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City-wide cognitive function screening study of older adults in Beijing reveal protective association of urban green space

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ABSTRACT

Green spaces offer a passive yet impactful component of urban design, with the potential to enhance cognitive function and reduce the risk of dementia in older adults. While the cognitive benefits of green spaces are recognized, particularly in improving cognitive performance among older populations, this area remains a critical yet underexplored domain within urban health research. This study aimed to investigate the association of exposure to green spaces with cognitive function among older adults across urban Beijing. A total of 62,333 participants from 114 communities were included in a city-wide screening program, utilizing an adapted version of the Mini-Mental State Examination (MMSE) and the Episodic Memory Test (EMT) to assess cognitive function. Green space exposure was quantified at the community level through multiple metrics, including accessibility (distance to large green spaces and parks), availability (Normalized Difference Vegetation Index [NDVI] and proportion of green space), and visibility (green view ratio). Multilevel linear and logistic regression models, adjusted for demographic and environmental covariates, were applied to data from 324 community healthcare centers. The findings indicated that greater exposure to green spaces, across all measured metrics, was associated with better cognitive function scores. A significant threshold was identified at 500 m from parks, beyond which cognitive function scores declined progressively with increasing distance. These results have important implications for urban planning, suggesting the need for accessible, community-level green spaces to support cognitive health for older adults in urban China.

1. Introduction

The WHO Age-Friendly Cities framework proposes that outdoor spaces and buildings are interconnected domains of urban life that can help identify and address barriers to the well-being and participation of older people (World Health Organization, 2007). Among the various

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attributes of outdoor spaces, green space has garnered growing interest in recent years. Urban green spaces encompass areas that are partially or fully covered with vegetation (e.g., trees, grass, and bushes), which are commonly used in cities as recreational areas to improve environmental quality and promote public health.

In recent years, urban greening has increasingly been framed around accessibility-oriented planning principles. One prominent example is the'3-30-300 rule' (Konijnendijk, 2023), which has been proposed to build healthier and greener cities by setting three key thresholds: (1) having at least 3 well-established trees in view from every home, school, and place of work; (2) ensuring no less than a 30% tree canopy in every neighborhood; and (3) living no more than 300m to the nearest public green space from every residence. In parallel, the Chinese government has issued its own urban park construction guidelines, which aim to ensure that residents can "see greenery within 300 m and access parks within 500 m" (The Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2024). These frameworks underscore a shared emphasis on proximity, availability, and visibility of green spaces in daily living environments. However, empirical evidence remains limited regarding which specific greenness indicators, such as greenness versus park proximity, in relation to specific health outcomes.

The global increase in cognitive decline represents a major public health challenge, driven in part by population aging and the growing prevalence of age-related cognitive impairment (Nichols et al., 2019; Livingston et al., 2024). Contact with natural outdoor environments has been identified as crucial and necessary in brain development (Dadvand et al., 2015), and should also have a role in preventing or delaying neuro-degeneration and associated cognitive decline, especially in low- and middle-income countries (LMICs) where community engagement is high (Zagnoli et al., 2022). As the capital of China, Beijing has undergone rapid urbanization in recent years due to population growth, economic development, and inner-city redevelopment, intensifying the trade-offs between human activities and urban green space (Yang et al., 2021a). However, the association between urban green spaces, particularly in the central urban area, and the cognitive function of older adults in Beijing remains unclear. Existing research on the association between urban green spaces and cognitive function has predominantly relied on a single metric to assess green space exposure (Zhu et al., 2019; Cherrie et al., 2018; Hystad et al., 2019; Wu et al., 2015). However, different indicators of greenness (e.g., proximity, vegetation density, and visual exposure) capture distinct spatial scales and experiential pathways, which may result in heterogeneous or non-linear associations with health outcomes. To date, few studies have comprehensively examined the association between different indicators of green space exposure and cognitive function on a city-wide scale (Zagnoli et al., 2022; Trott et al., 2025), or explicitly evaluated the distinct exposure pathways (Battiston and Schifanella, 2024) and potential threshold or non-linear exposure-response patterns (Wang et al., 2026). This is a critical area of research, as urban green spaces represent a cost-effective, nature-based solution that may have important implications for population health. This study aims to explore the association between urban green spaces and cognitive function among Beijing's older adults, focusing on identifying potential non-linear or threshold effects within these associations.

2. Methods

2.1. Study design, setting, and population

This study utilized data from the Beijing Community-based Cognitive Function Screening (CCFS) program, a city-wide, cross-sectional screening initiative conducted across central districts of Beijing in 2019 (Beijing Municipal Health Commission, 2021). The CCFS program is implemented through community healthcare centers and targets community-dwelling older adults residing within administratively defined urban communities. Participants were recruited through routine community health service visits and invited to undergo standardized cognitive screening. Individuals with available cognitive assessment data, key covariates, and valid community identifiers were eligible for inclusion. Additional details on the CCFS program design and recruitment procedures are provided in **Supplementary Note 1**.

