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Original Article

Association between Age-Friendly Environment, Sarcopenia and Frailty among Older Adults in China: A Longitudinal Study

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ABSTRACT

Background: Sarcopenia and frailty are interrelated complex geriatric syndromes that are associated with an increased risk of negative health outcomes. The construction of an age-friendly environment (AFE) is a key strategy for promoting health aging, but its associations with sarcopenia and frailty remain unclear. This study aimed to explore the association between AFE and the incidence of sarcopenia and frailty in older adults.
Methods: A total of 3,261 participants aged ≥60 years were included from the China Health and Retirement Longitudinal Study (CHARLS). Using a World Health Organization (WHO) AFE framework modified for Chinese context, we constructed an 8-domain, 35-component community environment score. Sarcopenia was defined according to the 2019 consensus guidelines by the Asian Working Group for Sarcopenia, while frailty status was assessed using the frailty index (FI). The longitudinal association between AFE score and the risk of developing incident sarcopenia and frailty was evaluated using Cox proportional hazards regression models.
Results: Over a 4-year follow-up, 297 (9.10%) participants developed sarcopenia; and participants with sarcopenia had a higher FI. Compared to the lowest quartile of AFE scores, participants in the highest AFE quartile had a 46% lower risk of incident sarcopenia (HR: 0.54, 95% CI: 0.38−0.77) and a 27% lower risk of incident frailty (HR: 0.73, 95% CI: 0.60−0.90), even after comprehensive confounding adjustment. Subgroup analyses showed a significant interaction between independent ADL and AFE was observed for sarcopenia, while significant interactions by residence and health status were observed for frailty.
Conclusions: Our findings underscore that constructing an age-friendly environment is of great significance for the prevention of incident sarcopenia and frailty among older adults in China.

1. Introduction

With the accelerated pace of global population ageing, a prevalent geriatric syndrome referred to as frailty is becoming a significant health burden [1]. Sarcopenia is defined as the decline in skeletal muscle mass and function, representing the key component of physical frailty and considered the biological basis of frailty [2]. Both sarcopenia and frailty increase adverse outcomes such as falls, hospitalization, and mortality, seriously impairing the quality of life for older adults [3]. According to different diagnostic criteria, the incidence of sarcopenia among community-dwelling older adults is approximately 10%–27%, while frailty is about 11% [4]. Therefore, identifying risk factors is essential in

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geriatric health research. These risk factors are common and complex, including physical inactivity, poor nutritional status, inflammatory responses, and chronic diseases [5]. Although many of these factors can be mitigated through lifestyle modifications, maintaining a healthy lifestyle is heavily reliant on adequate environmental support [6].

The World Health Organization (WHO) first proposed the "Age-Friendly Environment (AFE)" concept in 2005 and launched the AFE project globally [7]. To address demographic ageing, it developed AFE guidelines covering eight domains: outdoor spaces and buildings; transportation; housing; social participation; respect and social inclusion; civic participation and employment; communication and information; and community support and health services [8]. Previous research has consistently demonstrated associations between poor community environments and adverse health outcomes in older adults like falls, disability, and mortality [9]. Age-friendly physical and social environments foster healthy lifestyle behaviors among older adults, including increased physical activity, social engagement, and improved dietary choices [10–12]. Thus, creating an AFE may be positively associated with the prevention of sarcopenia and frailty in older adults.

Current research on the AFE-sarcopenia and frailty relationship mostly focused on single environmental factor rather than comprehensive AFE assessments, hindering accurate understanding of their associations in older adults. The China Health and Retirement Longitudinal Study (CHARLS), a large nationally representative longitudinal dataset offers a wealth of information at the individual, family, and community levels [13,14]. Through the CHARLS database, detailed information on older adults (including health status, lifestyle, socio-economic conditions, and living environments) can be obtained. This enables a comprehensive assessment of AFE scores and analyzing its relationship with sarcopenia and frailty.

This study aimed to explore the association between AFE and the incidence of sarcopenia and frailty in older adults, thereby providing a scientific basis for formulating effective interventions and policies to promote older adults' health, improve their quality of life, and further advance healthy aging.

2. Material and methods

2.1. Study design and participants

This study employed a cohort design, utilizing data prospectively collected over a four-year period from CHARLS, which is a nationally representative cohort of community-dwelling adults aged 45 years and older in China. Initiated in 2011 (baseline), the study recruited 17,708 participants from 150 counties across 28 provinces in China. Ethical approval for CHARLS was obtained from the Biomedical Ethics Committee of Peking University, and all participants provided written informed consent prior to their inclusion [15].

For this longitudinal analysis, we extracted data from CHARLS 2011 (wave 1) and 2015 (wave 3). The initial sample at wave 1 included 17,708 participants, from which we first excluded those aged <60 years or with missing age data (N = 10,148), leaving 7,560 participants with complete baseline data. Subsequently, we further excluded participants with sarcopenia at baseline (N = 544), lacking the data on sarcopenia data (N = 1,702), missing sarcopenia status data during follow-up (N = 1,517), and missing more than 20% of data across all variables (N = 536). Ultimately, 3,261 participants were included in the final analysis, as illustrated in Fig. 1.

