Alcohol Consumption, Poor Lifestyle Choices and Air Pollution Worsen Cognitive Function in Seniors: a Cohort Study in China

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Research

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Abstract

Background: Based on the complexity of cognitive-related influences and the specificity of Chinese liquor culture, this study aimed to explore the associations and potential interactions between demographic characteristics, alcohol consumption, life and atmospheric environment and cognitive function in seniors through a comprehensive analysis, in order to provide evidence support and feasible recommendations.

Methods: The study sample was selected from the Chinese Longitudinal Healthy Longevity Survey, which included 40,583 seniors aged 65-115 years. Data analysis and processing were performed by R 4.0.4. The relationship between the factors and cognition was modeled and analyzed by generalized additive model, and the interaction was explored by combining the ANOVA.

Results: The generalized additive model confirmed that alcohol consumption was detrimental to the cognitive status of older adults, especially for liquor ($\geq 38^\circ$) and beer. The higher the average daily alcohol consumption, the greater the impairment. SO_2 and $\text{PM}_{2.5}$ showed the same negative effects. In contrast, life environment factors such as good education, balanced diet and positive activity participation had a positive effect on cognition in seniors. In addition, interactions between alcohol consumption and average daily alcohol consumption, frequency of vegetable and meat intake, and between open-air activities and air pollution were also confirmed.

Conclusions: Poor lifestyle choices such as alcohol consumption, unbalanced diet, lower activity participation, and air pollution deteriorate cognitive function in seniors. It is recommended that the elderly population should avoid alcohol consumption, maintain a balanced diet and be physically active. Attention should also be paid to the effects of air quality.

Introduction

Worldwide, the trend of aging is getting more and more serious. China's elderly population will exceed 300 million during the 14th Five-Year Plan, and the country will enter a moderately aging society.[1] By 2050, China, Russia, and many countries in Europe and North America are expected to reach 30% of their elderly populations. [2] The surge in demand for elderly care is sweeping the world.

Among the many health issues of aging, cognitive-related problems (cognitive impairment, dementia, Alzheimer's disease, etc.) are gaining more and more attention. As of 2019, according to the International Alzheimer's Association, there were more than 50 million people with dementia worldwide, and on average, there was a new case of dementia every three seconds.[2, 3] The complex interaction of alcohol, diet, exercise, education, environment, and genetics, among other factors, has a subtle impact on cognitive status.[4–6]

There has been a quiet shift in alcohol consumption patterns globally, with China showing an increase in alcohol consumption.[7] Whether the effects of alcohol consumption on cognitive function are positive or negative has been controversial.[8–10] The complex environment created by many factors and the

interaction between them also needs to be further explored. Therefore, this study examined the cognitive profile of the Chinese seniors in the context of a specific drinking culture (Baijiu), focusing on alcohol, life, and the natural environment. The study aimed to explore the associations and potential interactions between demographic characteristics, lifestyle, atmospheric environment and the cognitive status of the elderly, in order to provide rational recommendations for the health care, as well as to add new evidence to the research in this field.

Methods

Data sources

The sample for this study was obtained from the Chinese Longitudinal Healthy Longevity Survey (CLHLS) 1998–2018 database, covering 23 provinces and municipalities (34 provinces in total). The CLHLS used questionnaires to collect information on aspects such as sociodemographic characteristics, lifestyles, and health. From a total of 8 surveys (i.e., 1998, 2000, 2002, 2005, 2008, 2012, 2014, 2018), 40,583 seniors aged 65–115 years were selected after multiple screening, and the proportion of elderly males was approximately 41.96%. The screening process was shown in Fig. 1.

Cognitive Data

The cognitive status was based on the Mini-mental State Examination (MMSE) used by the CLHLS, which consists of five components: general ability, reactivity, attention and calculation, recall, language, comprehension and self-coordination. The higher the score, the better the cognitive status. Outliers were eliminated by taking into account the individual's true responses, and the screening range was $-3 < \text{MMSE z-score} < 3$ (after adjustment for gender and age).

