

The Effects of Greenness Exposure on Hypertension Incidence Among Chinese Oldest Old: A 10-Year Prospective Cohort Study

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Research

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Abstract

Background

Present studies showed greenness affected hypertension incidence. While population-based epidemiologic studies are limited in the oldest-old population (aged 80+).

Methods

This was a 10-year prospective cohort study that included oldest old (80 years +) from the Chinese Longitudinal Healthy Longevity Survey (CLHLS). Participants were free of hypertension at baseline (2008) and were followed up at 2011/2012, 2014, and 2018 waves. The 1-year average of the Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI) at 16-Day 500 m buffer before the year of hypertension event occurrence or last interview (for censoring) was estimated at 652 counties/districts units level of the participants resided and as exposure indicator. The non-linear association between greenness and hypertension incidence was performed by the Cox proportional hazards model with the penalized spline. The links between greenness and hypertension incidence were performed by the random-effects Cox proportional hazards model adjusted for potential confounding variables. We also examined the causal mediation effects of BMI, leisure activity, and PM_{2.5} on the association between greenness exposure and hypertension.

Results

Among 5432 participants, the incidence of hypertension was 7.25 (95% CI: 6.83 to 7.67) per 100 person-years. We found a non-linear association existed between greenness exposure and hypertension risk. In the fully adjusted model, the third tertile of NDVI value presenting protective effects on hypertension incidence compared with the first tertile (hazard ratios (HRs): 0.51; 95% confidence interval: 0.40-0.64). The third tertile of EVI value had a significant protective effect on hypertension incidence, compared with participants in the first tertile (HRs:0.44, 95%CI: 0.34-0.55). The effect of greenness exposure on hypertension was more pronounced in participants living in central/western China. We observed there were 41.63% and 17.01% of the association between NDVI/EVI exposure and hypertension was mediated by PM_{2.5}, respectively.

Conclusions

Greenness could decrease approximate 50% risk induced by hypertension among oldest-old people, that is, expanding greenness is a recommended approach to hypertension prevention for the them. In particular, implementing plans to expanding green space construction in central/western China is needed. It is also emphasized the the importance of improve air quality when greenness exposure is existing.

Background

Greenness, comprised of vegetation and closely connected with natural elements [1], which was a heatedly discussed environmental indicator in medical and health sciences field [2]. Increasing number of studies confirmed that greenness was very benefit to cardiovascular health. From the view of biologically reasons, greenness can able to thwarting environmental hazards' attack then reduce the damage to cardiocerebral vascular system caused by air pollutants, noise et al; spend time to greenness can relieve mental stress; exposure to greenness help to prevent overweight and obesity also [3].

Currently, the ensuing rapid trends of the aging and expanding oldest old population size (i.e., those aged 80+ years) has resulted in large disease burdens of cardiovascular diseases (CVDs) [4, 5]. Hypertension, which is a well-known important contributor to CVDs, not only as the first leading preventable risk factor for CVDs but also has the highest prevalence among oldest old [2, 6]. Nowadays, make effort to prevent the onset of hypertension is critical to reduce the disease burden of CVDs and promote healthy aging.

Previous studies have revealed a negative association between greenness and hypertension risk [7–10], despite it, a number of questions remain unanswered. First, number of studies investigated the association between greenness and hypertension in older adults, but the result findings were mixed. For instance, prior two surveys found there were not significant association between greenness exposure and blood pressure in the older adults [11, 12]. Second, there are inadequate studies in the literature involving elderly aged over 80 years, although the prevalence of hypertension in the oldest-old elderly was quite high and they were more vulnerable to environmental risk factors due to organ function decline [13]. Third, published studies reported there was a modification effect of the relationship between greenness and blood pressure varied by elderly's age. Some studies proposed this protective effects were stronger in younger age elderly but others were not, due to the rare sample for oldest-old people, this modification effect of age was not fully understand [9, 10, 14]. In addition, previous cross-sectional study designs have dominated the literature [7, 15, 16]. However, hypertension's prevalence is usually chronic progression and relate to long-term greenness exposure. There were rare data on the prospective effects of greenness exposure on hypertension incidence, implying a restricted causal inference ability when generalizing results. Furthermore, there were lots of published literature characterized by local areas and mostly with small sample sizes that influenced the sample representativeness [17, 18].

Numerous studies have explored air pollution, body mass index (BMI), and physical activity may be the mediators in the mechanism association between greenness and health [7, 19], but little is known in oldest-old elderly and study characterised by survival outcome. Meanwhile, some surveys emphasized that greenness could promote elder's leisure activity, thereby reducing the risk of adverse health outcomes [20, 21]. To date, however, this potential pathway between greenness and hypertension whether mediated by leisure activity was unclear.

Importantly, the recommendations in the guideline for the prevention of geriatric hypertension was updated every few years relying on newer evidences for the influence of risk factors on hypertension. However, far less attention has been paid to environmental risk in practice guideline for the elderly. Although

environmental factors omnipresent nature and surely have clinically meaningful effects on hypertension [22], probably due to limited evidences for population-based sample and causal inference. As societies are progressively aging and continuous increment in geriatric hypertension prevalence, a deeper understanding for the association between greenness and hypertension in specific older adults is expected to be reported.