2.2. Diagnosis of sarcopenia

The diagnosis of sarcopenia adhered to the 2019 consensus guidelines by the Asian Working Group for Sarcopenia (AWGS), which is based on three key parameters: muscle strength, appendicular skeletal

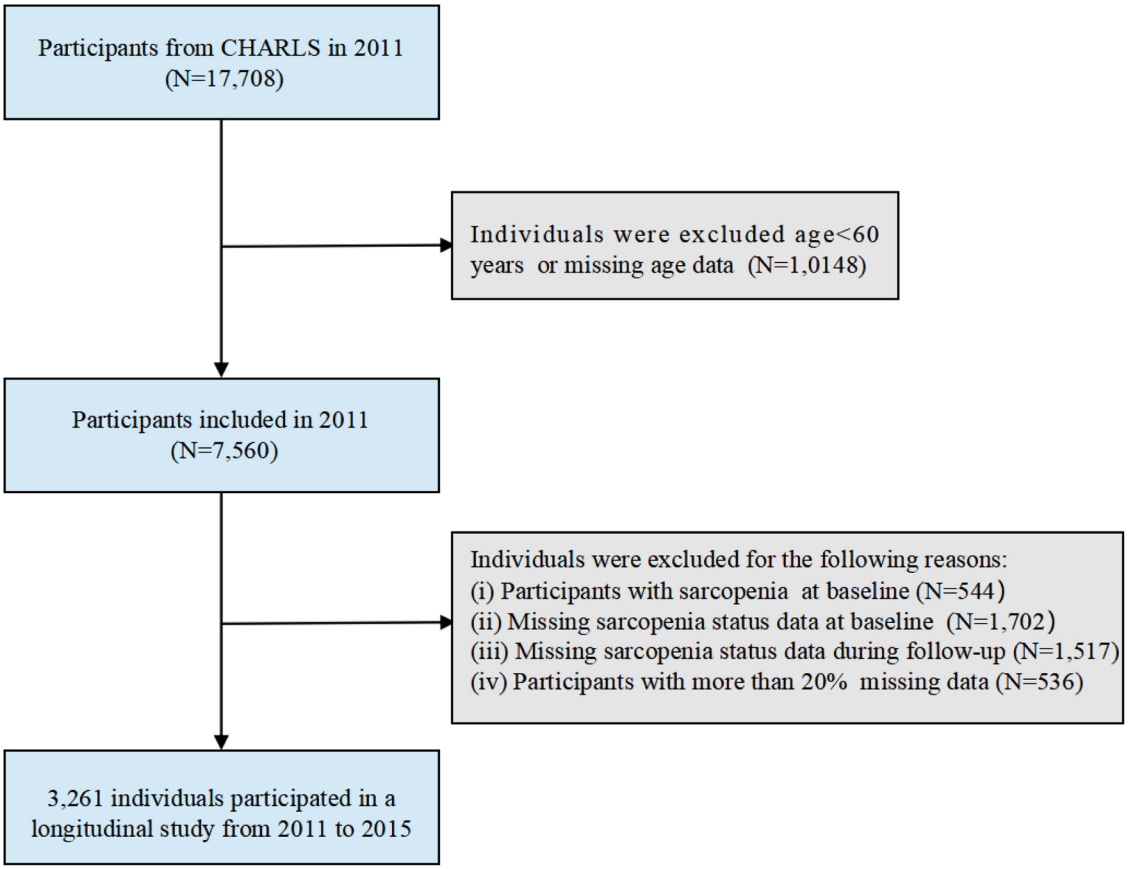


Fig. 1. Flow chart of participants selection.

muscle mass (ASM), and physical performance. Participants with low muscle mass, combined with either low muscle strength or low physical performance, were diagnosed with sarcopenia. Muscle strength was measured using handgrip strength, with the measurement protocol previously described in detail [16]. According to the AWGS 2019 criteria, low muscle strength was defined as an average handgrip strength <28 kg for males and <18 kg for females. The ASM was estimated using a validated formula specific to the Chinese population, which has demonstrated good consistency with dual energy X-ray absorptiometry (DXA) in previous research [17]. The formula for calculating ASM is: ASM = 0.193 × weight (kg) + 0.107 × height (cm) − 4.157 × sex − 0.037 × age (years) − 2.631. Body weight and height were measured using the Omron™ HN-286 scale and Seca™213 stadiometer, respectively. In the formula, males were coded as 1 and females as 2. The skeletal muscle mass index (SMI) was calculated by dividing ASM by the square of height (ASM/height^2). Drawing on prior studies, low muscle mass was defined as the sex-specific lowest 20% of SMI in the study population, corresponding to values <6.99 kg/m^2 for males and <5.27 kg/m^2 for females [18]. Physical performance was evaluated via gait speed and the 5-time chair stand test. Low physical performance was defined as a gait speed <1.0 m/s or a 5-time chair stand test result ≥12 s [19].

2.3. Age-friendly environment

The original AFE framework, as proposed by the WHO, encompasses eight domains of the community environment [20]. However, the CHARLS questionnaire lacked items corresponding to certain domains within the AFE framework, such as "Civic Participation and Employment" and "Respect and Social Inclusion". To adapt to the Chinese context and the available data in CHARLS, we modified the original AFE framework. The modified framework in our study consisted of eight domains: "Community facilities and services for older adults' health," "Outdoor spaces and buildings," "Housing," "Transportation," "Facilities and associations for social participation," "Neighbourly support," "Local government's age-friendliness in supporting older adults," and "Infrastructure for communication and information". We calculated and standardized the summary score for each domain for modelling (Table S1).

2.4. Participant characteristics

At the baseline survey in 2011, a range of sociodemographic characteristics were evaluated, including age, sex, body mass index (BMI), smoking status, alcohol consumption, activities of daily living (ADL), marital status, place of residence, educational level, and household income. Health-related diseases were identified through a combination of blood tests and self-reported questionnaires. Hypertension, diabetes, and dyslipidemia were diagnosed based on comprehensive criteria that integrated physical examination results, blood biomarker levels, self-reported disease history, or relevant medication use. Other chronic diseases were determined based on self-reported medical history diagnosed by healthcare professionals and as documented in the questionnaire. The presence or absence of chronic diseases was treated as a covariate in the analysis. Additionally, self-reported health status was included to assess individual health conditions. Besides the aforementioned blood indicators, additional biomarkers such as blood urea nitrogen, serum uric acid, and C-reactive protein (CRP) were analyzed through bioassay.