Alcohol consumption data

The alcohol consumption data covered three main components, namely, drinking status, alcohol categories and average daily drinking volume (unit: tael/day, 1 tael = 50 ml). Among them, the drinking status was divided into three categories according to the current or past drinking habits of the elderly: never drank, ever drank (abstainers) and long-term drank (non-abstainers). The categories of alcoholic beverages were separated into six main categories, namely liquor ($\geq 38^\circ$), liquor ($< 38^\circ$), wine, rice wine, beer and other types of alcoholic beverages.

Atmospheric data

The atmospheric environment includes two indicators: sulfur dioxide (SO_2 , unit: million tons), which represents total industrial and domestic emissions and was collected from the China Statistical Yearbook,[11] and fine particulate matter ($\text{PM}_{2.5}$), which was composed of data from Tracking air pollution in China (TAP)[12–15] and the Socioeconomic Data and Applications Center (SEDAC) (both publicly available),[16] recorded in terms of concentration ($\mu\text{g}/\text{m}^3$). Of these, the $\text{PM}_{2.5}$ data for 2000–2018 used data aggregated by TAP, and the data for 1998 were derived from SEDAC's extrapolated data.

Other data

The living environment mainly contained the current dietary and activity habits of the elderly. For diet, the frequency of vegetable and fruit intake was classified into four levels from high to low, representing high frequency consumption, regular consumption, occasional consumption, and rarely consumption. The rest of the food items were categorized as "high frequency", "occasionally" and "rarely". Activity participation was similarly divided into three levels (high frequency, occasional and rarely participation), while the overall status of exercise was graded according to never exercised, ever exercised and long-term exercised. In addition, educational level referred to the length of schooling. Data on economic indicator (per capita consumption of food, tobacco and alcohol) was obtained from the China Statistical Yearbook. [11]

Statistics analysis

R 4.0.4 was applied to data analysis and processing. The generalized additive model (GAM) was applied to model the association between cognitive status and various factors in seniors. The interaction was further studied in combination with "anova.gam" (similar to the type III ANOVA). A probability level of $p < 0.05$ represented the result with statistical significance.

GAM model

The study used the generalized additive model to analyze the association between cognitive status and influencing factors such as drinking habits, living environment, and atmospheric environment in older adults. Its principle is to minimize residual while maximizing simplicity. Some or all of the independent variables in the regression model adopt (spline) smoothing function to reduce the model risk caused by linear settings.[17–19] We used stepwise regression method (direction: both) to screen the 36 variables and 18 interaction terms initially selected. The final model incorporated a total of 33 variables and 5 interaction terms, and the model was as follows.

Cognitive score $\sim$ s(age) + s(education level) + gender + ethnicity + occupation + type of residence + residence status + stroke/cerebrovascular disease prevalence + alcohol consumption status + type of alcohol + s(average daily alcohol consumption) + smoking status + fruit intake + vegetables intake + meat intake + fish intake + eggs intake + legumes intake + pickles intake + sugar intake + garlic intake + exercise status + s(years of exercise) + housework participation + open-air activities + reading + raising animals + mahjong + television/radio + community activities + s(per capita consumption expenditure on food and tobacco and alcohol) + s(SO₂) + s(PM_{2.5}) + vegetables intake: alcohol consumption status + meat intake: alcohol consumption status + alcohol consumption status: average daily alcohol consumption + open-air activities: SO₂ + open-air activities: PM_{2.5}

where "s()" denotes a (spline) smooth transformation function, which was used to help set up a model using spline based smooths.

Further, we used "anova.gam" to perform hypothesis testing (similar to the type III ANOVA) on the factors of the fitted model to clarify the role of the interaction term. Meanwhile, with the help of the fitted GAM model, we analyzed the change in the effect of the interaction variables by fixing the value of one of the variables in the interaction term (e.g. the value of alcohol consumption status was adjusted to "never drank", while all other variables remained unchanged), in order to determine the interaction effect between them.

