Indoor Air Pollution and Cognitive Function Among Older Chinese

Abstract:
Background. We examine the negative effects from combustion of solid fuels of indoor air pollution (IAP) on cognitive function among older adults in China. Neurotoxic elements released from solid fuel combustion include particulate matter, gaseous elements, and metals.
Methods. We analyzed data from a national sample of older adults (CHARLS, Chinese Health and Retirement Longitudinal Study) with multilevel regression models to assess effects of current household use of solid fuels on memory, mental status, and global cognitive performance.
Results. More than half of older Chinese rely primarily on coal or biomass for household cooking or heating. We found that use of biomass for heating or cooking is associated with poorer memory, mental status, and global cognitive functioning. Also, we found that use of coal for heating is associated with poorer memory.
Conclusion. IAP is an important but modifiable risk factor for poor cognitive functioning among older Chinese. Public health efforts to reduce IAP with increased access to clean household fuels will be important to reduce the costly burden of care of dementia in China.

Introduction

Air pollution from outdoor and indoor sources negatively affects cognitive function at all ages, though research has only recently focused on older adults (Ailshire & Crimmins, 2014; Clifford, Lang, Chen, Anstey, & Seaton, 2016; Gatto et al., 2014; Peters, Peters, Booth, & Mudway, 2015; Saenz, Wong, & Ailshire, 2018; Weuve et al., 2012; Zeng, Gu, Purser, Hoenig, & Christakis, 2010). In rapidly aging China, some research indicates that middle aged and older adults have appreciably higher levels of cognitive impairment than high-income countries, while other research suggests that levels are comparable (Chan et al., 2013; Jia et al., 2014; Y. Zhang et al., 2012). Prevalence levels of dementia among adults age 60 and older will reach 5.8% in 2020 and 6.7% in 2030, with concomitant rising costs of dementia care (Xu et al., 2017). Exposure to indoor air pollution (IAP) as a major health risk factor in China primarily arises from use of solid fuels for cooking and heating, used by more than half of China's population (Zhang & Wu, 2012). Understanding the social and environmental determinants of cognitive impairment is important to identify modifiable risk factors in order to reduce costs of personal and health care by families and society and to extend the quality of life of older Chinese.

Cognitive functioning

Rapid population aging in China draws attention to the determinants and consequences of physical and cognitive health. Cognitive function includes memory, reasoning, executive function, and the knowing part (Freedman, Aykan, & Martin, 2001). Adequate cognitive function allows continued independence and a positive quality of life among older adults (Langa et al., 2009) . In contrast, compared with other chronic diseases, cognitive impairment makes the larger contribution to disability, and it is the most strongly and independently associated chronic health disorders (Sousa et al., 2009) . Informal care for the persons with cognitive impairment is a heavy burden for family caregivers (Arai et al., 2004) .

Efforts to promote cognitive health among older Chinese is crucial given its millions of older adults and the incomplete health and economic support programs in China. In 2005, the percentage of people age 65 or older in China surpassed 7% for the first time, and quickly increased to 8.91% in 2011 (National Bureau of Statistics of People's Republic of China, 2010). The number of people older than 65 will be 200 and 300 million in 2025 and 2033 respectively, and will be 350 million in 2050, according to China population and development research center (2010). Given the size of the older population, even a small percentage of people with cognitive impairment pose a significant burden of care to families and society (H. Liu et al., 2017). Current government old age support programs are unable to meet the care demands from cognitive impairment, which yields a massive care gap between the need for and supply of elder care (Zhu & Walker, 2018). As a result, families bear the primary responsibility for care provision (Smith, Shen, Strauss, Zhe, & Zhao, 2012; Zhu & Walker, 2018), which produces subjective stress on caregivers especially for a single child who lacks siblings to assist parental care (Wang, Xiao, Li, De Bellis, & Ullah, 2015). Understanding the social and environmental determinants of cognitive impairment, such as IAP, provides insight into potential interventions worth development in order to reduce the risk of cognitive impairment.