2.5. Frailty assessment

Frailty was evaluated through the frailty index (FI), a metric derived from the aggregation of various health deficits associated with aging. We constructed a FI using 28 items, encompassing functional limitations, self-reported health status, depressive symptoms, medical conditions, and cognitive status (detailed item definitions are provided in Table S2). The 28 health variables were assigned values of 0 or 1 (where 0 signifies the absence of a health deficit and 1 indicates the presence of a health deficit). The FI was calculated as the ratio of each participant's total item scores to the total number of items, yielding a range of 0 to 1. A higher FI indicated greater frailty, and a frailty status was defined as an FI score of 0.25 or higher [21].

2.6. Statistical analysis

Data analysis was conducted using R software (version 4.4.0). To ensure data quality, the interquartile range (IQR) method was adopted to detect and eliminate outliers, which were treated as missing values. For missing data, variables with a missing rate exceeding 20% were excluded to avoid data bias. Variables with a missing rate lower than 20% were processed using the multiple imputation method.

The AFE encompasses 8 areas with a total of 35 factors, and the total calculated score ranges from 0 to 35. Thus, we divided the participants into four groups based on quartiles: Q1-Q4. The higher the score, the better the quality of the living environment. Measurement data conforming to the normal distribution were expressed as mean ± standard deviation (SD), and the differences between groups were compared using analysis of variance (ANOVA). For the measurement data with non-normal distribution, the median and interquartile range [M (P25, P75)] were expressed, and the differences between groups were compared using the rank sum test (Kruskal–Wallis test). Count data were presented as frequency and percentages (%), and the differences between groups were evaluated using chi-square test or Fisher's exact test. Participants were also grouped based on the occurrence of sarcopenia during the follow-up period.

To evaluate the association between the AFE and sarcopenia and frailty, the Cox proportional hazards model was first used to estimate the hazard ratio (HR) and its 95% confidence interval (CI) between the AFE and sarcopenia and frailty. Model 1 was adjusted for age, sex, and BMI; Model 2 incorporated additional adjustments for current smoking status, current alcohol consumption, ADL status, self-reported health status, marital status, place of residence, educational level, and household income; Model 3 further adjusted for systolic blood pressure, diastolic blood pressure, presence of comorbidities, hemoglobin A1c, glucose, total cholesterol, triglycerides, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, blood urea nitrogen, serum creatinine, uric acid, and cystatin C. The AFE score was entered into each model as both a continuous variable and a categorical variable (quartile groups). Additionally, the 35 individual components of the AFE were analyzed as independent variables to explore their associations with sarcopenia.

To prevent overfitting, the variance inflation factor (VIF) was used to evaluate multicollinearity among variables, and variables with a VIF value ≥5 were excluded. Furthermore, stratified analyses were conducted based on factors such as age, sex, BMI, residence, educational level, ADL, cognitive function, and health status to examine the consistency of the association between AFE, sarcopenia and frailty. Among all the analyses, a P value <0.05 was regarded as statistically significant.

3. Results

3.1. Participant characteristics

Table 1 presents the characteristics of the participants according to the quartiles of AFE score (Q1: 22.53−29.48, Q2: 29.48−31.31, Q3: 31.31−33.06, and Q4: 33.06−35.00). A total of 3,261 participants (baseline age ≥60 years) met the inclusion criteria and were included in the final analysis. The overall study population had a mean age of 66.76 ± 5.67 years, with 1,650 (50.60%) being male. Among these 3,261 older adults, individuals with higher AFE scores were more likely to reside in rural areas, have lower BMI, lower ADL independence, poorer health

Table 1
Baseline characteristics of participants in this study according to age-friendly.