The CCFS program interviews participants in healthcare centers using a set of core questionnaires covering three domains: (1) demographic and socioeconomic characteristics, (2) medical history and health conditions, and (3) cognitive assessments. Cognitive function was assessed using two core instruments: the Mini-Mental State Examination (Mini-MMSE) and the Episodic Memory Test (EMT) (**Supplementary Note 2** for detailed items) (China Association of Gerontology and Geriatrics and Academy of Cognitive Neuroscience and Health; Chinese Geriatrics Society, 2019).

2.2. Cognitive function tests

The Mini-MMSE is an adapted and condensed version of the classical MMSE, specifically developed for rapid administration in large-scale community settings. It assesses global cognitive function across four domains, including memory, orientation, logic, and attention, with total scores ranging from 0 to 13. The EMT employs a structured encoding-retrieval paradigm to evaluate episodic memory performance, with scores ranging from 0 to 100. By specifically targeting memory processes that are sensitive to early cognitive decline, the EMT complements the Mini-MMSE and enhances detection of subtle cognitive variation that may not be fully captured by brief global screening instruments.

Both instruments have been evaluated in independent community-based methodological validation studies conducted within the Beijing Aging Brain Rejuvenation Initiative (BABRI) (Yang et al., 2021b). When benchmarked against comprehensive neuropsychological batteries and Petersen criteria, the Mini-MMSE demonstrated acceptable screening validity and discriminative performance for mild cognitive impairment, supporting the use of the Mini-MMSE together with the EMT for population-based cognitive screening among older adults (Jiang et al., 2022).

2.3. Assessment of greenness exposure assessment

Community-level greenness exposure was assessed using the geographical coordinates of each community centroid, which represented the smallest spatial unit available because individual residential coordinates were not accessible due to privacy restrictions. Communities in Beijing are compact, high-density administrative units, making centroid-based exposure assignment a commonly used and pragmatic approach in urban epidemiological studies (Xu et al., 2021; Zhou et al., 2025).

Greenness indicators were selected a priori to capture three complementary exposure dimensions: accessibility, availability, and visibility (**Supplementary Note 3**). Accessibility was measured as the distance to large green spaces (>5000 m^2) and distance to parks. Availability was quantified using the Normalized Difference Vegetation Index (NDVI) and the proportion of green space within each community. Visibility was assessed using the green view ratio, derived from street view images using deep learning-based semantic segmentation. Conceptual illustrations of the three greenness exposure dimensions examined in this study are shown in Fig. 1.

Spatial data for large green spaces and parks were based on municipal geographic datasets compiled closest to the 2019 study period. NDVI was derived from satellite imagery acquired in 2019, corresponding to the year of the cognitive screening and primarily representing peak growing-season conditions. Street-level images used to calculate the green view ratio were obtained from Baidu Map Street View and were predominantly captured in or around 2019. In contrast, the proportion of green space was calculated using the most recent officially available land-use classification dataset (2014), resulting in an