Indoor air pollution

Exposure to IAP

Sources of household air pollution in Chinese households primarily are from combustion of coal and biomass fuels for cooking and heating in comparison to clean commercial fuels such as electricity, natural gas, biogas, and liquefied petroleum gas (LPG). Much of the research on IAP from solid fuels in China focuses on cooking fuels (Chen et al., 2018; Hou et al., 2017; Jin Liu, Hou, Ma, & Liao, 2018; Nie, Sousa-Poza, & Xue, 2016; Peabody et al., 2005; Rosenthal, Quinn, Grieshop, Pillarisetti, & Glass, 2018; Saenz et al., 2018). More recently, researchers turned their attention to IAP from use of coal and biomass for heating in China (Baumgartner et al., 2011; Y. L. Jin et al., 2005; Y. Jin et al., 2006; Yeatts et al., 2013; J. Zhang & Smith, n.d.).

Biomass fuels includes agricultural and forestry resources such as straw, wood and animal dung. Biomass may be converted into a clean fuel (biogas) through use of technology such as biodigesters. Burning biomass directly inside the household for heating and cooking carries serious health risks. Because biomass is generally available, with women and children gathering local biomass for household consumption or sale in local markets, it is an affordable fuel. Household use of biomass as a primary cooking fuel is highest in the rural north (62%) and south (59%), but still common in urban areas (19-23%) (Mestl et al., 2007). Zhang & Smith (2005) contend that "in 2003, about 80% of the energy consumed by rural households was in the form of biomass."

Domestic use of coal-based fuels in China was high until 1990s "when cooking coal was extensively replaced" with clean fuels with implementation of the National Improved Stove Project (NISP) (Global Alliance for clean stoves, 2016; World Bank, 2013). Centralized heating systems became much more common in urban areas with implementation of district heating plans, although coal remains the primary source of fuels for district heating production (Tsinghua University & International Energy Agency, 2016). Rural households are most likely to rely primarily on solid fuels for home-heating, particularly using coal in central and northern areas and biomass in the south. As living standards rise, the demand for household heating will increase and thus maintain steady demand for coal, particularly in the colder northern prefectures, which offsets the decline is use of coal for household cooking (Mestl et al, 2007; World Bank, 2013).

Exposure to IAP is prevalent across all regions of China, but appreciably higher in rural areas where more than half of China's population lives. Approximately one third of urban Chinese use either coal (25%) or biomass (10%) as their primary cooking fuel, whereas rural households use higher levels of biomass (60%) but comparable levels of coal (25%) for cooking (World Bank, 2013).

Total use of solid fuels is higher in northern prefectures because colder temperatures prompt solid fuel use for household heating (Global Alliance for Clean Cookstoves, 2016; Hou et al., 2017; Mestl et al., 2007). Use of solid fuels in rural areas will decline only slightly and rural households will continue to rely primarily on them over the next two decades (Hou et al., 2017; International Energy Agency, 2010; World Bank, 2013; Zhang & Wu, 2012). Consequently, exposure to IAP will remain a significant health risk, especially to households in western and northern China.

Older adults are likely more susceptible to the deleterious health effects of IAP because they spend more time indoors when no longer working outside the household or working fewer hours. The exposure is higher among the oldest old and those most frail.

Mestl et al. (2007) calculates age-sex specific exposure to IAP from solid fuel use in China, taking time activity patterns and housing-specific microenvironments in to consideration. They conclude that rural adults age 65 and older have the highest exposures to biomass of all adults. Older adults in the rural south have higher exposure to IAP from coal compared to adults less than age 65. For older Chinese who are currently using clean cooking fuels, most only recently climbed the energy ladder to switch to clean fuels from solid fuels; thus the lifetime exposure to IAP may be higher among those who are currently older than age 65. Greater health risks of IAP for older adults includes higher risk of premature mortality and morbidity, including cognitive impairment from Alzheimer Disease and from the vascular conditions that produce cognitive impairment from vascular dementia.

Negative health impact of IAP

Combustion of coal and biomass fuels releases particulate matter (PM), noxious gases such as carbon dioxide and carbon monoxide, and dangerous elements such as arsenic, selenium, mercury, and fluorides (Baumgartner et al., 2011; Y. Jin et al., 2006; Nie et al., 2016; J. Zhang & Smith, n.d.). IAP is a direct cause of premature mortality (WHO 2016), ranks among the top 10 risk factors for morbidity (Forouzanfar et al., 2016), and is especially detrimental for cerebrovascular health in China (Feigin et al., 2016).