Variable	Q1 (N = 816)	Q2 (N = 815)	Q3 (N = 815)	Q4 (N = 815)	*P*
Age, years, mean (SD)	67.16 (6.05)	66.46 (5.39)	66.50 (5.45)	66.91 (5.74)	0.159
Sex, n (%)					0.864
Female	401.00 (49.14)	412.00 (50.55)	403.00 (49.45)	395.00 (48.47)	
Male	415.00 (50.86)	403.00 (49.45)	412.00 (50.55)	420.00 (51.53)	
BMI, kg/m^2, mean (SD)	23.50 (3.58)	22.91 (3.40)	23.40 (3.51)	22.89 (3.74)	<0.001
Current smoking, n (%)					0.754
Yes	255.00 (31.25)	266.00 (32.64)	248.00 (30.43)	264.00 (32.39)	
No	561.00 (68.75)	549.00 (67.36)	567.00 (69.57)	551.00 (67.61)	
Current drinking, n (%)					0.004
Yes	221.00 (27.08)	254.00 (31.17)	289.00 (35.46)	256.00 (31.41)	
No	595.00 (72.92)	561.00 (68.83)	526.00 (64.54)	559.00 (68.59)	
ADL, n (%)					<0.001
Independent	700.00 (85.78)	638.00 (78.28)	639.00 (78.40)	635.00 (77.91)	
Non-independent	116.00 (14.22)	177.00 (21.72)	176.00 (21.60)	180.00 (22.09)	
Health status, n (%)					0.007
Poor	229.00 (28.06)	225.00 (27.61)	257.00 (31.53)	261.00 (32.02)	
Fair	390.00 (47.79)	441.00 (54.11)	407.00 (49.94)	400.00 (49.08)	
Good	197.00 (24.14)	149.00 (18.28)	151.00 (18.53)	154.00 (18.90)	
Marital, n (%)					0.640
Single	145.00 (17.77)	156.00 (19.14)	137.00 (16.81)	141.00 (17.30)	
Married	671.00 (82.23)	659.00 (80.86)	678.00 (83.19)	674.00 (82.70)	
Residence, n (%)					<0.001
Urban	449.00 (55.02)	236.00 (28.96)	155.00 (19.02)	185.00 (22.70)	
Rural	367.00 (44.98)	579.00 (71.04)	660.00 (80.98)	630.00 (77.30)	
Education, n (%)					0.001
Primary school or below	650.00 (79.66)	661.00 (81.10)	675.00 (82.82)	715.00 (87.73)	
Middle school	117.00 (14.34)	109.00 (13.37)	104.00 (12.76)	73.00 (8.96)	
High school or above	49.00 (6.00)	45.00 (5.52)	36.00 (4.42)	27.00 (3.31)	
Family income, One thousand yuan, mean (SD)	21.83 (24.18)	19.23 (23.00)	17.70 (24.48)	15.65 (22.69)	<0.001
Comorbidity, n (%)					0.316
Yes	606.00 (74.26)	600.00 (73.62)	629.00 (77.18)	602.00 (73.87)	
No	210.00 (25.74)	215.00 (26.38)	186.00 (22.82)	213.00 (26.13)	
SBP, mmHg, mean (SD)	134.69 (21.69)	133.59 (22.01)	134.05 (21.91)	132.42 (21.25)	0.143
DBP, mmHg, mean (SD)	74.62 (11.23)	74.83 (11.84)	74.46 (11.58)	74.65 (10.80)	0.918
HbA1c, mean (SD)	5.15 (0.47)	5.18 (0.47)	5.27 (0.46)	5.17 (0.41)	<0.001
FBG, mg/dL, mean (SD)	105.14 (18.20)	106.71 (17.89)	106.88 (17.11)	105.96 (16.37)	0.029
Total cholesterol, mg/dL, mean (SD)	195.43 (40.23)	195.32 (37.64)	195.75 (36.25)	193.95 (39.03)	0.428
TG, mg/dL, mean (SD)	127.07 (69.22)	120.70 (64.64)	121.47 (66.04)	117.51 (62.01)	0.034
HDL-C, mg/dL, mean (SD)	49.44 (14.68)	51.26 (15.21)	52.21 (15.17)	52.37 (15.95)	0.001
LDL-C, mg/dL, mean (SD)	119.47 (36.86)	117.54 (33.85)	120.20 (32.07)	115.70 (34.47)	0.007
BUN, mg/dL, mean (SD)	16.42 (4.45)	15.93 (4.31)	16.47 (4.62)	16.41 (4.31)	0.060
Serum creatinine, mg/dL, mean (SD)	0.83 (0.18)	0.79 (0.18)	0.79 (0.19)	0.79 (0.18)	<0.001
Uric acid, mg/dL, mean (SD)	4.84 (1.26)	4.46 (1.20)	4.55 (1.31)	4.48 (1.21)	<0.001
Cystatin C, mg/dL, mean (SD)	1.09 (0.24)	1.04 (0.22)	1.08 (0.23)	1.06 (0.22)	<0.001
CRP, mg/L, mean (SD)	1.65 (1.50)	1.48 (1.32)	1.51 (1.31)	1.51 (1.38)	0.210
Frailty index, mean (SD)	0.17 (0.12)	0.19 (0.13)	0.20 (0.13)	0.20 (0.14)	<0.001
Grip strength, kg, mean (SD)	31.32 (9.20)	30.86 (8.64)	31.04 (9.11)	30.04 (9.53)	0.045
ASMI, kg/m^2, mean (SD)	6.71 (1.17)	6.56 (1.13)	6.72 (2.11)	6.63 (1.55)	0.075

BMI, Body mass index; ADL, Activities of daily living; SBP, Systolic blood pressure; DBP, Diastolic blood pressure; FBG, Fasting blood glucose; HDL-C, High-density lipoprotein cholesterol; LDL-C, Low-density lipoprotein cholesterol; BUN, Blood urea nitrogen; CRP, C-reactive Protein; ASMI, Appendicular skeletal muscle mass index; SD, Standard deviation.

status, lower educational attainment, lower family income, lower levels of triglycerides (TG), and higher frailty index (FI) (all $P < 0.05$).

The baseline characteristics of participants (N = 3,261) included in the sarcopenia analysis are presented in Table S3. A total of 297 participants developed sarcopenia during an average follow-up period of 47.84 months. Compared with those without sarcopenia, participants who were diagnosed with sarcopenia were characterized by older age, female sex, lower BMI, rural residence, lower education, and reduced family income. Metabolically, they had lower fasting blood glucose (FBG), HbA1c, serum creatinine, and uric acid, but higher HDL-C, cystatin C and FI. In terms of the environment, sarcopenic individuals had limited access to outdoor exercise facilities and markets, and poorer road tidiness, along with reduced social engagement in senior centers and associations. They also had lower home internet connectivity and reliance on neighbor help.

In addition, we compared the baseline characteristics of excluded participants (N = 4,299) and included participants (N = 3,261). Included participants were younger, had a higher BMI, and higher proportions of current smoking and drinking compared to excluded participants. They were also more likely to have independent ADL and better self-reported health status. Clinically, included participants had lower systolic blood pressure, serum creatinine, uric acid, and cystatin C levels, but higher fasting blood glucose. Notably, they also showed better muscle health, with higher grip strength and ASMI (Table S4).

3.2. Associations of AFE scores with sarcopenia and frailty

We performed Cox regression analysis based on quartile groups of AFE scores (Table 2). After adjusting for demographic, socioeconomic, lifestyle, and metabolic factors (Model 3), we identified a negative association between higher AFE scores and sarcopenia risk. Specifically, participants in the highest quartile had a 46% lower risk of incident sarcopenia (HR: 0.54, 95% CI: 0.38, 0.77) compared with those in the lowest quartile. Notably, the hazard ratios became slightly attenuated but retained significance with increasing model complexity, confirming the independent association between AFE and incident sarcopenia. Meanwhile, we explored the association between AFE scores and frailty risk (Table S5). The regression analysis demonstrated that the negative and significant association between AFE scores and frailty risk still existed (HR: 0.73, 95% CI: 0.60, 0.90).

Table 3 shows the independent associations between specific

Table 2
Association between age-friendly environment and sarcopenia.

