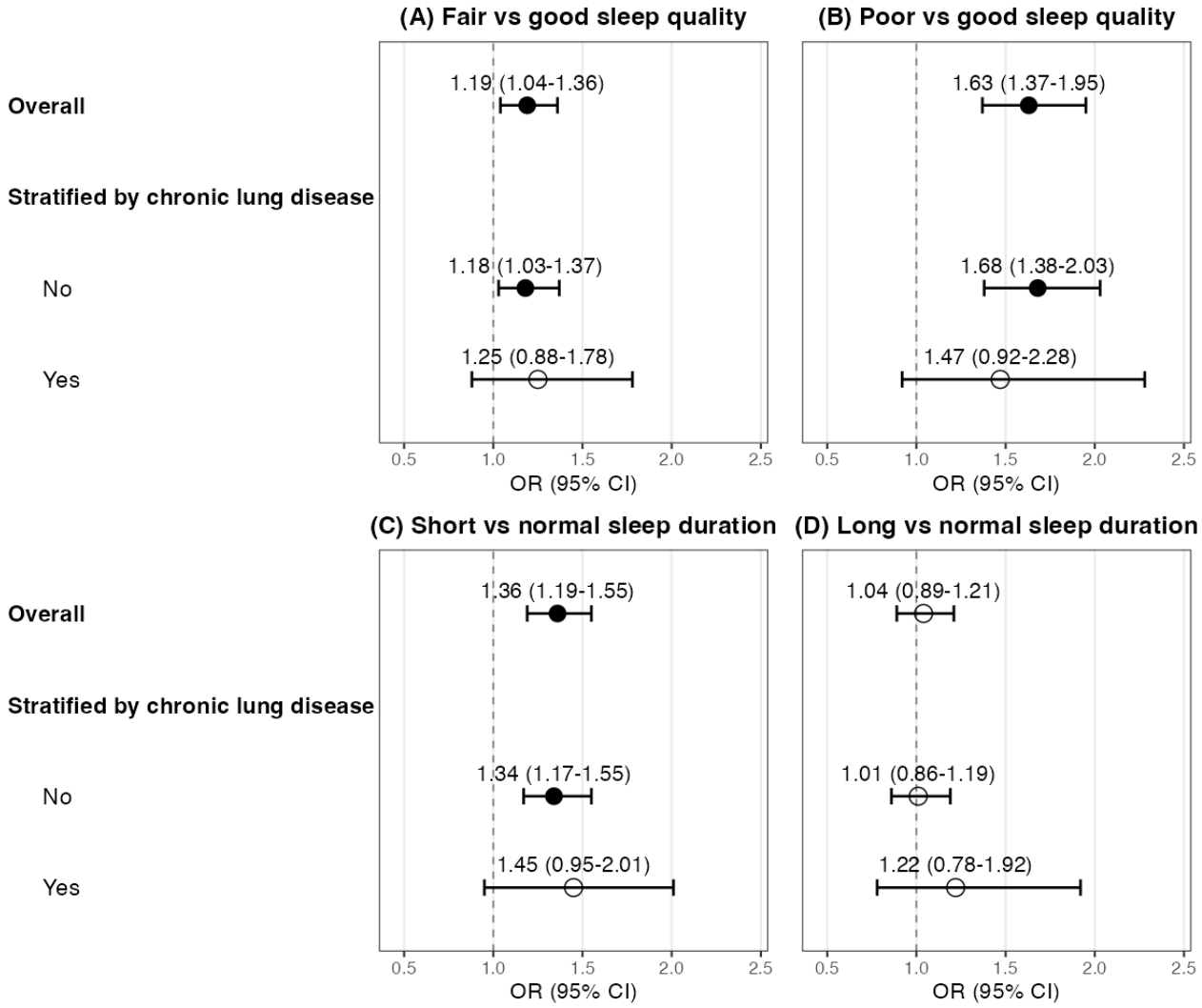
Table 2. Associations between indoor musty odors and sleep outcomes[a].