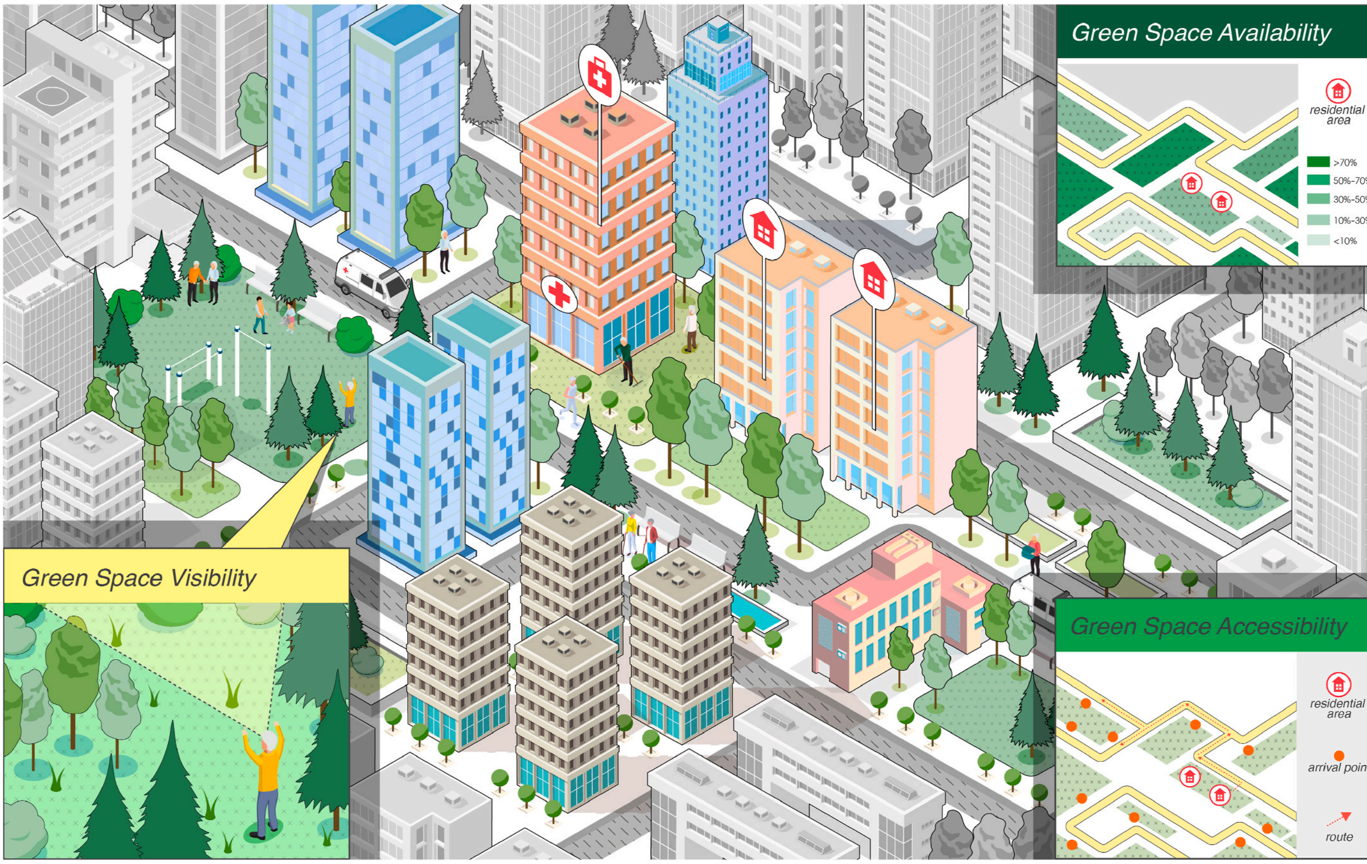

Fig. 1. Conceptual framework of greenness exposure dimensions.
The figure illustrates the three greenness exposure dimensions examined in this study: accessibility (distance to large green spaces and parks), availability (NDVI and proportion of green space), and visibility (street-level green view ratio). This schematic is intended to illustrate exposure constructs and pathways rather than observed spatial distributions. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

approximate five-year temporal lag relative to the cognitive assessment.

2.4. Covariates

We adjusted for a set of individual- and community-level covariates selected a priori based on prior literature and data availability. Individual level covariates included age, sex, marital status, educational attainment, occupational class, and number of chronic conditions. Community-level covariates included annual mean $PM_{2.5}$ concentration, economic vitality, population density, and density of general hospitals. Definitions, data sources, and measurement details for all covariates are detailed in **Supplementary Note 4**.

2.5. Statistical analysis

Within the framework of the CCFS program, we restricted the analysis to communities located within the Fifth Ring Road of Beijing, which represents the city's urban core and is characterized by high population density and intensive built development (Supplementary Fig. 1). We described the characteristics of participants using percentage (%) for categorical data and mean (standard deviation, SD) for continuous data. Since the cognitive test scores were right-skewed distributions (Supplementary Fig. 2), we log-transformed them in primary analyses to improve normality and model fit. Multivariable linear regression models were used to examine the associations between per unit increase in greenness and ln-transformed cognitive scores. Cognitive outcomes were dichotomized into screening-based normal cognitive function using age-and instrument-specific thresholds. Multivariable logistic regression models were used to examine the associations between per interquartile range [IQR] increase in greenness exposure and the odds of normal cognitive function. For the non-linear associations, restricted cubic spline (RCS) models with 3 knots at fixed and equally spaced percentiles (25th, 50th, and 75th) were performed to assess the nonlinearity and exposure-response effects of each community greenness measurements on cognitive function. In sensitivity analyses, models using untransformed cognitive test scores to assess robustness. Participants with complete cognitive function assessments and valid community location identifiers were included in the analyses; individuals with missing outcome data or missing community information were excluded, and no imputation was performed. All estimates are presented as regression coefficients (β) or odds ratio (OR) with 95% confidence intervals (CIs). All analyses and RCS plotting were conducted using Stata 16.0 and R 4.4.2 (R Project for Statistical Computing).

3. Results

We studied 324 community healthcare centers across 114 communities in Beijing. A total of 62,333 participants were included in the analysis, with a mean (standard deviation, SD) age of 70.9 (6.5) years, comprising 60.5% females and 39.5% males. Most participants were married (96.0%), and approximately 70.5% reported a non-manual occupation. Educational attainment varied, with 42.9% having completed high school or higher education, while 18.8% had primary school education or below, including 1.8% who were illiterate. Further details regarding participants' sociodemographic characteristics, health status, and cognitive performance can be found in Table 1.

The mean (SD) values for various green space exposure, including distance to large green space (>5000 m^2) [each unit of 1 km], distance

Table 1
Sociodemographic and health characteristics of study participants and their cognitive test scores in the CCFS program.