	Age-friendly environment score (HR, 95% CI)					*P* for trend[a]
	Continuous variable	Q1 (22.53−29.48)	Q2 (29.48−31.31)	Q3 (31.31−33.06)	Q4 (33.06−35.00)	
Model 1 (95%CI)	0.96 (0.92, 1.00)	Ref.	0.81 (0.58, 1.12)	0.92 (0.66, 1.28)	0.64 (0.46, 0.89)**	0.021
Model 2 (95%CI)	0.93 (0.89, 0.97)**	Ref.	0.64 (0.45, 0.89)**	0.67 (0.47, 0.95)*	0.52 (0.37,0.74)***	0.001
Model 3 (95%CI)	0.93 (0.89, 0.98)**	Ref.	0.66 (0.47, 0.93)*	0.69 (0.49, 0.99)*	0.54 (0.38, 0.77)**	0.002

CI, Confidence interval; HR, Hazard ratio; Ref, Reference.
Model 1 was adjusted for age, sex (male/female) and body mass index.
Model 2 was additionally adjusted for current smokers (yes/no), current drinking status (yes/no), Activities of Daily Living (Independence/Non-independent), health status(poor/fair/good), marital status (single/married), place of residence (urban/rural), education level (primary school or below/middle school/high school or above) and family income.
Model 3 was additionally adjusted for systolic blood pressure, diastolic blood pressure, comorbidities (yes/no), hemoglobin A1c, glucose, total cholesterol, triglycerides, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, blood urea nitrogen, serum creatinine, uric acid and cystatin C.
*$P < 0.05$,**$P < 0.01$,***$P < 0.001$.
[a] *P* for trend was estimated by including the quartile of the age-friendly environment score as a continuous variable.

environmental factors and sarcopenia risk, demonstrating significant inverse relationships for road tidiness, indoor barrier-free facilities, main road quality, structured physical activity groups, neighbor help, and home internet connectivity. Interestingly, the presence of market/convenience store in the community increased the risk of sarcopenia (detailed definitions of AFE composition are provided in Table S1).

3.3. Subgroup analysis and interaction

Subgroup analyses were stratified by age, sex, BMI, education, residence, cognitive function, ADL, and health status (Table 4). For sarcopenia, the results revealed significant association modification by ADL independence ($P < 0.05$ for interaction). Specifically, among individuals with independent ADL, higher AFE scores were associated with a 42% lower risk of incident sarcopenia (HR: 0.58, 95% CI: 0.39−0.85), whereas no significant association was observed in the subgroup of individuals with non-independent ADL. For frailty, significant interactions were found for residence ($P < 0.001$ for interaction) and health status ($P = 0.023$ for interaction) in subgroup analyses (Table S6). In the rural population, those with high AFE scores had a protective effect with a significant trend (HR: 0.68, 95% CI: 0.53−0.87). Furthermore, in participants with poor health status, a clear protective effect of higher environment scores was observed (HR: 0.58, 95% CI: 0.43−0.78). No interactions were detected for other variables (all $P > 0.05$).

3.4. Sensitivity analysis and overlapping risk

A sensitivity analysis including excluded participants with missing covariate data was performed to evaluate the robustness of our findings (Table S7). The association between AFE scores and the risk of incident sarcopenia and frailty remained significant across all adjusted models in this sensitivity analysis, confirming the stability of the primary results.

Next, among 3,261 older adults, data in Table S8 showed that 297 (9.1%) had sarcopenia, 855 (26.2%) had frailty, and 117 individuals exhibited concurrent sarcopenia and frailty, with a significant association between the two conditions ($\chi^2 = 29.32$, $P < 0.001$). Stratified analysis further revealed robust protective effects of higher AFE scores against "sarcopenia only" (HR: 0.23, 95% CI: 0.13−0.41) and "frailty only" (HR: 0.59, 95% CI: 0.47−0.75), though no significant trend was observed for concurrent sarcopenia and frailty (*P* for trend = 0.141) (Table S9).

4. Discussion

Using nationally representative longitudinal data from CHARLS, we investigated the association between AFE and the risk of sarcopenia and frailty in Chinese adults aged ≥60 years over a 4.0-year follow-up period. Our findings revealed a robust inverse association between AFE and the risk of both conditions, with the highest AFE score quartile showing a significantly reduced risk compared to the lowest, even after adjusting for a comprehensive set of confounding variables. These findings provide new insights into how environmental factors may be associated with healthy aging and emphasize the importance of building an age-friendly environment in addressing age-related syndromes such as sarcopenia and frailty.

AFE is a pivotal strategy for achieving the Sustainable Development Goals (SDGs) outlined by the United Nations, and it plays a positive role in enhancing the intrinsic capabilities of older adults and promoting healthy aging [12]. Previous studies have mainly explored the relationship between a single environmental factor and sarcopenia. For instance, the improvement of housing quality was a protective factor against sarcopenia [13]. Our research explored the association of AFE on sarcopenia from multiple dimensions. After adjusting for various demographic and lifestyle factors, a significant relationship was found between AFE and the risk of incident sarcopenia. Although sarcopenia and frailty are classified as different conditions, they share many similarities in etiology and clinical manifestations [22]. Fried et al. proposed that sarcopenia, characterized by muscle loss and changes in physical function, might be a key factor in the occurrence and progression of frailty [23]. Therefore, intervention measures specifically targeting skeletal muscles may have more advantages in preventing and treating frailty [24]. Our research indicated that AFE is also associated with a lower risk of frailty in older adults, which is consistent with previous studies [25].