Cognition Prevalence levels of dementia are higher among older adults in northern China compared to the southern region, and among rural elderly relative to the urban elderly (Jia et al. 2014; Wu et al. 2018). Multiple studies demonstrate the neural toxicity of the heavy metals, carbon compounds and PM from IAP on cognition (Ailshire & Crimmins, 2014; Lai et al., 2016; Li et al., 2016; Jianghong Liu & Lewis, 2014; Tyler & Allan, 2014; Vinceti et al., 2014).

Cardiovascular IAP directly raises risks of cardiovascular disease (Nie et al., 2016) which indirectly raises risks of cognitive impairment (Yuan et al., 2016). Vascular dementia is much higher in the northern prefectures than southern ones, consistent with a concomitant exposure to indoor air pollution from coal-based cooking and heating fuels. Vascular dementia is more common in urban than rural areas, whereas Alzheimer Disease is more common among the rural elderly (Jia et al., 2014). IAP results is appreciable risk of short-term and long-term respiratory conditions such as chronic bronchitis, asthma, chronic obstructive pulmonary disease, and lung cancer (Nie et al., 2016; Zhang & Smith, 2005).

METHODS

Data

The current study uses data from the China Health and Retirement Longitudinal Study (CHARLS), which is a panel survey with a nationally representative sample of Chinese residents aged 45 and older (Zhao, Hu, Smith, Strauss, & Yang, 2014). With a multi-stage area probability sampling design, CHARLS fielded its baseline wave in 2011 with a total response rate of 80.5% (Zhao et al., 2014). 10,287 households were sampled in 450 villages/urban communities in 150 counties/districts in 28 of China's provinces excluding Tibet. Within each household, a person older than 45 was randomly selected and surveyed along with his/her spouse. The current study uses the baseline wave and community data from the baseline wave to construct our key variables of interests.

Cognitive functioning

The cognitive health in the CHARLS is assessed using word recall, a Serial 7's subtraction test, and recall of the date and season to assess orientation. This measure of cognitive health has been widely and commonly applied in large-sample community surveys of cognitive function for its short and clear-cut content.

Word recall includes immediate (scored 0 to 10) and delayed word recall (scored 0 to 10). Interviewers read a list of ten nouns, and respondents were asked immediately to recall as many of the words as they could in any order. About ten minutes later, after the respondents had finished measurements of self-reported depression, numeracy, and drawing, they were asked again to recall as many of the original words as possible. The ten words were familiar to the old, like "rice" "clothes" "doctor" and "hand". Orientation includes five questions in this part, from awareness of the date (year, month and day), the day of the week and season of the year. The respondent does not have to answer the year, month and day in order. If the respondent marked the data by the lunar calendar, the date is correct as long as it matches the solar calendar. The orientation score is based on the number of the correct answers, ranging from zero to five. The Serial 7's test asks respondents to successively subtract 7 for five trials, beginning with 100 and ending at 65. Correct subtractions are based on the prior answer given. Even if one trial is wrong, the subsequent trial could be correct, as it is evaluated on the given (perhaps incorrect) answer.

This study created a total cognitive score and 2 separate components of cognitive function: memory and mental status. The numbers of correctly recalled words in the immediate and delayed recall were summed to a memory score ranging from 0 to 20. Similarly, the number of correct answers to the orientation and serial 7's were summed to create a mental status score that ranges from 0 to 10. These two components represent two distinct components of cognitive function and should be investigated separately. The total cognitive score is the sum of memory and mental status score.

Indoor air pollution

Indoor air pollution is assessed by the main source of heating fuel and cooking fuel. Possible cooking fuel includes natural and marsh gas, coal, liquefied petroleum gas, electricity, crop residue/wood burning. We combined natural gas, marsh gas, liquefied petroleum and electric into clean fuel and created a multinomial variable with three categories: clean fuel, coal, and biomass. Heating is not required by law in provinces south of the Huai River and poorer households in the south may be unable to afford optional heating (Mestl et al., 2007). Possible heating fuel includes centralized heating, solar, coal, natural gas, liquefied petroleum gas, electric, crop residue/wood burning, and no heating. We combined centralized heating, solar, natural gas, liquefied petroleum gas, and electricity into clean fuel and created a multinomial variable with four categories: clean fuel, coal, biomass, and no heating.