Therefore, the objective of the study was to examine the association between greenness exposure and hypertension incidence based on a 10-year prospective cohort study of elderly aged 80+ in China. We also aimed to respond to whether the mediation effects of BMI, air pollution, and leisure activity exist between greenness and hypertension incidence.

Method

Study design and population

The participants were derived from a public open database – CLHLS , which was a national investigation recruited elderly aged over 65 years and older from 23 of 31 province/ autonomous region / municipality in mainland China. Since the first investigation (1998), the CLHLS has conducted eighth investigations until 2018 wave. Detailed introduction of CLHLS was published elsewhere [23].

To protect the participants' privacy, the home address information was removed in this open-public database. Thus, we selected fifth (2008) wave as baseline due to the information of residence units (at counties/districts level) of the participants resided were available from community investigation questionnaire [24]. At baseline, participants were excluded if they were aged under 80 years, missing on relevant information (demographic characteristics, blood pressure and exposure assessment), and had hypertension (systolic blood pressure (SBP) ≥ 140 mm Hg 140 or diastolic blood pressure (DBP) ≥ 90 mm Hg or normal blood pressure but diagnosed with hypertension by $\times\times\times$ hospital). The participants were followed up in sixth (2011/2012), seventh (2014), and eighth (2018) investigation. The detailed flow chart of current study is shown in Figure 1. Finally, we focused on 5253 participants who older than 80 years old with available information and were followed up in the study. Only 1.3% of participants changed their residence (county/district) in our study. Thus, the sample population was highly stationary because they were less likely to move to another address with advanced age and hukou household registration system [25]. We also performed sensitivity analysis by excluding participants changed residence (Table S4).

The Research Ethics Committees of Peking University and Duke University granted approval for the Protection of Human Subjects for the Chinese Longitudinal Healthy Longevity Survey, including collection of the data used for present study. The survey respondents gave informed consent before participation.

The duration of follow-up was from the date participants enrolled in the project to the date of hypertension event occurrence or death or end of follow-up, whichever occurs first. Person years were calculated by precise method (days/365). The follow-up ended when hypertension event occurrence or

discontinued their participation (i.e. censoring including death, lost follow-up and not identified as hypertension).

Hypertension assessment

As a part of CLHLS, in baseline and each interview, the participants' SBP and DBP were measured between five minutes rest interval by mercurial sphygmomanometer and performed by trained physician. Through two times repeated measurement (between five or longer rest interval) of blood pressure, the average value of SBP and DBP were calculated. Specifically, for bedbound participants, blood pressure measurements were obtained in a recumbent position. Simultaneously, participants were also asked to respond to the following question: "Are you suffering from hypertension and diagnosed by hospital or not?". According to guideline, in our study, hypertension was defined as SBP \geq 140 mm Hg 140 or DBP \geq 90 mm Hg or normal blood pressure value but self-reported be diagnosed with hypertension by hospital. Similar study used same definition of hypertension basing on the CLHLS database was published previously [26].

Greenness assessment

The Normalized Difference Vegetation Index (NDVI) and enhanced vegetation index (EVI) sourced from the Moderate Resolution Imaging Spectroradiometer (MODIS) Terra were used as estimation of greenness. They were recorded per 16-day at a spatial resolution of 250, 500, and 1000 m, respectively. The two satellite-derived vegetation indices reflected vegetation of ground with range from -1 to 1. In general, NDVI of 0.1 or below reflected barren areas of rock, sand or snow; NDVI between 0.2 to 0.4 reflected shrub and grassland. The higher value of NDVI/EVI, the denser greenness. Referring to previous study [27], based on NDVI/EVI free of cloud of 16-day recorded for 500 m buffer, the 1-year average of NDVI/EVI value before the year of last interview (only for censoring) or hypertension event occurrence was treated as greenness exposure in our study. Because this window period had greatest impacts on hypertension incidence (Table S1). In particular, due to the individual privacy protection, exact address of residence was unavailable, thus, the exposure was assessed at a community-based unit level (districts/counties) the elderly resided. Those cloud-free of NDVI/EVI value were available downloaded from the Google Earth Engine (<https://developers.google.cn/earth-engine>) and they were extracted through ArcGIS 10.6 (ESRI, Redlands, CA, USA) in this study. Specific, the one year average of NDVI/ EVI before event at a spatial resolution of 16-day with 250 m and 1000 m buffer were used to sensitivity analyses.

Potential confounding variables and mediators

Some of the baseline characteristics were used to control confounding in the study. Including: age, gender (female, male), residence (rural/town, urban), geographical regions (eastern China, central/western China), pension (yes, no), living arrangements (with family member, nursing home/alone), education attainment (uneducated, educated), marital status (married/living together, widowed, and /single/divorced/separated), smoking status at the present (yes, no), drinking status at the

present (yes, no), exercising habit at the present (yes, no), self-reported heart disease (yes, no), self-reported diabetes (yes, no), and ADL (Activities of Daily Living). In particular, ADL was evaluated by self-report regarding physical ability in basic self-care tasks, which was consist with six items including bathing, dressing, eating, toileting, continence, and transferring [28, 29]. If an participant is able to perform an activity, he/she gets score 1, and if he/she is limited to do and unable to do so, will get score 2 and 3, respectively. The more scores of the individual, indicates poor ADL ability.