Results

A total of 40,583 Chinese seniors aged 65–115 years were included in this study (elderly males: 41.96%), with a mean age of 86.64 (11.34) and a ratio of 1:2.87 between the older persons and the oldest old (with 80 years as the cut-off point [20]). The mean MMSE score among all seniors was 24.21 (6.29). Moreover, 11,294 seniors had drinking habits (including former and long-term drinkers) with a mean age of 85.46 (11.16), of which older males accounted for approximately 70.38%. High-level liquor ($\geq 38^\circ$) was the most preferred alcoholic product among the Chinese elderly population, with its share reaching 45.82%, far exceeding other categories. Their average daily alcohol consumption, on the other hand, was mostly concentrated in the range of 1–3 tael/day (upper and lower quartiles).

The GAM model showed a statistically significant association between individual cognitive levels (MMSE scores) and various environmental indicators ($R_{adj}^2 = 0.412$, Deviance explained = 41.3%, GCV = 23.369).

The cognitive status showed a clear trend of decline with age, and the decline was particularly pronounced in the advanced age. In contrast, the male group and the Hui elderly had a better cognitive level. Educational attainment also released a positive signal: individuals with longer schooling tended to have higher cognitive levels, and the effect of education was particularly pronounced at the initial stage. This was also reflected in the work, where management workers, service workers, workers, farmers, and jobless individuals had poorer cognitive profiles in old age compared to those in highly skilled professions (professionals, doctors, teachers, etc.).

In addition, although the effect was minimal, the cognitive status of the elderly living in the city was slightly worse than that of the group in the countryside. In terms of living environment, the cognitive status of the elderly living alone was better than that of those living with family members, while the situation of seniors living in the rest home was worse. There was also a difference in the prevalence of stroke or cerebrovascular disease (CVDs), with the results confirming that cognitive performance was worse among those who suffered from these diseases. Detailed results were shown in Fig. 2 (a-b), Table 1–2.

Table 1
Approximate significance of GAM model smooth terms

Smooth terms	edf	Ref.df	<i>F</i>	<i>p</i> -value
s(Age)	8.5336	8.888	570.386	0.000
s(Education level)	4.8094	5.697	37.949	0.000
s(Drinking volume)	0.8129	1.170	144.224	0.000
s(Activity years)	6.1656	7.250	8.442	0.000
s(Per capita expenditure on food, tobacco and alcohol)	6.7015	7.738	8.061	0.000
s(SO ₂ emissions)	7.2377	7.990	35.026	0.000
s(PM _{2.5} concentration)	6.8564	7.880	77.296	0.000

Table 2
Demographic characteristics variables of the GAM model

Factor	Estimate	Std. Error	t-value	p-value
Gender. female	-1.240	0.066	-18.820	0.000
Ethnicity				
Han	Reference			
Hui	1.112	0.273	4.076	0.000
Zhuang	-0.007	0.142	-0.048	0.962
Yao	-0.638	0.428	-1.490	0.136
Korean	1.487	1.294	1.149	0.250
Manchu	0.237	0.342	0.692	0.489
Mongolian	0.243	1.459	0.167	0.867
Others	0.354	0.242	1.459	0.145
Occupation				
Technical staff / doctor / teacher	Reference			
Administration	-0.407	0.177	-2.300	0.021
General employee / service staff / workers	-0.376	0.143	-2.638	0.008
Freelancer	0.247	0.226	1.089	0.276
Farmer	-0.615	0.145	-4.245	0.000
Domestic worker	-0.091	0.160	-0.570	0.569
Military personnel	-0.197	0.315	-0.626	0.532
Unemployed	-0.528	0.173	-3.063	0.002
Others	-0.239	0.223	-1.069	0.285
Type of residence				
City	Reference			
Town	0.030	0.073	0.415	0.678
Village	0.073	0.076	-2.506	0.012
Current living conditions				
Living with family (including caregiver)	Reference			
Living alone	0.242	0.074	3.274	0.001