Control variable

Control variables in the current study include individual level factors and community level factors. Individual-level factors comprise demographic factors, socioeconomic factors, and health factors. Demographic factors include age, gender, and hukou status (household registration). Socioeconomic factors include the year of education and logarithm of household expenditure last year. Household expenditures over the last year show the sum of expenditures on 14 items, for example, clothing, heating, traveling, and education. To deal with zero expenditures, we calculate the variable logarithm of expenditure as the logarithm of expenditure plus one (C. Zhang, Lei, Strauss, & Zhao, 2017).

Health condition is measured by the number of doctor-diagnosed chronic illness and smoking status. The number of chronic diseases is the existence of diseases including hypertension, diabetes or high blood sugar, respiratory, heart disease, and stroke. It ranges from 0 conditions to 5. Smoking status is binary: never smoke (=1) and ever smoked or still smoking (=0).

The community-level factor is the type of community and region. Type of community is community (=1), village (=2), and both community and village (=3). The region is binary: north (=1) and south (=0). Provinces north of the Huai River are exist in a northern climate "heating zone" where heating is required by law. Descriptions of all the variables are provided in Table 1 and Table 2.

Analytical strategy

The current study uses multilevel linear regression models. The data used in the current study are structured hierarchically: The 12284 individuals were nested within 429 communities. Thus, all the respondents were clustered in the community and, therefore, have similar access to heating and cooking fuel, as the availability of gas and distribution of certain fuel is similar within the community. We thus used multilevel models to account for the clustering of respondents within the community.

Total cognitive score and its two components are modeled individually. Analyzing cognitive components separately allows us to determine whether indoor air pollution is associated with cognitive function broadly, or only with specific tasks. Five models are presented for the total cognitive score and each component. In the first model, each score is modeled as a function of only age and gender. The second model includes heating and cooking fuel. The third model adds SES factors including the year of education and household expenditure last year. In the fourth model, we add the health condition (number of chronic diseases) and health behaviors (smoking). The fully adjusted model adjusted for hukou status and community-level factors.

Results

Descriptive results:

Table 1 presents our sample characteristics stratified by reported type of heating fuel. About 30.68% of the sample reported using clean heating fuel, while 27.45% relied on coal, 25.10% relied on biomass, and 16.77% didn't use any heating fuel. Respondents who used coal, biomass, and no heating fuel have a significantly lower mean score across all cognitive assessments than those who used clean fuel as the main heating fuel. Furthermore, compared with those who used clean heating fuel, those who used coal, biomass, and no heating fuel have fewer years of education, lower expenditure last year, and are more likely to have agricultural hukou and more likely to live in a village. Respondents using coal have the lower number of chronic disease than respondents using clean fuel. However, respondents using biomass and no heating fuel have a higher number of chronic diseases than respondents using clean heating fuel. Respondents heating with coal and biomass are more likely to never smoke compared with respondents using clean heating fuel.

The distribution of sample characteristics is shown separately for each cooking fuel in table 2. About 48.09% of the sample reported using clean cooking fuel, while 10.29% relied on coal, 41.62% relied on biomass. According to the t-test, respondents who mainly cook with coal and biomass have a significantly lower mean score across all cognitive assessments than respondents using clean cooking fuel. Years of education and household expenditure last year are lower among respondents cooking with coal and biomass. Respondents cooking with coal and biomass are more likely to have agricultural hukou, more likely to live in a village, and more likely to be in the northern region. Respondents cooking with coal are likely to have more chronic diseases than respondents cooking with clean fuel. Finally, respondents cooking with biomass are more likely to be smokers than respondents cooking with clean fuel.