According to prior studies, we selected contemporaneous PM_{2.5} concentration, BMI index, and leisure activity at the baseline as mediators in the analysis. Among them, baseline PM_{2.5} concentration in 652 units of the subjects resided was collected from a public open database built by Atmospheric Composition Analysis Group from University of Washington [30]. Researchers used satellite combining Aerosol Optical Depth (AOD) retrievals from multiple satellite products (MISR, MODIS Dark Target, MODIS and SeaWiFS Deep Blue, and MODIS MAIAC) to report ground-level of PM_{2.5} concentration with 1.1x1.1 km resolution.

Leisure activity was collected from individual questionnaire included following activity: housework ; personal outdoor activities; garden work; read newspapers/books; raising domestic animals; playing cards and/or mahjongg; watching television and/or listening to the radio; organized activities. The checklist was ratings using a 5-point Likert scale. Each opinion was scored on a scale of 1 (never), 2 (not every month, but sometimes), 3 (not every week, but at least once a month), 4 (not every day, but at least once a week), or 5 (almost every day). As recommend, we calculated total points and divided by the full score to measure leisure activity (range = 0-1) [31].

Statistic analysis

Descriptive statistic analysis was performed firstly. The continuous variables with normal distribution were reported as mean \pm standard deviation (SD). Median (interquartile range) was presented for variables with non-normal distribution. The categorical variables were reported as number and percentage.

The Cox proportional hazards regression models of penalized spline with different degree of freedom (2/3/4) was conducted to examine the potential non-linear association between greenness and hypertension incidence basing on minimum AIC (Akechi information criterion) value.

Given the set clustering of the study designs, to evaluate the associations of greenness exposure with the occurrence of hypertension, the random-effects Cox proportional hazards regression models were performed. In this analysis, the 652 units was set as a random effects term in the models. We first explored the links between 0.1-unit increment in greenness and hypertension. Furthermore, due to the non-linear association between greenness exposure and hypertension (Figure S2 and S3). We categorized NDVI/EVI into three categories basing on tertile: first tertile (lowest and as reference, $\leq P_{50}$), second tertile (P_{50} - P_{75}), and third tertile (highest, $>P_{75}$). The crude model only included NDVI/ EVI (model 1). The model

2 was developed by further adjusting for age, gender, residence, geographical regions, pension, living arrangements, education attainment, marital status, smoking status at the present, drinking status at the present, exercising habit at the present, self-reported heart disease, self-reported diabetes, PM_{2.5}, leisure activity, and BMI (model 2). We also built trend analysis between greenness exposure and hypertension risk by setting NDVI/EVI tertile as continuous variables in the models. For a robustness check, the EVI/NDVI in 250 and 1000 m buffer was used to test the sensitivity of our results. In addition, we excluded the participants who were self-reported had diabetes/heart disease/dead during follow-up to verify the effects of residential greenness exposure and hypertension incidence (Table S4). Subgroup and interaction effects analysis were performed to identify vulnerable population affected by greenness exposure. The interaction effects of NDVI/ EVI and four variables on hypertension incidence by perform a cross-product term.

We conducted a one-mediator model to explore the mediation effects of each 0.1-unit increment in greenness exposure and hypertension incidence mediated by mediators (PM_{2.5}, leisure activity, and BMI) based on the survival outcomes. The detailed theoretical foundation, R codes, and calculation principle were published in the study of Huang and Yang [32]. In the model, the product of the two effects in the hazard ratio scale: $TE_{HR} = DE_{HR} \times IE_{HR}$, or equivalently, $TE_{\log HR} = DE_{\log HR} + IE_{\log HR}$. The mediation proportion was calculated as the natural log of indirect effect divided the total effect and expressed as a percentage [33].

Effect estimates are showed as hazard ratio (HR) and corresponding 95% confidence intervals (CIs). The map of China was derived from National Geomatics Center of China (<http://www.ngcc.cn/ngcc/>), the statistics map was generated by ArcGIS Geospatial Analyst module v10.6 (ESRI, Redlands, CA, USA). All of analysis were 2-sided level of significance was set at 0.05. All of analysis were performed using R studio (R 4.0.5, R Foundation for Statistical Computing, Vienna, Austria).

Result

The demographic characteristics of the participants are given in Table 1. Among 5432 participants, a total of 1048 new cases of hypertension were observed, including 14454.64 person-years of follow-up, with an incidence of 7.25 (95% CI: 6.83 to 7.67) per 100 person-years. The mean age of the subjects was 93.7 years (SD=7.16) with range from 81 to 116 years. Over half of the participants (60.9%) were females. Only 28.4% of the elderly were educated. 80.9% of them living in town/rural areas, and most of them were widowed (81.7%), living with family members (83.4%). Most of the participants had not pension. The mean ADL value of the elderly was 7.25 (SD=2.61) (Table 1).