This study confirmed a significant positive association between neighbors help and better muscle health in older people. The existing literature has analyzed the possible mechanisms of the relationship. As people age, neighbors have become primary social

ties for the elderly [26]. A Japanese study found that neighborly mutual assistance increases dietary diversity and improves nutritional status, both of which are crucial for sarcopenia prevention and treatment [27]. Similarly, our research highlighted that internet use is associated with better muscle health in older adults. Research has found that the use of the internet is associated with higher grip strength, while the frequency of internet use in older patients with sarcopenia is significantly reduced [28]. This could be attributed to the potential of internet use to facilitate the acquisition of knowledge and skills, enhance self-efficacy, cultivate a positive aging attitude, and increase physical activity to improve muscle health [29]. These findings provide substantial evidence for supporting the establishment of age-friendly environment and addressing geriatric syndromes like sarcopenia and frailty.

For the health of older adults, the built environment is another important environmental dimension [30].Walkability and facility convenience are important predictors of physical activity among older adults [31]. The built environment has been shown to be associated with outcomes such as falls, sarcopenia, frailty, and other chronic conditions

Table 3
Association between age-friendly environment components and sarcopenia.

Components of age-friendly environment score	Model 1 HR (95% CI)	*P*	Model 2 HR (95% CI)	*P*	Model 3 HR (95% CI)	*P*
Outdoor Exercise Facilities	1.24 (0.93, 1.65)	0.149	1.05 (0.78, 1.41)	0.769	1.10 (0.81, 1.49)	0.533
Nursing Home	1.17 (0.76, 1.80)	0.478	0.96 (0.62, 1.49)	0.857	0.85 (0.54, 1.33)	0.466
Older Adult Day Care Centre	1.20 (0.64, 2.26)	0.578	0.98 (0.51, 1.88)	0.959	0.99 (0.52, 1.90)	0.986
Use Day Care Services	0.96 (0.42, 2.16)	0.917	1.46 (0.62, 3.45)	0.382	1.41 (0.60, 3.34)	0.435
Clinic	0.67 (0.37, 1.22)	0.191	0.67 (0.36, 1.23)	0.193	0.66 (0.35, 1.23)	0.187
Nearby Pharmacy	0.93 (0.62, 1.38)	0.707	0.84 (0.56, 1.25)	0.383	0.91 (0.61, 1.37)	0.658
Public Restroom	1.13 (0.87, 1.47)	0.347	1.00 (0.76, 1.31)	0.973	1.05 (0.80, 1.39)	0.722
Market Convenience Store	1.62 (1.25, 2.11)	<0.001	1.44 (1.10, 1.89)	0.008	1.50 (1.14, 1.97)	0.004
Community Structure	0.86 (0.63, 1.18)	0.345	0.94 (0.68, 1.30)	0.714	0.92 (0.66, 1.27)	0.607
Community Crowdedness	0.87 (0.69, 1.10)	0.251	0.80 (0.63, 1.03)	0.079	0.84 (0.65, 1.07)	0.162
Handicapped Access	0.99 (0.62, 1.58)	0.975	1.15 (0.72, 1.85)	0.56	1.06 (0.65, 1.71)	0.827
Road Tidiness	0.57 (0.43, 0.75)	<0.001	0.61 (0.45, 0.81)	<0.001	0.59 (0.44, 0.79)	<0.001
Industrial Pollution	1.01 (0.71, 1.42)	0.971	1.00 (0.71, 1.42)	0.995	1.04 (0.73, 1.48)	0.836
Indoor Barrier Free Facilities	0.58 (0.38, 0.88)	0.010	0.59 (0.38, 0.90)	0.014	0.58 (0.37, 0.89)	0.013
Elevators in Buildings	0.82 (0.51, 1.27)	0.707	0.73 (0.45, 1.14)	0.383	0.80 (0.50, 1.26)	0.658
Bus Stop within 1km	0.79 (0.63, 1.00)	0.052	0.88 (0.70, 1.12)	0.311	0.84 (0.66, 1.07)	0.155
Roads Accessible for Cars	0.82 (0.65, 1.03)	0.086	0.91 (0.72, 1.15)	0.416	0.89 (0.70, 1.13)	0.352
Main Road Type	0.64 (0.50, 0.82)	<0.001	0.67 (0.52, 0.86)	0.002	0.67 (0.52, 0.86)	0.002
Card Chess Room	1.19 (0.92, 1.54)	0.191	1.00 (0.76, 1.31)	0.986	1.03 (0.78, 1.35)	0.848
Help Org for Older Disabled	0.85 (0.65, 1.11)	0.238	0.64 (0.48, 0.84)	0.002	0.68 (0.51, 0.90)	0.008
Older Adult Activity Centre	1.09 (0.83, 1.44)	0.515	0.95 (0.71, 1.25)	0.699	0.99 (0.74, 1.32)	0.954
Older Adult Association	1.28 (0.95, 1.72)	0.104	1.09 (0.80, 1.47)	0.597	1.10 (0.81, 1.50)	0.539
Dancing Exercise Org	0.91 (0.70, 1.19)	0.487	0.66 (0.49, 0.88)	0.005	0.70 (0.52, 0.94)	0.017
Calligraphy Painting Assoc	1.02 (0.54, 1.93)	0.946	0.82 (0.43, 1.56)	0.537	0.77 (0.40, 1.48)	0.437
Volunteer Charity Participation	0.53 (0.36, 1.03)	0.059	0.71 (0.45, 1.11)	0.338	0.68 (0.42, 1.06)	0.241
Care for Disabled Patients	1.03 (0.60, 1.31)	0.971	1.00 (0.61, 1.33)	0.995	1.03 (0.62, 1.37)	0.836
Neighbour Interaction	0.86 (0.46, 1.60)	0.627	0.81 (0.43, 1.51)	0.503	0.82 (0.43, 1.56)	0.545
Neighbour Help	0.08 (0.01, 0.39)	0.002	0.10 (0.02, 0.52)	0.006	0.09 (0.02, 0.48)	0.005
Pension Insurance	0.52 (0.27, 0.99)	0.047	0.54 (0.28, 1.04)	0.065	0.51 (0.26, 1.01)	0.053
Health Insurance	1.15 (0.74, 1.79)	0.541	0.98 (0.62, 1.56)	0.94	0.92 (0.57, 1.48)	0.731
Minimum Living Allowance	0.95 (0.70, 1.28)	0.726	0.97 (0.72, 1.30)	0.834	0.98 (0.73, 1.32)	0.901
Pensions for 65 Plus	1.25 (0.91, 1.72)	0.169	1.29 (0.94, 1.79)	0.118	1.31 (0.95, 1.82)	0.105
Telephone at Home	0.69 (0.47, 1.01)	0.059	0.82 (0.56, 1.22)	0.338	0.79 (0.53, 1.17)	0.241
TV at Home	0.81 (0.29, 2.30)	0.693	1.32 (0.42, 4.16)	0.634	1.53 (0.47, 4.97)	0.482
Internet Connection at Home	0.10 (0.03, 0.30)	<0.001	0.15 (0.04, 0.55)	0.004	0.12 (0.03, 0.47)	0.002