Regression analyses

Table 3 to Table 5 shows the multilevel regression models of cognitive function. Table 3 focuses on models for memory score. In model 1, older age is associated with lower memory score, male is associated with higher memory score than female. In model 2, using coal, biomass, and no heating fuel is associated with lower memory score. Cooking with biomass is associated with lower memory score. However, cooking with coal is not significantly associated with memory score. In model 3, when the year of education and household expenditure last year is controlled, using coal, biomass, and no heating fuel remains significantly related to lower memory score than using clean fuel but the difference becomes smaller. Cooking with biomass remains significantly associated with lower memory score. We then adjust for the number of chronic disease and smoking status in model 4, the memory score of respondents with coal, biomass, and no heating and score of respondents cooking with biomass remains significantly lower than respondents using clean heating and cooking fuel respectively. This lower memory score remains significant in the fully adjusted model (model 5) when individual hukou status and community factor are controlled.

The multilevel analysis for indoor air pollution and mental status is presented in table 4. Each model in table 4 includes the covariates of the corresponding model in table 3. In model 6, older age is associated with a lower mental status score, being male is associated with a higher mental status score than female. In model 7, using coal, biomass, and no heating fuel is associated with a lower mental status score when age and gender are controlled. Using coal and biomass as cooking fuel is associated with lower memory score than respondents using clean cooking fuel as well. In model 3, when the year of education and household expenditure last year is controlled, respondents using coal, biomass, and no heating fuel remain significantly related to lower memory score but the difference in score reduces. Similarly, respondents cooking with biomass remain significantly related to lower mental status score but the difference in score reduced. However, the difference in mental status score between respondents heating with coal and respondents heating with clean fuel is not significant anymore. The difference in mental status score between respondents cooking with coal and respondents cooking with clean fuel is not significant either. In model 9 and model 10, health conditions, individual hukou status, and community factors are controlled sequentially. The mental status score of respondents using biomass and no heating remains significantly lower than respondents using clean heating fuel. Similarly, the mental status score of respondents cooking with biomass remains significantly lower than respondents cooking with clean fuel.

We also examined the association between indoor air pollution and total cognitive score. Results are shown in Table 5. Each model in table 5 includes the covariates of the corresponding model in table 3. In the fully adjusted model (model 15), respondents using biomass and no heating fuel are significantly associated with a lower total cognitive score than respondents using clean heating fuel. Respondents cooking with biomass show lower total cognitive score than respondents using clean cooking fuel.

Sensitivity analyses

We further conducted sensitivity analyses to test the robustness of our results. First, we stratified our analyses by gender and found that the interaction between gender and cooking fuel and the interaction between gender and heating fuel are significant for mental status but not for memory. The negative association between heating with biomass and mental status score is stronger for female than for male and the negative association between no heating and mental status score is stronger for female than for male as well. Similarly, the negative association between cooking with coal and mental status is stronger for female than for male, as is the same with the association between cooking with biomass and mental status score. Female may be exposed to more indoor air pollution, as they are more likely to be responsible for cooking (Bruce, Perez-Padilla, & Albalak, 2000). Second, we stratified the analyses by cohort and found that the interaction between cohort and cooking fuel and interaction between cohort and heating fuel are significant on total cognitive score and its two subdomains. The negative association of cooking with coal and memory is stronger among the older cohorts than the younger cohorts; however the association between heating fuel and memory is not moderated by cohort. As for mental status, the negative association between heating with coal and mental status score is stronger for the older cohorts than the younger cohorts. The negative association between cooking with coal and mental status score is stronger for the older cohorts than younger cohorts; so as is for the negative association between cooking with biomass and mental status score. This might be partially due to more indoor time of older people (Mestl et al., 2007). Sensitivity analyses results are not presented but are available upon request.

Discussion

In this cross-sectional study of middle-aged and older Chinese, more than half of older Chinese rely primarily on coal or biomass for household cooking and heating. This differed greatly by individual socioeconomic status and type of communities. Respondents with lower years of education, with lower household expenditure, and living in village are more likely to report using biomass and coal fuel. In our analysis, we also found that exposure to IAP was associated with cognitive function after adjustment for individual demographic and socioeconomic factors and community factors. More specifically, use of biomass for heating or cooking is associated with poorer memory, mental status, and global cognitive functioning. Also, we found that use of coal for heating is associated with poorer memory. These results suggest that IAP is an important factor in the cognitive aging of the elderly. Cooking and heating with coal and biomass could be harmful to both memory and mental status.