Table 1
Demographic characteristics of the participants at baseline (N=5253)

Variables	Overall	n(%) / mean \pm SD
Age		93.7 (7.16)
Gender		
	Female	3201 (60.9)
	Male	2052 (39.1)
Education attainment		
	Uneducated	3763 (71.6)
	Educated	1490 (28.4)
Pension		
	No	4525 (86.1)
	Yes	728 (13.9)
Residence		
	Rural/Town	4251 (80.9)
	Urban	1002 (19.1)
Living arrangement		
	Nursing home/alone	871 (16.6)
	Living with family members	4382 (83.4)
Region		
	Central/western China	3208 (61.1)
	Eastern China	2045 (38.9)
Marital status		
	Single/divorced/separated	57 (1.1)
	Widow	4294 (81.7)
	Married/living together	902 (17.2)
Smoking status at the present		
	No	4517 (86.0)
	Yes	736 (14.0)
Drinking status at the present		

Variables	Overall	n(%) / mean ± SD
	No	4409 (83.9)
	Yes	844 (16.1)
Exercising habit at the present		
	No	4089 (77.8)
	Yes	1164 (22.2)
Self-reported diabetes		
	No	5184 (98.7)
	Yes	69.0 (1.3)
Self-reported heart disease		
	No	4988 (95.0)
	Yes	265 (5.0)
ADL		6.0(6.0-7.0)
BMI		19.0(17.3-21.1)
Leisure activity		0.1(0.0-0.3)

The spatial distribution of NDVI/EVI value at baseline in 652 units among 5253 oldest-old elderly of China is presented in Figure 1. We also presented spatial distribution of NDVI/EVI value at baseline across China (Figure S1). The mean NDVI and EVI of the units were 0.46 (SD=0.11) and 0.29 (SD=0.07), respectively. The participants exposure to PM_{2.5} with mean concentration was 53.93 (SD=16.00) (Table 2).

Table 2
Descriptive statistics analysis for greenness exposure and air pollutant

Variables	Mean	SD	Min	Quantiles			Max	Interquartile range
				P ₂₅	P ₅₀	P ₇₅		
EVI	0.29	0.07	0.05	0.25	0.30	0.34	0.44	0.19
NDVI	0.46	0.11	0.09	0.39	0.48	0.54	0.69	0.15
PM _{2.5}	53.93	16.00	9.44	42.78	51.81	68.02	95.60	25.24

Table 3 reported the results of random-effects Cox proportion hazard models for the association between greenness exposure and hypertension incidence. The NDVI and EVI value were strongly correlated with hypertension incidence in the crude model. In the fully adjusted model, referring to the 1st tertile of NDVI value, the HRs for the second tertile and third tertile were 0.86 (95%CI: 0.70-1.05) and 0.51 (95%CI: 0.40-0.64), respectively. We found the third tertile of EVI value was significant associated with hypertension incidence after controlling for confounding variables (HR=0.44, 95%CI: 0.34-0.55). Each 0.1-unit increase in NDVI/EVI was associated with lower hypertension risk (HR=0.80, 95%CI:0.74-0.87 for NDVI; HR=0.68, 95%CI: 0.60-0.77 for EVI). We performed tests for linear trend by entering the tertile of NDVI/EVI as a continuous variable in the models, and these associations did reach statistical significance (P for trend <0.05) (Table 3). When examining the association between NDVI/EVI value in the 250 m and 1000 m buffer and hypertension occurrence, this association remained significant in sensitivity analysis (Table S2). Besides, the results were not substantially changed after excluding participants self-reported had diabetes, changed residence, death during follow up and heart disease (Table S3).

Table 3

The association between greenness exposure and hypertension incidence among 5453 oldest old population

Index	Groups	Model 1	Model 2	P for trend ^a	Increment in each 0.1 unit increase in greenness exposure ^a
NDVI					
	Tertile 1	1	1	<0.001	0.80 (0.74-0.87)
	Tertile 2	0.99(0.81-1.20)	0.86(0.70-1.05)		
	Tertile 3	0.68(0.53-0.84)	0.51(0.40-0.64)		
EVI					
	Tertile 1	1	1	<0.001	0.68 (0.60-0.77)
	Tertile 2	0.97(0.80-1.17)	0.85 (0.70-1.03)		
	Tertile 3	0.52(0.41-0.66)	0.44(0.34-0.55)		
Note:					
Model 1: Crude model only included NDVI/EVI.					
Model 2: Crude model + further adjusted for age, living arrangement, PM _{2.5} , regions, ADL, residence, gender, smoking, drinking, exercising, pension, marital status, education attainment, self-reported diabetes, self-reported heart disease, and BMI.					
^a Adjusted for age, living arrangement, PM _{2.5} , regions, ADL, residence, gender, smoking, drinking, exercising, pension, marital status, education attainment, self-reported diabetes, self-reported heart disease, and BMI.					

Table 4
Subgroup analysis for the association between NDVI value and hypertension incidence

Covariates	1st tertiles	2nd tertiles	3rd tertiles	P value for interaction
	HR (95%CI)	HR (95%CI)	HR (95%CI)	
Regions				
Central/western	1	0.82(0.64-1.05)	0.35(0.25-0.47)	0.002
Eastern	1	0.60(0.38-0.94)	0.92(0.64-1.32)	
Gender				
Male	1	0.91(0.68-1.24)	0.73(0.53-1.01)	0.084
Female	1	0.89(0.69-1.14)	0.50(0.38-0.67)	
Residence				
Rural/Town	1	0.87(0.71-1.08)	0.50(0.40-0.64)	0.130
Urban	1	0.60(0.26-1.39)	0.35(0.08-1.59)	
Smoking status at the present				0.230
Yes	1	0.76(0.46-1.25)	0.73(0.42-1.24)	
No	1	0.89(0.71-1.11)	0.50(0.39-0.64)	
Drinking status at the present				0.570
Yes	1	0.97(0.64-1.46)	0.57(0.35-0.90)	
No	1	0.87(0.70-1.09)	0.54(0.42-0.69)	

Note:

The associations were adjusted by age, living arrangement, PM_{2.5}, regions, ADL, residence, gender, smoking, drinking, exercising, pension, marital status, leisure activity, education attainment, self-reported diabetes, self-reported heart disease, and BMI.