Model	Sleep quality				Sleep duration			
	Fair vs good		Poor vs good		Short vs normal		Long vs normal	
	OR[b] (95% CI)	*P* value	OR (95% CI)	*P* value	OR (95% CI)	*P* value	OR (95% CI)	*P* value
Overall (10,449 person-wave observations)								
Unadjusted	1.25 (1.10-1.41)	.001	1.73 (1.47-2.03)	<.001	1.41 (1.24-1.59)	<.001	1.06 (0.92-1.22)	.43
Fully adjusted	1.19 (1.04-1.36)	.01	1.63 (1.37-1.95)	<.001	1.36 (1.19-1.55)	<.001	1.04 (0.89-1.21)	.66
Stratified by chronic lung disease								
Without chronic lung disease (9099 person-wave observations)								
Unadjusted	1.23 (1.07-1.40)	.003	1.73 (1.44-2.07)	<.001	1.37 (1.19-1.57)	<.001	1.04 (0.89-1.21)	.65
Fully adjusted	1.18 (1.03-1.37)	.02	1.68 (1.38-2.03)	<.001	1.34 (1.17-1.55)	<.001	1.01 (0.86-1.19)	.96
With chronic lung disease (1350 person-wave observations)								
Unadjusted	1.34 (0.90-1.87)	.08	1.61 (1.10-2.36)	.01	1.55 (1.02-2.08)	.04	1.20 (0.80-1.81)	.38
Fully adjusted	1.25 (0.88-1.78)	.20	1.47 (0.92-2.28)	.12	1.45 (0.95-2.01)	.10	1.22 (0.78-1.92)	.44

[a]Fully adjusted models were adjusted for sociodemographic factors, health-related factors, lifestyle factors, and residential environment factors.
[b]OR: odds ratio.

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Figure 1. Associations between indoor musty odors and sleep outcomes among older adults, overall and stratified by chronic lung disease status. (A) Fair vs good sleep quality. (B) Poor vs good sleep quality. (C) Short vs normal sleep duration. (D) Long vs normal sleep duration. OR: odds ratio.



Stratified Analyses

In stratified analyses by chronic lung disease status, the associations remained statistically significant among participants without chronic lung disease (9099 person-wave observations). In the fully adjusted models, exposure to indoor musty odors was associated with higher odds of fair sleep quality (OR 1.18, 95% CI 1.03-1.37; *P*=.02), poor sleep quality (OR 1.68, 95% CI 1.38-2.03; *P*<.001), and short sleep duration (OR 1.34, 95% CI 1.17-1.55; *P*<.001), while no significant association was observed for long sleep duration (*P*=.96). In contrast, among participants with chronic lung disease (1350 person-wave observations), no statistically significant associations were observed for fair sleep quality (*P*=.20), poor sleep quality (*P*=.12), short sleep duration (*P*=.10), or long sleep duration (*P*=.44) in the fully adjusted models. No statistically significant interaction was observed by chronic lung disease status (*P* for interaction=.92, .56, .61, and .53 for fair sleep quality, poor sleep quality, short sleep duration, and long sleep duration, respectively).

Sensitivity Analysis

In the sensitivity analysis using <6 hours/day to define short sleep duration, the findings were generally consistent with those of the primary analysis. Indoor musty odors remained significantly associated with short sleep duration in the overall sample (OR 1.37, 95% CI 1.17-1.59; *P*<.001) and among participants without chronic lung disease (OR 1.36, 95% CI 1.15-1.61; *P*<.001) but not among those with chronic lung disease (*P*=.11). No significant associations with long sleep duration were observed (*P*=.52, .38, and .70, respectively) (Table S3 in Multimedia Appendix 1).

Discussion

Principal Results

On the basis of nationwide data from the CLHLS (2011-2018), this study found that exposure to indoor musty odors was associated with higher odds of poor sleep quality and short sleep duration among older adults. Similar patterns were observed across subgroups, although the associations appeared more evident among participants without chronic lung disease.