Variables	All participants		Mini-MMSE score		EMT score	
	Nos.	%	Mean	SD	Mean	SD
Age						
Mean (SD)	70.9	6.5				
Sex						
Male	24638	39.5%	12.36	1.26	90.61	9.32
Female	37695	60.5%	12.34	1.30	90.62	9.12
Marital status						
Married	59855	96.0%	12.37	1.26	90.73	9.12
Widow	2171	3.5%	11.87	1.77	87.66	10.87
Divorced/Never married/Separate	280	0.4%	12.05	1.39	89.53	8.96
Other	27	0.1%	12.48	1.09	89.67	6.97
Main occupation						
Non-manual	43930	70.5%	12.36	1.26	91.03	8.97
Manual	9626	15.4%	12.28	1.37	89.25	10.06
Others/unemployed	8777	14.1%	12.36	1.31	90.04	9.16
Educational level						
Coll./Uni.	13142	21.1%	12.40	1.17	90.70	8.66
High school	13595	21.8%	12.43	1.17	90.85	9.04
Secondary school	23883	38.3%	12.41	1.15	90.79	8.95
Primary school or below	10581	17.0%	12.17	1.55	90.10	10.09
Illiterate	1132	1.8%	11.27	2.55	88.06	12.39
Years of schooling						
Mean (SD)	9.99	3.6				
Number of chronic conditions						
0	13099	21.0%	12.47	1.15	90.84	9.01
1 to 2	31213	50.1%	12.37	1.26	90.74	9.14
3 to 4	14526	23.3%	12.26	1.35	90.36	9.31
≥5	3495	5.6%	12.06	1.59	89.75	9.89

to parks [1 km], NDVI [0.01], proportion of green space [0.01], and green view ratio [0.01], were as follows: 0.28 (0.22), 0.50 (0.31), 0.38 (0.04), 0.11 (0.17), and 0.08 (0.05), respectively (Table 2). The spatial distributions of these green space exposures within the 5th ring roads in Beijing are displayed in Fig. 2 for distance to large green spaces and parks and in Supplementary Fig. 3 for other greenness measurements.

3.1. Characteristics associated with cognitive functions

The mean scores were 12.3 (SD 1.3) out of 13 in the adapted Mini-Mental State Examination (Mini-MMSE) and 90.6 (9.2) out of 100 in the Episodic Memory Test (EMT). Each year increase in age is associated with a 0.025 (0.023-0.027) decrease in Mini-MMSE scores and 0.143 (0.132-0.155) in EMT scores (Supplementary Table 1). The spatial distributions of cognitive scores within six central districts are shown in Supplementary Fig. 4. Both cognitive test scores were associated with a range of baseline characteristics (Supplementary Fig. 5), and all these characteristic variables were included as covariates in subsequent analyses, along with additional environmental factors (Supplementary Table 2).

3.2. Association between increased greenness and cognitive functions

Table 3 shows the results of multiple regression analysis examining the association between per unit increase in greenness measurements and ln-transformed cognitive scores. In the fully adjusted model, we observed positive associations between increased greenness and log-transformed Mini-MMSE scores. The associations included distance close to large green space (β = 0.048, 95% CI = 0.043 to 0.053), distance close to parks (β = 0.011, 95% CI = 0.008 to 0.015), NDVI (β = 0.067, 95% CI = 0.041 to 0.094), proportion of green space (β = 0.008, 95% CI = 0.001 to 0.014), and green view ratio (β = 0.032, 95% CI = 0.009 to 0.055). A similar pattern was observed for EMT scores in relation to distance close to large green space and parks, although not for NDVI, proportion of green space, or green view ratio. These sensitivity analyses with untransformed cognitive test scores showed patterns of association that were consistent with the primary analyses (Supplementary Table 3).

Fig. 3 presents the non-linear associations between per unit increase in distance to large green space and parks and ln-transformed cognitive scores, using restricted cubic splines (RCS). The smooth curves of the associations between greenness measurements and cognitive scores agreed well. An exposure-response pattern was evident concerning the distance to large green spaces. In contrast, the distance to parks exhibited an inverted U-shape association with Mini-MMSE and EMT scores, with a turning point at a radius of 0.5 km (Fig. 3). A similar inverted U-shaped relationship was also observed for NDVI and the proportion of green space, with corresponding turning points at radius of 0.40 and 0.25, respectively, while a linear association was observed for the green view ratio (Supplementary Fig. 6).

3.3. Association between per IQR increase in greenness and risk of cognitive decline

After categorizing cognitive function scores, we investigated the associations between the increase in greenness measurements per IQR and the likelihood of maintaining healthy cognition (Table 4). In a fully adjusted model, per IQR increment in all greenness measurements showed positive associations with higher odds of maintaining healthy cognitive function, as assessed by Mini-MMSE. Similar patterns were observed in the association of greenness measurement with EMT scores, except for NDVI and the green view ratio.

4. Discussion

Community green space was associated with better cognitive function in the elderly population in Beijing, China. Our screening data revealed heterogeneous exposure-response patterns across greenness indicators, with distance to green space and green view ratio showing largely monotonic associations with cognitive performance, while distance to parks, NDVI, and proportion of green space exhibited inverted U-shapes relationships with cognitive scores. This study is among the first to explore the relationship between various measurements of greenness and cognitive health in older adult, utilizing representative city-wide screening data.

There exists a scarcity of studies investigating the association

Table 2
Descriptive statistics of community-level green space exposure indicators.