Covariates	1st tertiles	2nd tertiles	3rd tertiles	P value for interaction
	HR (95%CI)	HR (95%CI)	HR (95%CI)	
Exercising habit at the present				0.610
Yes	1	0.85(0.59-1.24)	0.69(0.48-1.00)	
No	1	0.91(0.72-1.14)	0.52(0.40-0.68)	
<i>Note:</i>				
The associations were adjusted by age, living arrangement, PM _{2.5} , regions, ADL, residence, gender, smoking, drinking, exercising, pension, martial status, leisure activity, education attainment, self-reported diabetes, self-reported heart disease, and BMI.				

Table 5
Subgroup analysis for the association between EVI value and hypertension incidence

Covariates	1st tertiles	2nd tertiles	3rd tertiles	P value for interaction
	HR (95%CI)	HR (95%CI)	HR (95%CI)	
Regions				
Central/western	1	1.03(0.81-1.32)	0.47(0.35-0.63)	0.330
Eastern	1	0.60(0.43-0.83)	0.44(0.29-0.67)	
Gender				
Male	1	1.00(0.76-1.32)	0.55(0.39-0.77)	0.540
Female	1	0.84(0.66-1.06)	0.49(0.37-0.65)	
Residence				
Rural/Town	1	0.84(0.69-1.02)	0.41(0.32-0.53)	0.160
Urban	1	0.64(0.21-1.90)	0.77(0.31-1.95)	
Smoking status at the present				
Yes	1	0.84(0.54-1.31)	0.43(0.24-0.76)	0.410
No	1	0.88(0.72-1.09)	0.46(0.36-0.59)	
Drinking status at the present				
Yes	1	0.95(0.64-1.39)	0.44(0.27-0.72)	0.630
No	1	0.89(0.72-1.10)	0.49(0.38-0.64)	

Note:

The associations were adjusted by age, living arrangement, PM2.5, regions, ADL, residence, gender, smoking, drinking, exercising, pension, marital status, leisure activity, education attainment, self-reported diabetes, self-reported heart disease, and BMI.

Covariates	1st tertiles	2nd tertiles	3rd tertiles	P value for interaction
	HR (95%CI)	HR (95%CI)	HR (95%CI)	
Exercising habit at the present				
Yes	1	0.82(0.59-1.15)	0.65(0.45-0.94)	0.730
No	1	0.94(0.75-1.17)	0.44(0.34-0.58)	
<i>Note:</i>				
The associations were adjusted by age, living arrangement, PM2.5, regions, ADL, residence, gender, smoking, drinking, exercising, pension, marital status, leisure activity, education attainment, self-reported diabetes, self-reported heart disease, and BMI.				

The figure 3 and 4 report the subgroup analysis results of the study. Only a significant region × greenness interaction term for hypertension was detected ($p < 0.05$). The population from central/western regions were more vulnerable to greenness exposure than others reside in regions (HR=0.35, 95%CI: 0.25-0.47).

After adjusted for confounding variables, in our study, we found the association between greenness and hypertension was partly mediated by air pollution. As presented in Figure 3, direct and indirect effects of greenness had opposite effects. When giving the direct effects, greenness exposure was associated with lower risk of hypertension (direct effect: 0.80, 95%CI: 0.73-0.87 for NDVI; HR=0.71, 95%CI: 0.63-0.80 for EVI). However, the indirect effects of greenness exposure mediated through PM_{2.5} was related with increase risk of hypertension (indirect effect: HR=1.07, 95%CI: 1.04-1.10 for NDVI; HR=HR=1.06, 95%CI: 1.03-1.09 for EVI). There were 41.63% and 17.01% of its effects were mediated by PM_{2.5} for NDVI and EVI, respectively. We not observed significant mediation effects of BMI and leisure activity on the relationship between greenness and hypertension (Table S4).

Discussion

To our knowledge, this is the first prospective cohort study to examine the association between greenness exposure and hypertension incidence among the oldest-old population. The findings from our study showed the greatly protective effects of greenness exposure on hypertension incidence risk. Compared with the first tertile counterpart, the third tertile of NDVI value were associated with 49% lower hazard risks of hypertension incidence, respectively. Also for those participants at the highest tertile of EVI value, the risk of hypertension was reduced by 46%. We observed that region had modification effects on the association between greenness exposure and hypertension. We have found significant mediation effects of air pollution existed on the association between greenness and hypertension.

One of the highlights of our study was we observed the dose-response relationship between greenness and hypertension. As already discussed in past studies [20, 34, 35], non-linear (dose-response) association between greenness exposure and health outcomes such as serum uric acid levels, physical function, and mortality have been detected in middle-aged or older adults, but same non-linear association between greenness and hypertension remains unclear. In our study, we found the threshold value of hypertension incidence in NDVI/EVI value were very small (Figure S2-S3), it suggested that an effort to expand residential greenness space was positive with declining in hypertension incidence risk. Namely, expanding greenness space may be a very highly cost effective approach for hypertension prevention for these oldest-old elderly. Whereas, due to limited evidence of greenness threshold for hypertension incidence in other population, the comparison between oldest-old and younger people need more study.

