Alcohol consumption, poor lifestyle choices, and air pollution worsen cognitive function in seniors: a cohort study in China

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Abstract
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. 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. The generalized additive model confirmed that alcohol consumption was detrimental to the cognitive status of older adults, especially for liquor (≥ 38°) and beer. The higher the average daily alcohol consumption, the greater the impairment. SO2 and PM2.5 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. 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.

Keywords Alcohol consumption · Cognitive function · Seniors · Air pollution · Lifestyle · Interaction

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 (China 2020). By 2050, China, Russia, and many countries in Europe and North America are expected to reach 30% of their elderly populations (WHO 2016). 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 3 s (International 2019; WHO 2016). The complex interaction of alcohol, diet, exercise, education, environment, and genetics, among other factors, has a subtle impact on cognitive status (Wang et al. 2020a; Wesselman et al. 2020; Wu et al. 2020).

There has been a quiet shift in alcohol consumption patterns globally, with China showing an increase in alcohol consumption (Manthey et al. 2019). Whether the effects of alcohol consumption on cognitive function are positive or negative has been controversial (Fischer et al. 2018; Hogenkamp et al. 2014; Lopes et al. 2010). 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.

Materials and 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, and 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 $-3 < \text{MMSE } z \text{ score} < 3$ (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 ($\geq 38\%$), liquor ($< 38\%$), wine, rice wine, beer, and other types of alcoholic beverages.

Atmospheric data

The atmospheric environment includes two indicators: sulfur dioxide ($\text{SO}_2$, unit: million tons), which represents total industrial and domestic emissions and was collected from the China Statistical Yearbook (Statistics 2020), and fine particulate matter ($\text{PM}_{2.5}$), which was composed of data from tracking air pollution in China (TAP) (China 2021; Geng et al. 2021; Xiao et al. 2021a, b) and the Socioeconomic Data and Applications Center (SEDAC) (both publicly available) (Center for International Earth Science Information Network 2021), recorded in terms of concentration ($\mu g/m^3$). 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 (Statistics 2020).

Statistics analysis

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

Linear model and generalized additive model

The study used linear and 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. The comparison revealed that the linear model fit was weak \((R^2_{adj-LM} = 0.395, R^2_{adj-GAM} = 0.412)\) and that there were more non-linear associations between cognition and the factors. Therefore, GAM was used as the main analytical method for the study (see Additional file 1 for details of the linear model section.)

A generalized additive model can be written as follows:

\[
g(\mu_i) = \beta_0 + f_1(x_{i1}) + f_2(x_{i2}) + f_3(x_{i3}) + \cdots + f_p(x_{ip})
\]

where \( \mu_i = E(Y_i) \) and \( Y_i \) is a response variable that follows some exponential family distribution, \( f_p \) are smooth functions of the continuous independent variable \( x_i \) (e.g., “smoothing splines,” which are splines with knots at each different value of the variable). The principle of GAM is to minimize residual while maximizing simplicity. Some or all of the independent variables in the regression model adopt smoothing function to reduce the model risk caused by linear settings. The model flexibly illustrates the dependence of the response on the independent variables through “smoothing functions” rather than detailed parameter relationships. (Chiang 2007; Venables and Dichmont 2004; Wood and Augustin 2002) If interactions are considered, the model can be written as follows:

\[
g(\mu_i) = \beta_0 + \sum_{j=1}^{p} f_j(x_{ij}) + \sum_{j \neq k} f_{jk}(x_{ij}, x_{ik})
\]

We used stepwise regression method (direction: both) to screen the 38 variables and 18 interaction terms initially selected. The final model incorporated a total of 33 variables and 5 interaction terms (detailed information was shown in the Additional file 2).

Furthermore, 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, 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 (WHO 2000)). 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 (≥ 38°) 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 showed a statistically significant association between individual cognitive levels (MMSE scores) and various environmental indicators \( (R^2_{adj} = 0.412, \text{Deviance explained} = 41.3\%, \text{GCV} = 23.369) \).

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. 2a and b; Tables 1 and 2.

Studies have demonstrated that alcohol consumption can have some negative cognitive effects, both in abstinent and chronic drinkers. Among them, both liquor (≥38°) 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

| Smooth terms                                      | edf | Ref.df | F     | p 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(years of exercise)                              | 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(SO₂ emissions)                                  | 7.2377 | 7.990 | 35.026 | 0.000   |
| s(PM₂.₅ concentration)                           | 6.8564 | 7.880 | 77.296 | 0.000   |

Fig. 2 Smooth function in GAM
average daily alcohol consumption. The results are shown in Table 2 and Fig. 2c.