The current study has several limitations. Firstly, we used a measure of indoor pollution that may be not complete. We were unable to determine full slate of fuels used in CHARLS. Respondents might use multiple sources for heating and cooking, however, they reported only the main cooking and heating fuel that they used. In addition, the current study was not able to control for stove types, pollution dispersion (housing characteristics and ventilation), which also affect the exposure to IAP from solid fuels (Y. Jin et al., 2006). CHARLS did not collect relevant information.

Secondly, total exposure to air pollution is underestimated without direct measures of outdoor air pollution. Outdoor air pollution is also related to cognitive health. Older adults living in areas with severe outdoor air pollution, as measured by higher PM2.5 concentrations, had worse cognitive health (Ailshire & Crimmins, 2014). Our study measured outdoor air pollution indirectly with community type (village, community, and both village and community) and region (north and south). The outdoor PM_{10} was found to be 41.7ug/m^3 higher in the areas north of the Huai River than south of the river, which is partially due to the Huai River heating policy (Ebenstein, Fan, Greenstone, He, & Zhou, 2017). Future studies should directly measure outdoor air pollution to evaluate associations between air quality and cognitive health.

Despite of these limitations, this study contributes to the literature on IAP and cognitive health. To our knowledge, this is one of only a handful of studies to investigate the association between IAP and cognitive health among the elderly using nationally representative sample. Additionally, we study the indoor air pollution and cognitive health among the middle-aged and older Chinese, a population who are likely more susceptible to the deleterious health effects of IAP. Compared with younger population, older people spend more time indoors. Finally, this study measured indoor air pollution with both cooking and heating fuels. Much of the research on IAP from solid fuels in China focuses on cooking fuels though; we turned our attention to IAP from use of coal and biomass for heating.

This study shows a negative association between IAP and cognitive health among the elderly. China needs to accelerate provision and adoption of clean fuels to reduce exposure to harmful gas from combustion of biomass and coal. However, it is undeniable that the coal-based energy structure might persist for years in China given its limited reserve of petroleum and natural gas and the relative abundance of coal. Thus, future study should explore the associations between efficient stove use, air cleanser and cognitive health. Use of clean and efficient stoves might reduce health deleterious effects of poor combustion stoves that use coal and biomass before clean alternative fuel become available.

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Table 1 Descriptive characteristics of adult character by exposure to indoor air pollution from heating (N=12284)

	Clean fuel		Coal			Biomass			No heating		
	Mean	SD	Mean	SD	T-test	Mean	SD	T-test	Mean	SD	T-test
Memory	8.186	3.458	7.439	3.223	-9.746*	6.796	3.187	-19.057*	6.954	3.311	-13.931*
Mental status	8.285	2.013	7.655	2.271	-13.795*	6.886	2.452	-28.088*	7.368	2.370	-16.125*
Total cognitive score	16.471	4.611	15.094	4.542	-13.368*	13.682	4.619	-25.648*	14.322	4.644	-17.468*
Age	57.723	9.427	57.627	9.183	1.321	58.957	9.281	9.426*	58.698	9.670	4.971*
Male	0.478	0.500	0.497	0.500	0.197	0.533	0.499	1.089*	0.511	0.500	0.495
Year of education	5.843	3.324	4.566	3.099	-20.674*	3.522	2.878	-39.066	3.894	3.175	-25.473*
Household expenditure	8.706	1.308	8.282	1.263	-17.803*	7.964	1.369	-27.601*	8.175	1.399	-17.101*
Number of chronic disease	0.579	0.817	0.611	0.839	4.259*	0.489	0.744	-3.166*	0.460	0.728	-4.343*
Never smoke	0.628	0.483	0.574	0.495	-4.326*	0.542	0.498	-5.212*	0.602	0.490	-0.984
Agricultural Hukou	0.515	0.500	0.814	0.389	31.394*	0.951	0.217	54.628*	0.832	0.374	29.509*
Village	0.445	0.497	0.766	0.423	34.937*	0.953	0.212	65.578*	0.807	0.395	34.530*
Community	0.543	0.498	0.228	0.419	-34.796*	0.027	0.162	-68.533*	0.175	0.380	-35.563*
Both village and community	0.012	0.111	0.006	0.079	-1.328	0.020	0.142	3.386*	0.018	0.135	2.811*
North region	0.453	0.498	0.840	0.367	44.935*	0.398	0.490	-5.713*	0.212	0.409	-18.759*
Number of observation	3769 (30.68%)		3372 (27.45%)			3083 (25.10%)			2060 (16.77%)		