Our findings was supported by prior studies that demonstrated the protective effects of greenness exposure on hypertension incidence [36–38]. Although few of studies have been devoted to the oldest-old adults. In a earlier community-based cross-sectional study of participants aged 18 to 91 has shown that about 45% risk of hypertension was reduced due to greenness exposure among older adults over 65 years [16]. One observational survey looking at 5 counties in central China have found greenness exposure was associated with approximately 5% lower risk of hypertension in the middle-age and older population (mean age: 55.58) [7]. A sample that included 249,405 Medicare beneficiaries from Florida revealed a 13% risk decrease in hypertension attributed to greenness among adults older aged from 65 to 111 years [39]. However, a recent study from 33 communities of China indicated that greenness exposure seemed was a risk factor for hypertension in the elderly over 65 years (the proportion accounting for 9% of their sample) but no statistical significance was detected in this study [9].

Owing to the total number of the specific age elderly (80+) was very limited, our national data incorporated large investigation complement study gaps existing in past literature with implications for illustrating the benefit of greenness on hypertension and deeper understanding the longevity. The determination that an association between greenness exposure and hypertension incidence is causal suggests improvement in residential greenness space may be helpful to supplement existing guidelines for the management of geriatric hypertension [40].

More importantly, the results of our study exhibited a greater protective effect of greenness exposure on hypertension incidence than prior published literature included older adults [9, 11, 14, 16], which indicated that the advantages of greenness for these oldest people were greater than expected. Our results provide new insights that the benefit of greenness exposure to hypertension prevention possible increases with age, especially for the oldest old people. Thus, it is of significant public health interest to expand capacious green space and offer accessible opportunity to green space in nursing home, geriatric hospital, and residence areas oldest-old gathered (e.g, longevity villages), may reduce specific age hypertension occurrence then prolong life-span.

Past studies proposed some explanations which may be part of the underlying mechanisms for the influence of greenness on hypertension, as following: 1) Exposure to greenness can alleviate emotional

symptoms and pressure a person faced [41, 42]. 2) Greenness space offers accessible opportunities for physical activity and social interaction for the individual [20, 43]. 3) The noise, air pollutants, and dust exposure can be offset in some extent by large greenness space [44]. Among them, weight control, physical activity, and reducing mental pressure were important prevention strategies involved in the current recommendations based on guidelines for the management of geriatric hypertension. The current study also emphasized continues to update recommendations for the prevention of hypertension due to our advancing understanding of the environmental factors for hypertension incidence.

According to the results of subgroup analysis, we observed that modified effects were appeared in regions, residence, gender, and lifestyle, however, we found only a significant interaction effect of regions between greenness and hypertension. Oldest old population who living in Central/Western regions were be more vulnerable to greenness exposure than eastern regions (Figure 3). Generally, the greenness space reflects the level of social and economic development. As figure 2 presented, a relatively flourishing greenness covering distributed in eastern regions, which was confirmed by another study reported the greenness in China follows a pattern of south-high and north-low, east-high, and west-low [45]. Moreover, the urbanization rate was faster in the central and western regions than in the eastern and northeastern areas, rapidly urbanization consumed a number of open space and forest in central/western regions [46]. As scholars summarized that urbanization had a positive effect on eco-efficiency in the eastern China instead of central and western regions [47]. Hence, the findings support the policy decision that effective greenness space construction plan should be taken to deal with the risk of hypertension across regions especially central/western regions.

Recently, more and more studies paid attention to the underlying mediation effect of air pollutants on the association between greenness and hypertension/blood pressure but most of them were focusing on middle-aged or younger population and reported mixed study results involving partly, complete, and null mediation effects. A cross-sectional study enrolled over thirty thousand of middle-aged adults reported that air pollution partially mediated the relationships between residential greenness and DBP (mediation proportion was 21.6%) [7]. In turn, Huang et al found air pollution completely mediated the influence of greenness on hypertension in 5,806 urban middle aged and elderly people [8]. In a study focusing on children and adolescents, the results showed not significant evidences for the potential mediation effect of air pollution on the greenness-BP association [15]. Similar to Jiang et al [7], we also found a partly mediation effects of air pollutant on the links between greenness and hypertension. And the proportion of mediation effect was higher than the study of Jiang et al, may be due to the more weaker body function the more easily the oldest old people was affected by air pollutants. It is well-known that forests, trees, and vegetation space are able to deal with unclean air environment through leaf stomata on the plant surface, then mitigating the health effects [48]. Therefore, implement practical air quality management and improve air quality still a effective measure to promote cardiovascular health, especially for China, which has more severe air environment and heavier air pollution related disease burden than western developed countries.