CI, Confidence interval; HR, Hazard ratio.
Model 1 was adjusted for age, sex (male/female) and body mass index.
Model 2 was additionally adjusted for current smokers (yes/no), current drinking status (yes/no), Activities of Daily Living (Independence/Non-independent), health status(poor/fair/good), marital status (single/married), place of residence (urban/rural), education level (primary school or below/middle school/high school or above) and family income.
Model 3 was additionally adjusted for systolic blood pressure, diastolic blood pressure, comorbidities (yes/no), hemoglobin A1c, glucose, total cholesterol, triglycerides, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, blood urea nitrogen, serum creatinine, uric acid and cystatin C.

[32]. In line with previous research, our results also suggested that older adults can benefit from high levels of street connectivity [33]. This might be because accessibility to essential resources and destinations addresses the basic needs for muscle health in older adults, thereby encouraging regular physical activity [34]. Indoor barrier-free facilities further reduced the risk of falls and fractures among the elderly [35]. Therefore, linking architectural design to the physical functions of older adults may be associated with a lower risk of incident sarcopenia and frailty.

Our findings revealed that the presence of supermarkets or convenience stores in the community was associated with an increased risk of incident sarcopenia in older adults. Notably, while no prior direct evidence has linked the presence of such retail outlets to sarcopenia risk, nutritional intake is well established as a key mediator of sarcopenia development [36]. Numerous studies have demonstrated that convenience stores and small grocery stores typically stock high-calorie, low-nutrient processed foods (often categorized as “junk foods”), a factor associated with higher obesity prevalence and suboptimal dietary patterns among residents [37,38]. This discrepancy in food offerings is

Table 4
Subgroup analyses of the association between age-friendly environment and sarcopenia.

Subgroup	Age-friendly environment score (HR, 95% CI)					*P* for trend[a]	*P* for inter-action[b]
	Continuous variable	Q1 (22.53-29.48)	Q2 (29.48−31.31)	Q3 (31.31−33.06)	Q4 (33.06−35.00)		
Age							0.379
<75 years	0.93 (0.87, 0.98)*	Ref.	0.58 (0.38, 0.89)*	0.69 (0.45, 1.06)	0.49 (0.32, 0.76)**	0.013	
> = 75 years	0.94 (0.86, 1.03)	Ref.	0.94 (0.50, 1.78)	0.63 (0.31, 1.28)	0.61 (0.32, 1.17)	0.087	
Sex							0.429
Female	0.93 (0.87, 0.99)*	Ref.	0.57 (0.35, 0.93)*	0.68 (0.42, 1.11)	0.44 (0.27, 0.72)**	0.006	
Male	0.94 (0.87, 1.01)	Ref.	0.87 (0.52, 1.46)	0.67 (0.38, 1.18)	0.70 (0.42, 1.16)	0.122	
BMI							0.713
<25 kg/m^2	0.93 (0.89, 0.98)**	Ref.	0.66 (0.46, 0.93)*	0.67 (0.47, 0.96)*	0.53 (0.37, 0.75)***	0.002	
> = 25 kg/m^2	0.97 (0.70, 1.32)	Ref.	0.24 (0.01, 5.75)	1.37 (0.12, 15.18)	0.61 (0.05, 6.77)	0.974	
Residence							0.570
Urban	0.91 (0.83, 1.00)	Ref.	0.53 (0.22, 1.29)	0.88 (0.35, 2.25)	0.42 (0.19, 0.93)*	0.051	
Rural	0.93 (0.88, 0.98)*	Ref.	0.69 (0.46, 1.02)	0.72 (0.48, 1.07)	0.53 (0.35, 0.79)**	0.006	
Education							0.161
Primary school or below	0.94 (0.89, 0.98)**	Ref.	0.60 (0.41, 0.87)**	0.71 (0.49, 1.03)	0.53 (0.37, 0.77)**	0.006	
Middle school	0.95 (0.72, 1.25)	Ref.	0.59 (0.10, 3.43)	0.11 (0.01, 1.12)	0.66 (0.11, 3.82)	0.705	
High school or above	0.87 (0.60, 1.10)	Ref.	0.57 (0.39, 1.18)	0.68 (0.46, 1.03)	0.48 (0.33, 1.16)	0.560	
ADL							0.020
Independent	0.94 (0.89, 0.99)	Ref.	0.71 (0.48, 1.04)	0.79 (0.54, 1.18)	0.58 (0.39, 0.85)*	0.018	
Non-independent	0.92 (0.83, 1.03)*	Ref.	0.54 (0.24, 1.23)	0.43 (0.18, 1.03)	0.43 (0.19, 0.97)**	0.061	
Health status							0.067
Poor	0.95 (0.87, 1.02)	Ref.	0.55 (0.31, 0.99)*	0.40 (0.21, 0.75)**	0.57 (0.32, 0.99)*	0.078	
Fair	0.90 (0.84, 0.97)**	Ref.	0.84 (0.50, 1.41)	0.86 (0.50, 1.47)	0.46 (0.26, 0.79)**	0.006	
Good	0.97 (0.86, 1.10)	Ref.	0.30 (0.11, 0.82)*	1.10 (0.43, 2.83)	0.51 (0.20, 1.29)	0.700	
Cognitive function							0.192
Normal cognitive function	0.91 (0.83, 1.00)	Ref.	0.53 (0.22, 1.29)	0.88 (0.35, 2.25)	0.42 (0.19, 0.93)*	0.051	
Low cognitive function	0.93 (0.88, 0.98)*	Ref.	0.69 (0.46, 1.02)	0.72 (0.48, 1.07)	0.53 (0.35, 0.79)**	0.006	