Table 2 Descriptive characteristics of adult character by exposure to indoor air pollution from cooking (N=12284)

	Clean fuel		Coal			Biomass		
	Mean	SD	Mean	SD	T-test	Mean	SD	T-test
Memory	7.956	3.402	7.453	3.411	-4.699 *	6.806	3.164	-19.774 *
Mental status	8.126	2.108	7.680	2.254	-9.259 *	6.990	2.423	-27.385 *
Total cognitive score	16.082	4.613	15.134	4.669	-6.854 *	13.796	4.570	-26.564 *
Age	57.453	9.408	58.134	9.290	4.715 *	59.007	9.309	13.057 *
Male	0.486	0.500	0.493	0.500	-0.775	0.524	0.499	1.118
Year of education	5.491	3.287	4.592	3.069	-12.48 *	3.532	2.950	-39.965 *
Household expenditure last year	8.543	1.360	8.354	1.259	-7.44 *	8.041	1.329	-23.752 *
Number of chronic diseases	0.554	0.804	0.616	0.844	3.678 *	0.518	0.766	-1.304
Never smoke	0.617	0.486	0.602	0.490	-0.719	0.550	0.498	-5.146 *
Agricultural Hukou	0.593	0.491	0.775	0.418	13.731 *	0.949	0.220	54.983 *
Village	0.520	0.500	0.751	0.433	17.093 *	0.947	0.225	64.109 *
Community	0.468	0.499	0.237	0.426	-17.114 *	0.038	0.191	-67.024 *
Both village and community	0.013	0.111	0.012	0.108	-0.249	0.016	0.124	3.195 *
North region	0.471	0.499	0.721	0.449	20.291 *	0.490	0.500	3.332 *
Number of observation	4901 (48.09%)		1159 (10.29%)			4164 (41.62%)		

Table 3 Relationship between indoor air pollution and memory (N=12284)

	Model 1	Model 2	Model 3	Model 4	Model 5
Age	-0.098***	-0.094***	-0.066***	-0.064***	-0.068***
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Male	0.295***	0.292***	-0.272***	-0.346***	-0.332***
	(0.055)	(0.055)	(0.056)	(0.075)	(0.075)
Heating fuel					
Coal		-0.420***	-0.226*	-0.226*	-0.194*
		(0.099)	(0.096)	(0.096)	(0.098)
Biomass		-0.623***	-0.299**	-0.302**	-0.195+
		(0.106)	(0.103)	(0.103)	(0.104)
No heating		-0.499***	-0.272**	-0.273**	-0.187+
		(0.103)	(0.100)	(0.100)	(0.100)
Cooking fuel					
Coal		-0.126	-0.032	-0.026	-0.003
		(0.119)	(0.115)	(0.115)	(0.114)
Biomass		-0.446***	-0.186*	-0.188*	-0.099
		(0.083)	(0.081)	(0.081)	(0.082)
Year of education			0.289***	0.290***	0.268***
			(0.010)	(0.010)	(0.010)
Household expenditure last year			0.055*	0.060**	0.056**
			(0.021)	(0.021)	(0.021)
Number of chronic disease				-0.087*	-0.109**
				(0.035)	(0.035)
Never smoke				-0.101	-0.112
				(0.074)	(0.074)
Agricultural Hukou					-0.631***
					(0.105)
Type of community					
Village					-0.232
					(0.149)
Both village and community					-1.902***
					(0.485)
North region					0.257*
					(0.116)
Constant	13.028***	13.358***	9.888***	9.884***	10.679***
	(0.187)	(0.189)	(0.293)	(0.303)	(0.331)
SD (Constant)	1.319***	1.189***	1.061	1.064	1.001
	(0.056)	(0.053)	(0.048)	(0.048)	(0.046)
SD (Residual)	2.985***	2.982***	2.891***	2.890***	2.886***
	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)

Notes: 1) Standard errors in parentheses; 2) $^{+}$ $p < 0.10$, * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

Table 4 Relationship between indoor air pollution and mental status (N=12284)