Several limitations should be recognized. First, the individual precise residential address of the participant was not available due to privacy protection of the CLHLS. Under this condition, we used county/district level exposure information to reflect individual's exposure. Even though same method was applied in prior studies [49, 50], measurement error was exist to some extent although the units were set as random term in our analysis. But satellite data we used with high resolution, national-level representative sample enhanced the reliability and generalization of our findings. Also, previous published survey based on residential unit to examine the effects of exposure on health outcomes presented positive results, which was able to support the scientificity of our result [51–54]. Second, limited by the CLHLS project database, we could not collect information on greenness vegetation structure. That could not explain the estimation of the association between greenness areas and hypertension incidence varied by vegetation regions. Third, the baseline CLHLS project data lacked information on the measurement of physical activity (intensity and frequency). It was limited the generalization of our result to some extent. But it could be confirmed that the light-intensity physical activity pattern was dominated among the oldest-old population [55]. Fourth, it is not available to identify the exact event date of hypertension because a long interval between interviews which limited the ability to causal inference. However, the sensitivity analysis presented steady results (Table S3).

The strengths of our study provided evidence for the effects of greenness on hypertension among the elderly aged 80 and older basing on a prospective cohort design, large sample size, and 10-year follow-up, after controlling for various confounding variables. The study also underlined the importance of continued expansion for residential greenness space and promote the use of greens-space especially in central/western regions. Furthermore, improve air quality also as a critical factor to reduce hypertension risk under the direct effect of greenness exposure.

Lastly, because the greenness is independent of conventional hypertension risk factors. We expect a comprehensive assessment included environmental factors of hypertension risk is needed to older adults. We also hope existing guideline for hypertension prevention expected to updated, then physicians can be aware of these environmental factors and inform their service objectives the potential risk management measures they can adopt.

Conclusion

Taken together, the current study provide representative sample of oldest-old population to indicate the protective effects of greenness exposure on hypertension incidence, prove a cause-and-effect link between greenness and hypertension incidence. Given the centrality of prevention to hypertension, we call for the government continuous to expand the coverage of greenness particularly in central/western regions. Implement more efforts to improve air quality also a vital approach to strengthen greenness benefit.

Declarations

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Author's Contributions

Wensu Zhou, Fenfen Zhou: Data cleaning; Wensu Zhou, Wenjuan Wan, Fenfen Zhou, Wen Chen, Li Ling: Conceptualization; Wensu Zhou, Wen Chen, Fenfen Zhou, Wenjuan Wang: Data curation, Writing, Original draft preparation, Methodology, Software, Reviewing; Wensu Zhou, Fenfen Zhou, Wen Chen, Li Ling: Visualization. Wensu Zhou, Fenfen Zhou, Wen Chen, Li Ling, Wenjuan Wang: Supervision.

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Availability of data and materials

The CLHLS is an open-publish database which can be downloaded at website <http://cnsda.ruc.edu.cn/index.php?r=projects/view&id=52572397>.

Ethics approval and consent to participate

The Research Ethics Committees of Peking University and Duke University granted approval for the Protection of Human Subjects for the Chinese Longitudinal Healthy Longevity Survey, including collection of the data used for present study. The survey respondents gave informed consent before participation.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Figures