Green space measures	Mean across communities	SD	Min	Max	Median	25th	75th
Distance to large green space (>5000m^2) [1 km]	0.28	0.22	0.00	1.10	0.24	0.12	0.38
Distance to parks [1 km]	0.50	0.31	0.03	1.75	0.47	0.29	0.66
NDVI [0.01]	0.38	0.04	0.28	0.49	0.37	0.35	0.41
Proportion of green space [0.01]	0.11	0.17	0.00	1.00	0.05	0.00	0.13
Green view ratio [0.01]	0.08	0.05	0.01	0.50	0.07	0.05	0.09

Values summarize community-level greenness indicators assigned using centroid-based exposure assessment. Statistics reflect between-community variation and do not capture within-community heterogeneity.

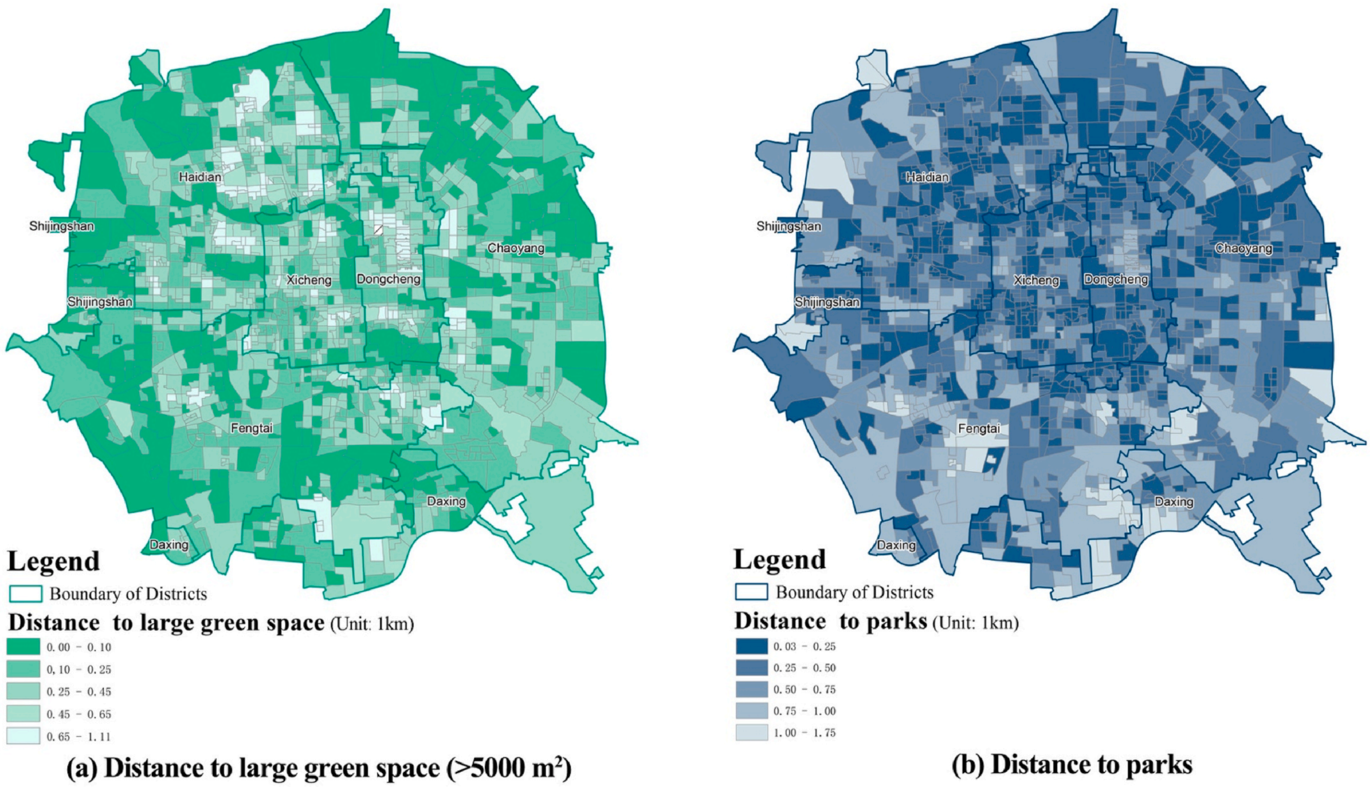

Fig. 2. The spatial distributions of (a) Distance to large green space and (b) Distance to parks within the 5th Ring Roads in Beijing. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 3
Adjusted β with 95% CI between per unit increase in greenness and log-transformed cognitive test scores in adjusted multivariable regression models[a].

Green space measures	log Mini-MMSE scores			log EMT scores		
	β	95%	CI	β	95%	CI
Distance close to large green space (>5000m2) [1 km]	0.048	0.043	0.053	0.030	0.026	0.035
Distance close to parks [1 km]	0.011	0.008	0.015	0.005	0.001	0.008
NDVI [0.01]	0.067	0.041	0.094	−0.018	−0.040	0.005
Proportion of green space [0.01]	0.008	0.001	0.014	0.002	−0.004	0.007
Green view ratio [0.01]	0.032	0.009	0.055	0.002	−0.018	0.022

Inference is based on effect estimates and confidence intervals rather than statistical significance thresholds.