Factor	Estimate	Std. Error	t-value	p-value
Living in a rest home	-0.456	0.137	-3.321	0.001
Prevalence of stroke / CVDs (self-reported)				
Prevalent	Reference			
Not prevalent	0.690	0.110	6.287	0.000
Unknown	0.277	0.163	1.696	0.090

Studies have demonstrated that alcohol consumption can have some negative cognitive effects, both in abstinent and chronic drinkers. Among them, both liquor ($\geq 38^\circ$) and beer showed significant negative effects (compared to non-alcoholic beverages). In contrast, a weak beneficial effect was detected for wine. On the other hand, the cognitive level decreased substantially with the increase in the average daily alcohol consumption. The results are shown in Table 2 and Fig. 2 (c).

The living environment indicators covered two main aspects: dietary and activity habits. The results demonstrated that a more balanced and comprehensive nutritional intake was more beneficial for cognitive development. Compared to high frequency intake, low frequency intake of fruits, vegetables, meat, fish, legumes and pickles were not beneficial for cognition. In contrast, moderate frequency of egg intake and low frequency of sugar intake were more helpful. The results were shown in Table 3.

Table 3
Living environment variables (diet component) of the GAM model

Factor		Estimate	Std. Error	t-value	p-value
Never drank		Reference			
Ever drank		-0.403	0.149	-2.709	0.007
Long-term drank		-0.218	0.108	-2.020	0.043
Categories of alcohol					
Non-alcoholic beverages		Reference			
Liquor ($\geq 38^\circ$)		-0.224	0.085	-2.631	0.009
Liquor ($< 38^\circ$)		-0.204	0.106	-1.919	0.055
Wine		0.303	0.153	1.978	0.048
Rice wine		0.063	0.114	0.552	0.581
Beer		-0.570	0.235	-2.427	0.015
Others		0.012	0.220	0.054	0.957
Never smoked		Reference			
Ever smoked		0.124	0.083	1.497	0.134
Long-term smoked		-0.006	0.075	-0.077	0.938
Dietary situation (details)					
High frequency consumption (almost daily)		Reference			
Fruit	Regularly	0.011	0.089	0.123	0.902
	Occasionally	-0.032	0.080	-0.397	0.691
	Rarely	-0.674	0.089	-7.614	0.000
Vegetable	Regularly	-0.254	0.072	-3.505	0.000
	Occasionally	-1.200	0.095	-12.697	0.000
	Rarely	-1.764	0.167	-10.534	0.000
Meat	Occasionally	-0.220	0.073	-3.029	0.002
	Rarely	-0.294	0.094	-3.130	0.002
Fish	Occasionally	-0.317	0.067	-4.707	0.000
	Rarely	-0.618	0.079	-7.862	0.000
Egg	Occasionally	0.125	0.063	1.972	0.049

Factor		Estimate	Std. Error	t-value	p-value
Legume	Rarely	0.067	0.084	0.798	0.425
	Occasionally	-0.141	0.059	-2.390	0.017
Pickle	Rarely	-0.419	0.080	-5.210	0.000
	Occasionally	-0.058	0.065	-0.893	0.372
Sugar	Rarely	-0.316	0.062	-5.090	0.000
	Occasionally	0.113	0.064	1.775	0.076
Garlic	Rarely	0.162	0.064	2.534	0.011
	Occasionally	0.097	0.065	1.490	0.136
	Rarely	0.040	0.068	0.587	0.557

The activity participation of the elderly also played a crucial role. The results in Table 4 indicated that the cognitive level of seniors was better when they were more active. Active participation in housework, open-air activities, reading, raising animals, mahjong, television/radio, and community activities had the positive effect on cognitive performance in seniors. Meanwhile, the habit of long-term exercise would be equally beneficial (Fig. 2 (d)).

In addition, a negative association was found between economic indicator (per capita consumption expenditure on food, tobacco and alcohol) and cognition (Fig. 2 (e)).