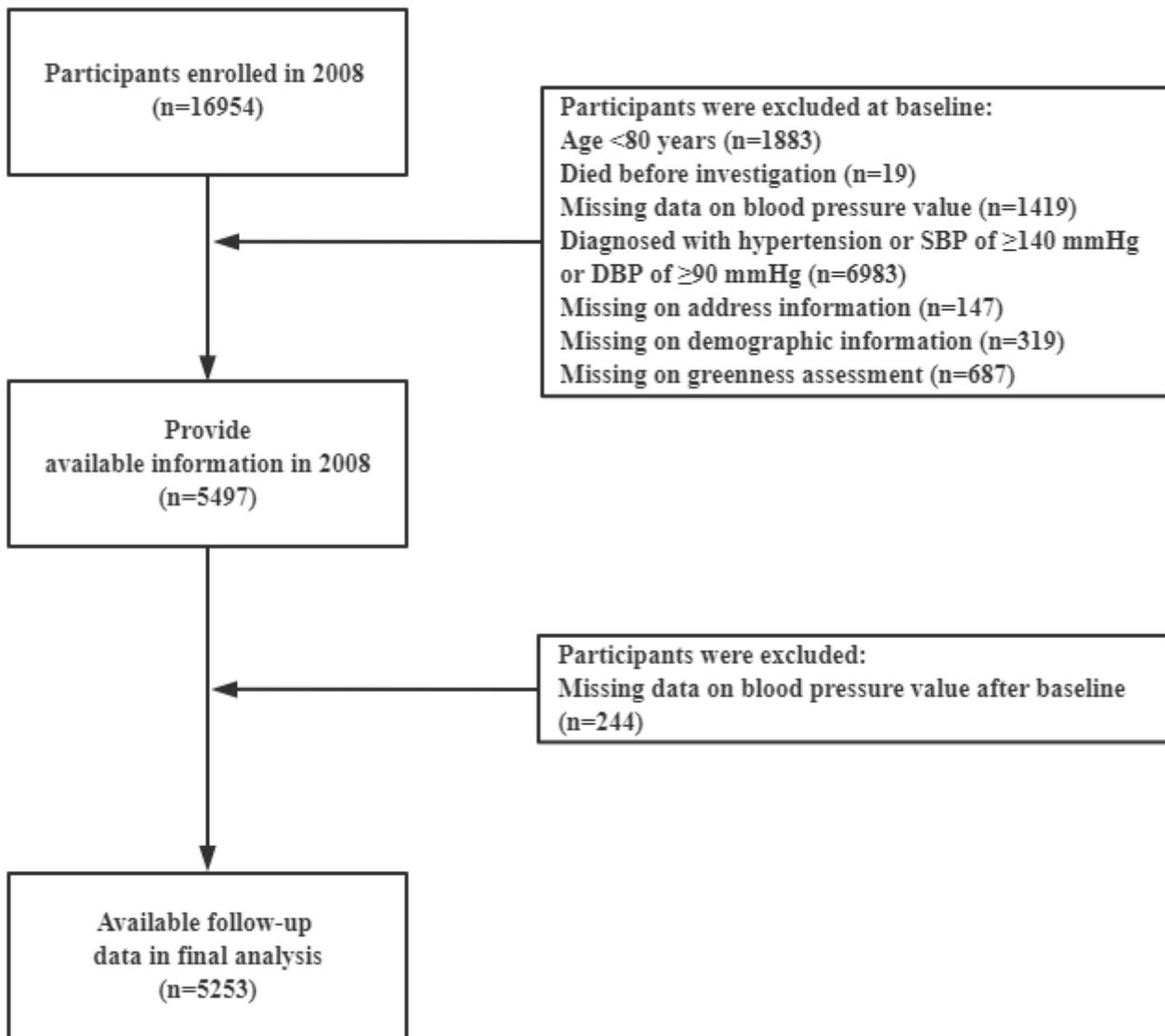


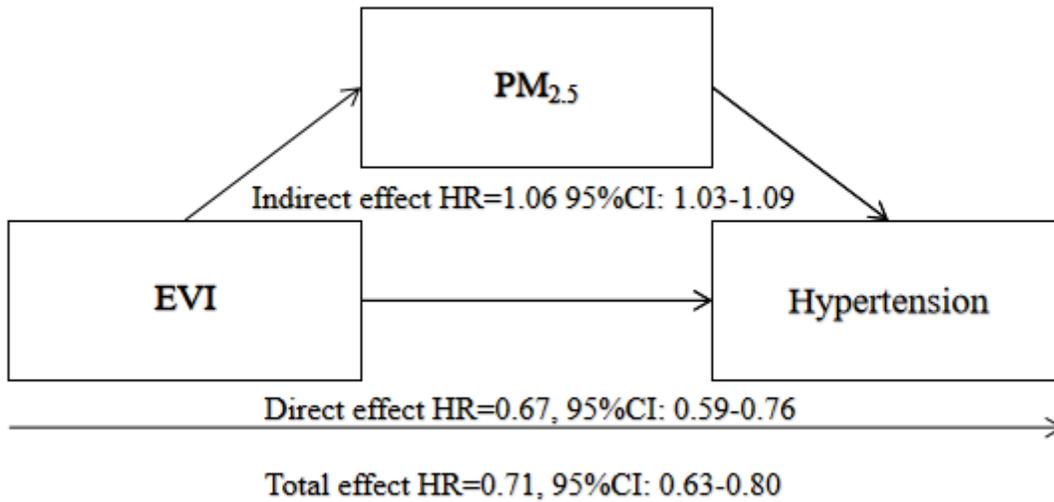
Figure 1

Flow diagram of study in group of people aged 80+

Figure 2

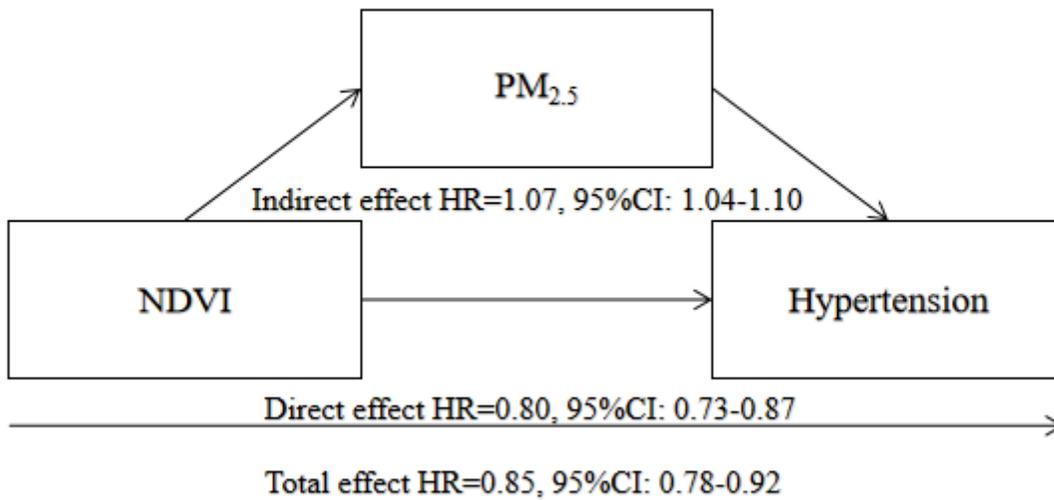
The NDVI/EVI value of in 652 units of 23 provinces in China at baseline for 5253 participants

A



The mediation proportion was 17.01%

B



The mediation proportion was 41.63%

Figure 3

(A) The association of EVI and hypertension mediated by PM_{2.5}. (B) The association of NDVI and hypertension mediated by PM_{2.5}. All of analysis was adjusted for age, living arrangement, regions, ADL, residence, gender, smoking, drinking, exercising, pension, marital status, education attainment, self-reported diabetes, and self-reported heart disease.

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