CI, Confidence interval; HR, Hazard ratio; Ref, Reference.
Model adjusted for all variables except the subgroup variable, including age, sex (male/female), body mass index, current smokers (yes/no), current drinking status (yes/no), Activities of Daily Living (Independence/Non-independent), health status(poor/fair/good), marital status (single/married), place of residence (urban/rural), education level (primary school or below/middle school/high school or above), family income, systolic blood pressure, diastolic blood pressure, comorbidities (yes/no), hemoglobin A1c, glucose, total cholesterol, triglycerides, high-density lipoprotein cholesterol, low-density lipoprotein cholesterol, blood urea nitrogen, serum creatinine, uric acid and cystatin C.
*$P < 0.05$,**$P < 0.01$,***$P < 0.001$.
[a] *P* for trend was estimated by including the quartile of the age-friendly environment score as a continuous variable.
[b] *P* for interaction was calculated by adding an interaction term of the quartile of the age-friendly environment score and the stratification variable in Cox regression models.

particularly pronounced in rural communities: these areas are disproportionately affected by limited access to large supermarkets and healthy food options, while small convenience stores remain more prevalent [39,40]. Thereby the presence of supermarkets or convenience stores in this study might be associated with an increased risk of incident sarcopenia by influencing suboptimal nutritional intake among older adults. It is necessary to further study the impact of the food environment on sarcopenia in the future.

The observed association between age-friendly environments and better muscle health in older adults is strongly contingent on their functional autonomy, especially independent ADL ability. Among older adults with independent ADL, more complete community facilities and social support can directly promote their physical activities, thereby maintaining muscle mass and function [41]. However, older adults with non-independent ADL often have limited mobility and rely long-term on care, which hinders their utilization of community resources and weakens the observed association between environment and muscle health [42]. Meanwhile, personalized support (such as home rehabilitation services and home health guidance) should be provided for individuals with non-independent ADL to address underutilization of community AFE resources due to mobility restrictions. Our subgroup analysis also revealed that the negative correlation between AFE and frailty was more pronounced in rural areas and among people with poorer health conditions. Issues such as inadequate infrastructure and limited neighborhood resource environment are widespread in rural areas, which makes rural older adults more sensitive to environmental improvements [43]. Older adults with poorer health conditions, due to their higher physical vulnerability and greater environmental dependence, may benefit more from the support of an age-friendly environment [44].

Stratified analysis revealed that the AFE exerted no significant protective effect on older adults with concurrent sarcopenia and frailty, in striking contrast to its robust protective role against isolated sarcopenia or isolated frailty. This null finding is attributed to the unique pathophysiological and functional traits of this comorbid subgroup. First, concurrent sarcopenia and frailty involve mutually reinforcing pathophysiological mechanisms, creating a vicious cycle that surpasses AFE's protective capacity [45]. Second, individuals with comorbid sarcopenia and frailty frequently exhibit reduced utilization of AFE resources, primarily due to mobility impairments [46]. Third, AFE is designed for primary prevention or addressing mild health deficits, not for reversing established severe syndromes [47,48]. These findings underscore that concurrent sarcopenia and frailty cannot be addressed by AFE alone; instead, AFE should serve as a supportive component, combined with targeted medical and rehabilitative interventions.

These findings carry significant policy implications for advancing healthy aging, emphasizing age-friendly environment as public health intervention cornerstones. However, there are still several limitations that warrant consideration. First, results are based on CHARLS, a prospective cohort study focusing on the urbanization process in China and its impact on middle-aged and older adults. Therefore, caution should be exercised when applying our findings to populations in other countries. Second, the questionnaires on age-friendly community environments were administered to and answered by community officials, and the data would be more accurate if they were cross-checked with other sources and local residents. Third, the CHARLS database lacks records of participants' dietary factors and nutrient intake, which are key potential mediating pathways linking environmental exposure to sarcopenia and

frailty. This may lead to residual confounding and thus affect the accuracy of the results.

5. Conclusions

This study highlights that constructing an age-friendly environment is of great significance for preventing incident sarcopenia and frailty among older adults in China. This serves as an important strategy for promoting healthy aging and provides a robust basis for policymakers to prioritize age-friendly environment construction as a policy goal.

CRediT authorship contribution statement

All authors read and approved the final version of the manuscript. XL and ZCY have verified the underlying data. Conceptualisation: JZ; Formal Analysis: HL, MS; Data curation: XL, ZCY, ZHW, HL; Data verification: ZCY, HL, JZ, BAH, MZ; Methodology: MZ, BAH; Investigation: All authors; Writing-original draft: XL; Writing-review & editing: All authors.

Consent for publication

Not applicable.

Ethics approval and consent to participate

The Biomedical Ethics Review Committee of Peking University approved CHARLS, and all participants were required to provide written informed consent. The ethical approval number was IRB00001052-11015. All participants provided written informed consent.

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There are no additional relationships to disclose.

Patents and intellectual property

There are no patents to disclose.

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Data sharing statement

Support the results of data set from the China health and retirement longitudinal study (CHARLS) project public access, after registration is available from: https://charls.charlsdata.com/pages/data/111/zh-cn.html.

Declaration of competing interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.jnha.2025.100725.

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