[a] Adjusted for age, sex, marital status, occupational class, educational level, Number of chronic conditions, $PM_{2.5}$, Economic vitality, Population density, and density of general hospitals.

between residential greenness and cognitive function among older adults (Zagnoli et al., 2022). Previous research has produced inconsistent outcomes regarding these associations (Zhu et al., 2019; Cherrie et al., 2018; Wu et al., 2015), with the majority of these studies predominantly relying on single metrics to assess greenness exposure (Zagnoli et al., 2022). Given the complex spatial configuration of greenspaces and population density in dense urban environments, different greenness indicators may capture distinct exposure pathways and operate at different spatial scales, potentially yielding heterogeneous or non-linear exposure-response patterns. Consequently, reliance on a single indicator may be insufficient to differentiate meaningful exposure contrasts across neighborhoods or population subgroups, even when focusing on a specific dimension of green space accessibility (Battiston and Schifanella, 2024). To address this limitation, our study incorporated multiple metrics, encompassing the accessibility, availability, and visibility of green spaces, enabling us to have a more comprehensive assessment of community greenness in relation to cognitive function in older adults.

The heterogeneous dose-response patterns observed across greenness indicators likely reflect the multidimensional nature of urban green environments rather than model inconsistency (Klompmaker et al., 2022). The indicators examined were selected a priori to capture distinct exposure dimensions, which differ in spatial scale, experiential pathways, and behavioral relevance (Zare Sakhvidi et al., 2025). Accordingly, each indicator was modeled separately using flexible spline functions, an intentional model specification designed to minimize collinearity and reduce the risk of overfitting while allowing exposure-response shapes to differ across dimensions. As a result, approximately linear associations may be observed for certain greenness indicators, whereas non-linear relationships may emerge for others once saturation effects or competing mechanisms become relevant.

Notably, the inverted U-shaped associations identified for several greenness measures are epidemiologically plausible and mirror recent dose-response evidence linking intermediate greenness exposure to the lowest dementia risk (Zagnoli et al., 2022). Such patterns may reflect a balance between beneficial effects of greenness (e.g., stress reduction and environmental buffering) and potential countervailing factors at higher exposure levels, including reduced walkability or access to services (Dong et al., 2024). Methodological factors may also contribute, as centroid-based exposure assignment and temporal heterogeneity across datasets may introduce non-differential misclassification, likely attenuating associations rather than producing spurious non-linearity (Jimenez et al., 2022; Larkin and Hystad, 2019). To minimize collinearity and overfitting, greenness indicators were modeled separately, and non-linearity was assessed using restricted cubic splines with pre-specified knots. Sensitivity analyses yielded consistent