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However, no statistically significant interaction by chronic lung disease status was identified.

In this study, 17.6% (1008/5712) of participants reported indoor musty odors at baseline. Similar prevalence has been reported in other studies, including 18.6% in Canada in 2010 [33] and 13.6% in China in 2018 [11]. In addition, studies using related indicators, such as the presence of mold, have reported prevalence estimates of 15.6% in Japan in 2001 [34] and 9.5% in the United States in 2017 to 2018 [35]. Although the reported prevalence varies across studies, potentially reflecting differences in study period and sample characteristics, the overall evidence suggests that mold-related conditions are relatively common in residential environments.

Our findings suggest that exposure to indoor musty odors was associated with higher odds of fair or poor sleep quality and short sleep duration among older adults, extending existing evidence from prior studies [12,13]. This may be explained by indoor musty odors, often indicative of dampness and mold growth, reflecting the presence of microbial volatile organic compounds and allergens that can induce respiratory irritation, inflammation, or discomfort, particularly affecting the upper airway [36]. Such irritation and inflammation may disrupt normal breathing during sleep and impair sleep continuity, thereby contributing to poorer sleep quality [37]. In addition, airway discomfort may lead to difficulty initiating sleep and early morning awakening, which may explain the higher likelihood of short sleep duration observed in this study. Unpleasant odors themselves may also act as sensory stressors, potentially activating the central nervous system and contributing to discomfort or difficulty initiating and maintaining sleep [38]. Furthermore, chronic exposure to poor indoor environmental conditions may be associated with psychological stress or reduced perceived environmental comfort, both of which are known to adversely affect sleep [39,40]. Taken together, these findings suggest that indoor musty odors may disrupt sleep through respiratory, sensory, and psychological pathways.

Interestingly, the associations between indoor musty odors and sleep outcomes were evident among individuals without chronic lung disease but not among those with chronic lung disease. Several explanations may account for this pattern. First, individuals with chronic lung disease are more likely to experience poorer sleep, as reflected in our sample by higher proportions of fair sleep quality (195/732, 26.6% vs 1209/4980, 24.3%), poor sleep quality (125/732, 17.1% vs 525/4980, 10.5%), and short sleep duration (285/732, 38.9% vs 1544/4980, 31%), compared with those without chronic lung disease at baseline. These underlying conditions, together with persistent respiratory symptoms, may attenuate or mask the additional impact of musty odors, thereby reducing the detectability of the marginal effect of indoor musty odors. Second, individuals with chronic lung conditions may adopt behavioral adaptations, such as improving indoor ventilation or avoiding damp environments to alleviate respiratory symptoms, which may reduce their actual exposure to mold-related pollutants and attenuate observable associations. Third, differential perception of odors and differential reporting of sleep quality and duration may also contribute to the observed differences across groups. Importantly, no statistically significant interaction was observed by chronic lung disease status, indicating no evidence of effect modification despite apparent differences in subgroup-specific estimates. These subgroup differences should therefore be interpreted with caution and may partly reflect limited statistical power, particularly in the subgroup with chronic lung disease. Future studies with larger sample sizes are needed to confirm these findings.

In contrast, no significant association was observed between indoor musty odors and long sleep duration. Previous research has linked dampness- and mold-related exposures primarily to sleep disturbances, including difficulties initiating or maintaining sleep [8], suggesting that these exposures may be more likely to disrupt sleep and contribute to shortened rather than prolonged sleep. Notably, the lack of association with long sleep duration persisted in the sensitivity analysis using an alternative sleep duration threshold, suggesting that this finding was unlikely to be explained solely by the choice of cutoff. However, evidence specifically examining indoor musty odors in relation to long sleep duration remains limited, and further studies are needed to clarify this association.