The results in Fig. 2 (f-g) illustrated the negative association between SO₂ emissions, PM_{2.5} concentrations, and cognitive status of the elderly. The cognitive status deteriorated sharply with the increase of emissions and concentrations.

Based on the above GAM model, combined with the results of the ANOVA (anova.gam), it was confirmed that there were five interactions affecting the elderly's cognitive status. They were frequency of vegetable intake and alcohol consumption, frequency of meat intake and alcohol consumption, alcohol consumption and average daily alcohol consumption, SO₂ emissions and open-air activity, and PM_{2.5} concentration and open-air activity. Among them, the interaction between open-air activity and air pollution indicators was mainly reflected by the fact that open-air activity was more beneficial to perception at low pollutant concentrations (or emissions), while it showed the opposite effect at high concentrations. The exact mechanism of the effect of other interaction terms could not be clarified for the moment (the results for alcohol consumption were not statistically significant after adjusting for the interaction variables). Details were shown in Figs. 3–4 and Table 5.

Table.4 Living environment variables (activity component) of the GAM model

Factor		Estimate	Std. Error	t-value	p-value
Never exercised		Reference			
Ever exercised		-0.127	0.218	-0.582	0.560
Long-term exercised		0.499	0.194	2.575	0.010
Activity participation (details)					
High frequency of participation		Reference			
Housework	Occasionally	-0.456	0.077	-5.889	0.000
	Rarely	-1.462	0.068	-21.464	0.000
Open air	Occasionally	-0.162	0.181	-0.894	0.371
	Rarely	-0.421	0.155	-2.716	0.007
Read	Occasionally	-0.086	0.114	-0.756	0.450
	Rarely	-0.312	0.101	-3.070	0.002
Raising animals	Occasionally	-0.191	0.106	-1.797	0.072
	Rarely	-0.443	0.075	-5.901	0.000
Mahjong	Occasionally	-0.049	0.127	-0.383	0.701
	Rarely	-0.747	0.111	-6.746	0.000
TV / radio	Occasionally	-0.478	0.067	-7.130	0.000
	Rarely	-1.848	0.068	-27.169	0.000
Community	Occasionally	-0.117	0.156	-0.750	0.453
	Rarely	-0.417	0.145	-2.886	0.004

Table. 5 Results of interaction terms in ANOVA

Interaction terms	df	F	p-value
Vegetable consumption & Drink	6	4.298	0.000
Meat consumption & Drink	4	6.263	0.000
Drink & Drinking volume	2	112.843	0.000
Open air activity participation & SO ₂ emissions	3	70.964	0.000
Open air activity participation & PM _{2.5} concentration	3	167.825	0.000

Discussion

The study conducted a comprehensive analysis of numerous factors associated with cognition in older adults, and the results revealed the influence of demographic characteristics, various environmental factors, and also uncovered some potential interactions. It was found that Hui seniors possessed higher cognitive scores (i.e., better cognitive levels) compared to Han seniors. Similar findings were confirmed in a 2019 study of Parkinson's disease patients, whose results illustrated that the Hui population had better recall domain function than the Han population.[21] Furthermore, the unique lifestyle and dietary habits of the Hui people (non-smoking and alcohol consumption, high consumption of fish, eggs and dairy foods, neighborhood interaction, and martial arts practice [22]) may also be relevant. In addition, the study similarly yielded results on demographic characteristics consistent with previous studies (negative effects of female, higher age, stroke and CVDs).[4, 23, 24]

Healthy cognitive development relies on a benign environment. This is reflected not only in the living environment such as diet, exercise, and living conditions, but also in the atmospheric environment and the social environment such as education. This study found that as individuals schooling time increases, so does their cognitive level, especially in the early years of education. The process of knowledge acquisition is also a process of brain development, and a good education means a better cognitive reserve.[25–27] A recent study explored the association between education level and [^{18}F]-fluorodeoxyglucose positron-emission-tomography (FDG-PET) hypometabolism.[28] This corroborated the association between high education level and relatively high cognitive performance. Moreover, this effect was also reflected in occupation—more specialized workers had a better cognitive level in old age.