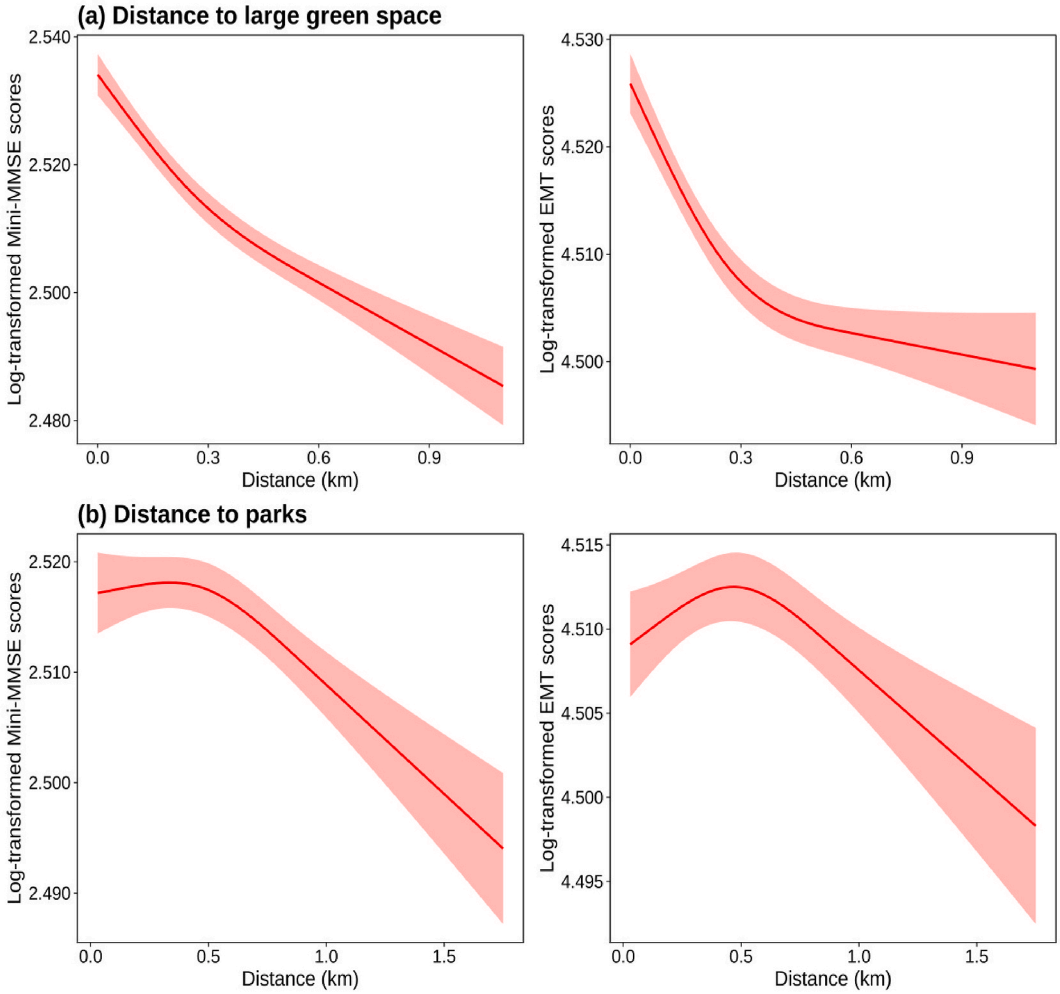

Fig. 3. RCS for the association between per unit increase in a) distance to large green space and b) distance to parks and ln-transformed cognitive scores. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 4
Adjusted OR with 95% CI for the association between per IQR increase in greenness and cognitive health, based on multivariable logistic regression models.

Green space measures	Normal cognitive functions					
	Mini-MMSE tests			EMT tests		
	OR	95%	CI	OR	95%	CI
Distance close to large green space (>5000m^2) [1 km]	1.116	1.094	1.139	1.113	1.075	1.152
Distance close to parks [1 km]	1.026	1.005	1.046	1.044	1.009	1.080
NDVI [0.01]	1.088	1.065	1.111	1.003	0.968	1.040
Proportion of green space [0.01]	1.080	1.058	1.102	1.096	1.059	1.134
Green view ratio [0.01]	1.032	1.011	1.054	1.022	0.987	1.058

Inference is based on effect estimates and confidence intervals rather than statistical significance thresholds.
Normal cognitive functions: Mini-MMSE Q1-Q3 total scores = 5, Q4≥4 and Q5≥2; EMT total scores ≥74.3 at age 60 or below, ≥73.5 at age 60-69, and ≥71.5 at age 70 or above.
Adjusted for age, sex, marital status, occupational class, educational level, Number of chronic conditions, $PM_{2.5}$, Economic vitality, Population density, and density of general hospitals.

exposure-response patterns, supporting the robustness of these findings. These findings should therefore be interpreted as descriptive, observational relationships reflecting the complexity of urban greenness exposure, rather than as evidence of causal thresholds, and warrant confirmation in longitudinal and mechanistic studies.

Our study observed that greater greenness accessibility, particularly shorter distance to large green spaces, was associated with better cognitive performance on screening measures. Similar associations between access to green spaces and cognitive outcomes have been reported in Western settings (Besser et al., 2021; Prohaska et al., 2009). Access to green space and parks may stimulate encouragement in physical activities (Ribeiro et al., 2015) and promote social interaction (Peters et al., 2010). These opportunities, such as increased walking and interpersonal engagement among older adults, may enhance cognitive function. These pathways are plausible but could not be directly examined in the present study, and therefore should be interpreted cautiously.

Our analysis further revealed a threshold-like spatial pattern, with cognitive function scores showing stronger associations within approximately a 500-m radius of green spaces, beyond which cognitive performance tended to decline with increasing distance. This distance threshold is conceptually consistent with the China's "500-m access to parks" planning principle and aligns with international urban greening framework, such as the European 3-30-300 guideline, which emphasize access to green spaces within short, walkable distances. However, given the cross-sectional design and potential exposure misclassification, this pattern should be interpreted as an observational association rather than evidence of policy effectiveness.

In contrast to the emphasis on 'access to green space', China's urban greening policies have historically given less attention to other dimensions of greenness, such as 'residential green' and 'visual green'. Our study identified that green availability measures, including NDVI and the proportion of green space, exhibited non-linear, inverted U-shaped relationships with cognitive function scores, while green visibility demonstrated a largely linear pattern. These heterogeneous exposure-response shapes suggest that different greenness indicators capture distinct dimensions of environmental exposure and may operate through partially different pathways in dense urban contexts.

To our knowledge, this is the first population-based studies to examine the association between visible green space and cognitive function among older adults. Numerous hypothesized mechanisms underlying the cognitive benefits of urban green spaces or natural environments highlight the potential relevance of visual exposure to greenery (Zhang et al., 2023), including stress reduction, attentional restoration, and sensory engagement. In addition, previous research has shown modest correlations between the Green View Index (GVI) and other green space metrics (ranging from −0.02 to 0.50), suggesting that measures derived from Google Street View (GSV) capture distinct and complementary information about individuals' exposure to green spaces (Larkin and Hystad, 2019). These findings highlight the importance of integrating these two components of urban greening into China's urban greening policies, offering new avenues for enhancing public health through urban planning.

5. Strengths and limitations

A key strength of our study is its city-wide implementation of the screening program, which facilitated the collection of a large, representative sample and ensured the reliability of the data through a well-established registration process. Importantly, this is the first study to employ multiple measures of greenness exposure in relation to cognitive function, offering a comprehensive evaluation of the potential health effects of community green spaces.