Implications

Our findings highlight that indoor environmental conditions may represent a practical and modifiable target for promoting sleep health among older adults. Air quality research has traditionally focused on health impacts among individuals with chronic respiratory diseases [41,42]. Extending this perspective, our findings further suggest that associations between indoor musty odors and adverse sleep outcomes may be more evident among individuals without chronic lung disease, although no statistically significant interaction was observed. These results underscore the need for broader public health attention to indoor musty odors, a dampness- and mold-related indicator of indoor air quality, beyond populations with preexisting respiratory conditions. Interventions such as improving household ventilation, reducing indoor dampness, optimizing building conditions, and minimizing exposure to mold-related pollutants may help mitigate the adverse effects of indoor musty odors and improve sleep outcomes [14].

Strengths and Limitations

To the best of our knowledge, this is the first study to examine the associations between indoor musty odors and both sleep quality and sleep duration among older adults, providing novel evidence in this area. In addition, the use of a nationally representative cohort with data collected across 3 waves over a 7-year period enhances the generalizability of the findings. We also conducted stratified analyses by chronic lung disease status, providing additional insights into subgroup-specific patterns. Nevertheless, this study has several limitations. First, sleep quality and sleep duration were assessed using self-reported measures, which may be subject to reporting bias or misclassification; however, we excluded extreme values of sleep duration and participants with cognitive impairment or dementia to minimize potential measurement error. Second, indoor musty odors were also self-reported, and the lack of objective measurements of specific indoor environmental pollutants may limit the precision of exposure assessment. In

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addition, indoor musty odors may reflect broader housing conditions and socioeconomic disadvantage, which could not be fully disentangled from mold-related exposures. Future studies incorporating objective measurements are warranted to validate these findings and better understand the underlying mechanisms. Third, information on sensory-related conditions (eg, olfactory impairment) was not available, which may influence individuals' perception of indoor odors and potentially affect the observed associations. Additionally, residual confounding by psychosocial factors, such as depressive symptoms, anxiety, and perceived stress, cannot be excluded because these factors were not consistently measured across all study waves. Fourth, the relatively small sample size in certain subgroups, particularly in participants with chronic lung disease, may have limited statistical power and reduced the precision of the estimates. Finally, causal relationships cannot be inferred due to the observational nature of the study. However, compared with cross-sectional analyses, the use of GEE models incorporating repeated assessments across 3 waves allowed us to account for within-subject correlation and may provide more robust estimates of associations.

Conclusions

This study provides evidence that exposure to indoor musty odors was associated with higher odds of fair or poor sleep quality and short sleep duration among older adults. These associations appeared more evident among individuals without chronic lung disease, although no statistically significant interaction was observed. Our findings suggest that indoor environmental conditions may play a role in sleep health and could be considered as part of strategies to promote healthy sleep and support healthy aging.

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Data Availability

The data that support the findings of this study are openly available through the Peking University Open Research Data Platform [43].

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Generative AI Use

The authors declare that generative AI was not used in the preparation of this manuscript.

Authors' Contributions

Conceptualization: JB, JL
Data curation: JB, JL
Formal analysis: JB
Investigation: JB, JL
Methodology: JB, PHC, KK, YC, SL, JL
Project administration: JL
Supervision: JL
Validation: SL
Visualization: JB
Writing—original draft: JB
Writing—review & editing: PHC, KK, YC, SL, JL
All authors reviewed and approved the final version of this paper.

Conflicts of Interest

None declared.

Multimedia Appendix 1

Study sample selection (Figure S1), baseline characteristics according to the presence of indoor musty odors (Table S1), associations between indoor musty odors and sleep outcomes (Table S2), and sensitivity analysis of sleep duration (Table S3).
[DOCX File , 132 KB-Multimedia Appendix 1]

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Abbreviations

CLHLS: Chinese Longitudinal Healthy Longevity Survey
FI: frailty index
GEE: generalized estimating equation
IPAW: inverse probability of attrition weights

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OR: odds ratio

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