Alcohol consumption in China has been rising in recent years.[7] Results based on more than 40,000 Chinese seniors revealed that alcohol consumption was detrimental to the development of cognition of elderly people, as well as excessive food and tobacco consumption. This was consistent with the findings of several previous studies.[29, 30] However, further refinement of the alcohol categories found that the negative effects were more likely to come from liquor ($\geq 38^\circ$) and beer. In contrast, wine showed a weak positive effect. In the context of China's unique baijiu culture, baijiu has a large audience in China, compared to the small number of people who drink wine may be the cause of this phenomenon. Alcohol affects individual cognitive function mainly through its neurotoxic effects, which may be mediated directly through damage to brain structures, or indirectly through malnutrition, metabolite toxicity, electrolyte imbalance, and adverse physiological disorders.[31] The effects brought about by ethanol on brain neurochemistry, as well as the neurochemical effects themselves, are highly dose- and time-dependent.[32] The risk of cognitive impairment and dementia is further exacerbated by high levels of ethanol intake.[33, 34]

Albeit the protective effect of alcohol on cognition cannot be dismissed in its entirety, the issue cannot be further corroborated. It is worth affirming that heavy alcohol consumption will definitely affect the benign development of individual health.[35–37] A recent study published in the *Lancet Oncology* confirms that

even small amounts of alcohol consumption can increase the risk of cancer.[38] In conclusion, we strongly recommend that the elderly population should avoid alcohol consumption.

As for the interactions associated with alcohol consumption, although their existence has been confirmed, the results of the alcohol consumption were not statistically significant after the variable adjustment, so it is not possible to clarify the specific mechanisms of these three interactions with the available results. This section needs to be further explored.

In addition, a balanced dietary pattern and active exercise habits have been highly recommended. The Mediterranean dietary pattern (vegetables and fruits, seafood, legumes, etc.) and good exercise habits were effective in improving the cognitive status of the elderly.[39–41] Differently, we found that the high frequency of meat consumption was beneficial to the cognitive level of seniors. This may have been influenced by factors such as famine (1959–1961) and living conditions during the early years. All of the elderly population included in the study were born before the 1940s. The environment of extreme food deprivation had a profound impact on the elderly. In addition, there were also studies confirming that different dietary patterns act on different fields of cognitive function: vegetables were more beneficial for memory capacity, while meat was more helpful in slowing down the decline of attention.[42] All of these revealed the importance of a balanced nutritional intake.

Whether rural residents or living alone (farming, self-care), or high-frequency activity participation, they invariably increase the high-cognitive load of the elderly. Exercise with high cognitive load enhances the functional connectivity of the superior frontal gyrus and prefrontal cortex at rest and reduces the functional connectivity of the middle occipital gyrus and postcentral gyrus, thus delaying cognitive decline.[43] As for the urban-rural differences, the effect of education was not observed in the Chinese elderly population because of the generally low level of education received in their early life. However, earlier research has confirmed that the impact of education was more profound than the activity factor, [27] so it is essential to enhance education for all age groups. Relevant government departments should continue to implement the requirements of the *Development Plan for Geriatric Education*,[44] further expand the supply of geriatric education resources and strengthen the corresponding service support through measures such as geriatric universities and free open museums, in order to comprehensively improve the quality of life and living of the elderly.