Certain limitations merit consideration. First, the cross-sectional design precludes inference about temporal ordering between greenness exposure and cognitive function, and thus reverse causality cannot be excluded. Longitudinal studies are needed to clarify directionality and cumulative effects. Second, cognitive function was assessed using brief screening instruments designed for population-level surveillance rather than clinical diagnosis. Ceiling effects are common in community-based cognitive screening samples with a high proportion of cognitively unimpaired participants and may limit sensitivity for detecting clinical impairment. However, because the present analyses focused on population-level variation in cognitive performance across environmental exposure gradients rather than diagnostic classification, relative differences in screening-based scores remain informative. Third, although several greenness indicators (e.g., NDVI and green view ratio) were derived from imagery acquired in or around the 2019 screening year, our assessment of greenness exposure did not fully capture longer-term temporal variability prior to cognitive assessment. In particular, the proportion of green space was derived from the most recent officially available land-use dataset (2014), resulting in a temporal mismatch in a rapidly urbanizing setting such as Beijing. This temporal discrepancy may introduce exposure misclassification; however, such misclassification is expected to be largely non-differential with respect to cognitive outcomes and therefore more likely to attenuate observed associations toward the null rather than generate spurious findings. Fourth, greenness exposure was assessed at the community level using centroid-based assignment, which reflects average neighborhood conditions but does not capture within-community spatial variability, particularly for individuals residing near community boundaries. Accordingly, findings should be interpreted at the community scale. Although community-level spatial visualizations were used to illustrate geographic variation in greenness exposure and cognitive performance, this spatial averaging may result in non-differential exposure misclassification, and thus the observed associations should be interpreted as conservative estimates. To contextualize this limitation, community size characteristics and greenness distributions are summarized in the Supplementary Table 4 and Table 2, respectively. Fifth, although we adjusted for a range of individual- and community-level covariates, including educational level, occupational class, air pollution, population density, hospital density, and economic vitality, some potentially important behavioral and psychosocial factors were not available in the screening dataset, such as physical activity, depressive symptoms, social engagement, and environmental noise exposure. These factors may act as confounders or mediators in the association between greenness exposure and cognitive function. In addition, while economic vitality captures broader neighborhood-level socioeconomic context, it may not fully reflect individual-level socioeconomic circumstances among older adults; residual confounding therefore cannot be entirely excluded. Finally, we did not account for individual time-activity patterns outside residential communities (e.g., time spent in workplaces or other recreational environments), nor did our greenness metrics differentiate between vegetation types, species composition, or spatial configuration. Future studies incorporating longitudinal designs, individual mobility data, and more detailed characterization of green space quality may help to clarify underlying mechanisms and strengthen causal interpretation.

6. Conclusions

Our city-wide screening data provide compelling evidence that greater exposure to green space, across all measured metrics, is associated with improved cognitive function among older adults. The large sample size of 62,333 participants from 114 communities ensures our findings' statistical power and generalizability within urban Beijing. A threshold was identified at a distance of 500 m from parks, beyond which cognitive function scores progressively declined with increasing distance from green spaces. These results support urban park development initiatives in China, emphasizing the critical importance of establishing "500-m access to parks" as a pivotal strategy for enhancing cognitive health in the population. This research highlights the importance of incorporating accessible green spaces into urban design to promote cognitive well-being and support healthy aging among older adults. Furthermore, by addressing urban health disparities in a non-Western context, this study fills a critical gap in global urban health research, offering unique insights into the relationship between green space exposure and cognitive function in rapidly urbanizing environments.

Consent for publication

Not applicable.

Availability of data and materials

The Beijing Municipal Commission of Health supervised this study, and the datasets generated or analyzed during the current study are not publicly available.

Ethics approval and consent to participate

Ethical approval for the screening program was obtained from the Ethics Committees of the State Key Laboratory of Cognitive Neuroscience and Learning at Beijing Normal University (ICBIR_A_0041_002_02). Written informed consent was obtained from all study participants.

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CRediT authorship contribution statement

Weiju Zhou: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. **Yaojing Chen:** Data curation, Writing – review & editing. **Yanxi Zeng:** Visualization. **He Li:** Data curation, Writing – review & editing. **Xiangwei Dai:** Data curation, Writing – review & editing. **Junying Zhang:** Data curation, Project administration, Writing – review & editing. **Jiuxuan Gao:** Software, Validation. **Yue Ma:** Methodology, Software. **Ying Long:** Methodology, Resources, Software. **Jun Yang:** Methodology, Resources. **Qingzhi Huang:** Investigation, Resources. **Yun Chen:** Investigation, Resources. **Zhanjun Zhang:** Conceptualization, Data curation, Funding acquisition, Project administration, Resources, Supervision, Writing – review & editing. **John S. Ji:** Conceptualization, Data curation, Funding acquisition, Methodology, Supervision, Validation, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no competing interests.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.socscimed.2026.119229.

Data availability

The data that has been used is confidential.

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