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.

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. 2d).

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

The results in Fig. 2f and g illustrated the negative association between SO₂ emissions, PM₁₀ concentrations, and cognitive status of the elderly. The cognitive status deteriorated sharply with the increase of emissions and concentrations.

Based on the above GAM, 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

| Table 2 | Demographic characteristics variables of the GAM |
|---------|-----------------------------------------------|
| 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   |
| 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   |
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 and 4 and Table 5.

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

| Factor                          | Estimate | Std. error | t value | p value |
|--------------------------------|----------|------------|---------|---------|
| Exercise situation             |          |            |         |         |
| 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|          |            |         |         |
| 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   |

Fig. 3  Interaction between air pollution, average daily alcohol consumption, and alcohol consumption status. a The effect reflected the level of individual cognition.
function than the Han population (Yao et al. 2019). 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 (Zang 2007)) 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) (Choi et al. 2020; Kapusta et al. 2020; Wang et al. 2020a).

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 (Borroni et al. 2009; Rodriguez et al. 2019; Rouillard et al. 2017). A recent study explored the association between education level and [18F]-fluorodeoxyglucose positron-emission-tomography (FDG-PET) hypometabolism (Beyer et al. 2021). 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 (Manthey et al. 2019). 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 (Jarvenpaa et al. 2005; Zhou et al. 2003). However, further refinement of the alcohol categories found that the negative effects were more likely to come from liquor (≥ 38°) 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 (Neiman

![Diagram](image_url)

**Fig. 4** Interaction between diet and alcohol consumption status. a The effect represented the coefficient of the variable of interest

| Interaction terms                                      | df   | F     | p value |
|--------------------------------------------------------|------|-------|---------|
| Vegetable consumption and drink                        | 6    | 4.298 | 0.000   |
| Meat consumption and drink                             | 4    | 6.263 | 0.000   |
| Drink and drinking volume                              | 2    | 112.843 | 0.000  |
| Open air activity participation and SO2 emissions      | 3    | 70.964 | 0.000   |
| Open air activity participation and PM2.5 concentration | 3    | 167.825 | 0.000  |
and good exercise habits were effective in improving the dietary pattern (vegetables and fruits, seafood, legumes, etc.) habits have been highly recommended. The Mediterranean available results. This section needs to be further explored.

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 (Kim et al. 2012; Oslin and Cary 2003; Thomas and Rockwood 2001). A recent study published in the Lancet Oncology confirms that even small amounts of alcohol consumption can increase the risk of cancer (Rumgay et al. 2021). 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 (Galbete et al. 2015; Psaltopoulou et al. 2013; Tsivgoulis et al. 2013). 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 (Chen et al. 2017). 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 (Chao et al. 2020). 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 (Rouillard et al. 2017), 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 (China 2016), 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$_{2.5}$ (Ebenstein et al. 2016; Gao et al. 2021; Schikowski et al. 2015). The results of our study also confirmed these findings. Air pollution reduces individuals’ cognitive-related semantic memory and visual construction abilities (Schikowski et al. 2015; Zhang et al. 2018). It can enter the body through the respiratory tract, gastrointestinal tract, and blood–brain barrier (Block et al. 2012), causing changes in the body’s gray matter, white matter, and total brain volume (Kipen et al. 2010), and further impairing cognitive functions through oxidative stress (Moller et al. 2010) and neuroinflammation (Block et al. 2012). 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 (Gao et al. 2021). This study also found interactions between open-air activities and SO$_2$ 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 (Gao et al. 2021; Kulick et al. 2020). 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) (Aging 2013) also need to be further updated.

While the results of the linear model also confirmed the presence of beneficial effects of diet and activity, it did not detect the effect of factors related to alcohol consumption and sulfur dioxide emissions. Combined with the GAM results, we believe that the linear setting masked the nonlinear effects involved, thus interfering with the accuracy of the linear model results.

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 cognition (Vlachos et al. 2020; Wang et al. 2020b).

**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.

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*Author contribution* 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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*Data availability* 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%2FWB07LK.

*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.

*Competing interests* The authors declare no competing interests.

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