A growing number of studies have shown a negative correlation between air pollutant exposure (long-term or short-term) and individual cognitive function, especially PM_{2.5}. [45–47] The results of our study also confirmed these findings. Air pollution reduces individuals' cognitive-related semantic memory and visual construction abilities.[47, 48] It can enter the body through the respiratory tract, gastrointestinal tract and blood-brain barrier,[49] causing changes in the body's gray matter, white matter and total brain volume,[50] and further impairing cognitive functions through oxidative stress[51] and neuroinflammation.[49] In particular, people with different levels of cognitive function are affected differently by air pollution exposure—the lower the individual's basal cognitive function, the greater the impact of exposure on cognition.[45] This study also found interactions between open-air activities and

SO₂ emissions and PM_{2.5} concentrations. When pollutant concentrations (or emissions) were low, the positive effects of exercise overwhelmed the negative effects of air pollution, whereas when pollutant concentrations (or emissions) were high, the act of regular open-air activity instead impaired cognitive function. This was consistent with the results of previous studies.[45, 52] Therefore, the effects of environmental factors should also be considered when advocating exercise for seniors. Documents such as the *Chinese Health Guidelines for the Elderly (2013 edition)* [53] also need to be further updated.

Due to the limitation of data, we could not know the specific urban areas where the study subjects were located. Therefore, the atmospheric indicators involved in the study were provincial data and could not be further refined. This also reduced the accuracy of the study results to some extent. The types of atmospheric environmental indicators and disease data also need to be enriched. In addition, we did not obtain the relevant genetic data, which is a crucial part of the study.[54, 55]

Conclusion

Poor lifestyle choices such as alcohol consumption, unbalanced diet, low activity participation, and air pollution played a significant negative role in the development of cognitive function in the elderly. In light of the available findings, we strongly recommend that the seniors should avoid alcohol intake and adopt a more balanced dietary pattern. The effects of air quality should be taken into account in addition to physical activity, and activities should be arranged appropriately. Meanwhile, educational resources for the elderly population should be further enriched in order to improve the quality of life, with a special focus on the elderly with no educational background. In addition, the relevant departments should continue to implement the *Elderly Education Development Plan, Health China 2030* and other policy requirements, and the corresponding health guidelines should be updated. We suggested that the recommendation of moderate alcohol consumption in the guidelines should be revised, and the guidance related to air pollution should be added.

Declarations

Ethics approval and consent to participate

The Research Ethics Committees of Peking University (number IRB00001052-13074) and Duke University granted approval for the CLHLS, including collections of questionnaire data with written informed consent before participation. The study was performed in accordance with the Declaration of Helsinki. This study only showed the secondary aggregated data, and we did not include any data of their personal information, including name, identity information, address, telephone number, etc. None of the authors in this study had access to identifying patient information during the analysis of the data.

Consent of publication

Not applicable

Availability of data and materials

The datasets generated and/or analyzed during the current study are available in the Peking University Open Research Data repository.

<https://opendata.pku.edu.cn/dataset.xhtml?persistentId=doi%3A10.18170%2FDVN%2FWBO7LK>

Competing interests

The authors declare that they have no competing interests.

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Author's Contributors

LH and JJ conceived and designed the study. LH collected the source data of the study. LH and JJ prepared software and performed the statistical analysis. LH prepared the manuscript and interpreted the data. JJ assisted with the editing of the paper and provided critical comments. JJ revised it critically for important intellectual content. All authors read and approved the final manuscript.

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The funder of the study had no role in the study design, data collection, data analysis, data interpretation, or writing of the report. The corresponding authors had full access to all the data in the study and had final responsibility for the decision to submit for publication.

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Figures

Figure 1

Flow chart of the sample screening process. a The survey years covered by CLHLS are: 1998, 2000, 2002, 2005, 2008/2009, 2011/2012, 2014 and 2017/2018/2019. b The variables involved in this part mainly cover demographic characteristics, living environment, air pollution indicators and some economic indicators. c The screening range for the MMSE score was $-3 < \text{MMSE z-score} < 3$ (after adjustment for gender and age).

Figure 2

Smooth function in GAM model

Figure 3

Interaction between air pollution, average daily alcohol consumption and alcohol consumption status. a The effect reflected the level of individual cognition.

Figure 4

Interaction between diet and alcohol consumption status. a The effect represented the coefficient of the variable of interest.