	Model 5	Model 6	Model 7	Model 8	Model 9
Age	-0.052***	-0.048***	-0.021***	-0.021***	-0.022***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Male	1.118***	1.115***	0.575***	0.618***	0.629***
	(0.037)	(0.037)	(0.037)	(0.049)	(0.049)
Heating fuel					
Coal		-0.229***	-0.061	-0.060	-0.001
		(0.067)	(0.061)	(0.061)	(0.063)
Biomass		-0.633***	-0.345***	-0.345***	-0.278***
		(0.071)	(0.066)	(0.066)	(0.067)
No heating		-0.422***	-0.200**	-0.200**	-0.158*
		(0.069)	(0.064)	(0.064)	(0.065)
Cooking fuel					
Coal		-0.163*	-0.078	-0.078	-0.051
		(0.080)	(0.074)	(0.074)	(0.074)
Biomass		-0.506***	-0.270***	-0.269***	-0.204***
		(0.056)	(0.052)	(0.052)	(0.053)
Year of education			0.276***	0.276***	0.267***
			(0.007)	(0.007)	(0.007)
Household expenditure last year			0.038**	0.038**	0.036**
			(0.014)	(0.014)	(0.014)
Number of chronic disease				-0.015	-0.024
				(0.023)	(0.023)
Never smoke				0.066	0.060
				(0.048)	(0.048)
Agricultural Hukou					-0.191**
					(0.068)
Type of community					
Village					-0.303**
					(0.092)
Both village and community					-0.087
					(0.294)
North region					-0.049
					(0.071)
Constant	10.094***	10.382***	7.219***	7.140***	7.614***
	(0.128)	(0.127)	(0.190)	(0.196)	(0.214)
SD (Constant)	0.968	0.769***	0.600***	0.600***	0.591***
	(0.039)	(0.035)	(0.029)	(0.029)	(0.028)
SD (Residual)	2.018***	2.012***	1.888***	1.888***	1.886***
	(0.013)	(0.013)	(0.012)	(0.012)	(0.012)

Notes: 1) Standard errors in parentheses; 2) $^{+}p < 0.10$, $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Table 5 Relationship between indoor air pollution and total cognitive score (N=12284)

	Model1	Model2	Model3	Model4	Model5
Age	-0.150***	-0.143***	-0.087***	-0.085***	-0.090***
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Male	1.419***	1.411***	0.306***	0.276**	0.298**
	(0.074)	(0.074)	(0.074)	(0.099)	(0.099)
Heating fuel					
Coal		-0.620***	-0.273*	-0.271*	-0.188
		(0.136)	(0.125)	(0.125)	(0.128)
Biomass		-1.216***	-0.627***	-0.630***	-0.463***
		(0.145)	(0.135)	(0.135)	(0.136)
No heating		-0.885***	-0.469***	-0.470***	-0.345**
		(0.141)	(0.131)	(0.131)	(0.132)
Cooking fuel					
Coal		-0.276+	-0.105	-0.099	-0.052
		(0.162)	(0.150)	(0.150)	(0.150)
Biomass		-0.924***	-0.445***	-0.446***	-0.299**
		(0.114)	(0.106)	(0.106)	(0.108)
Year of education			0.564***	0.565***	0.535***
			(0.013)	(0.013)	(0.014)
Household expenditure last year			0.093***	0.098***	0.092***
			(0.028)	(0.028)	(0.028)
Number of chronic disease				-0.103*	-0.133**
				(0.046)	(0.046)
Never smoke				-0.033	-0.051
				(0.097)	(0.097)
Agricultural Hukou					-0.828***
					(0.138)
Type of community					
Village					-0.543**
					(0.194)
Both village and community					-1.991**
					(0.633)
North region					0.205
					(0.152)
Constant	23.140***	23.727***	17.106***	17.022***	18.301***
	(0.260)	(0.259)	(0.383)	(0.397)	(0.433)
SD (Constant)	2.069***	1.719***	1.372***	1.375***	1.303***
	(0.083)	(0.075)	(0.063)	(0.063)	(0.060)
SD (Residual)	4.059***	4.049***	3.791***	3.790***	3.782***
	(0.026)	(0.026)	(0.025)	(0.025)	(0.025)