Associations between neighborhood park space and cognition in older adults vary by US location: The Multi-Ethnic Study of Atherosclerosis

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A B S T R A C T

We used cross-sectional Multi-Ethnic Study of Atherosclerosis data from six US cities/counties and adjusted multilevel linear regression to examine park space-cognition associations among non-demented older adults (n = 4084). We found that greater neighborhood park space 1-mile around the residence (measured continuously) was associated with better processing speed in the overall sample (estimate: 0.48; 95% CI: 0.03, 0.92). However, greater neighborhood park space (½-mile around residence) was associated with worse global cognition in Los Angeles, California (estimate: -2.66; 95% CI: -4.70, −0.62) and worse processing speed in Forsyth County, North Carolina (estimate: -0.72; 95% CI: -1.37, −0.08). Dichotomizing at the mean, having ≥6% park space (½-mile around residence) was associated with better global cognition in Saint Paul, Minnesota (estimate: 0.21; 95% CI: 0.05, 0.38), and better processing speed in New York City (estimate: 0.19; 95% CI: 0.04, 0.35). Park space-cognition associations varied by city/county, suggesting problems with pooling multiple sites without accounting for geographic context or regionally-varying park characteristics (e.g., quality).

1. Introduction

Alzheimer's disease (AD) currently affects 5.8 million individuals, is the sixth leading cause of death in the US, and is the most common cause of dementia (Alzheimer's Association, 2019). Worldwide, dementia is estimated to affect 47 million people (World Health Organization) and its prevalence is expected to increase dramatically over the next few decades with the projected rise in the population of older adults. In the US, an estimated 14 million will have Alzheimer's disease in 2050 (Alzheimer's Association, 2019).

Currently there is no cure or effective treatment to help delay the onset or progression of dementias due to neurodegenerative diseases such as AD. However, preventive behaviors such as regular physical activity and healthy diets have been shown to delay onset of disease symptoms (Scarmeas et al., 2006; Tolppanen et al., 2015). Individual have different levels of susceptibility (or resistance) to developing pathology associated with neurodegenerative disease, as well as differing levels of resilience in maintaining regular cognitive function in spite of pathological burden (Montine et al., 2019). For instance, individuals who have at least one copy of the apolipoprotein E (APOE) ε4 allele have at least a 3-fold greater risk of developing AD (Alzheimer's Association, 2019; Yu et al., 2014). Although genetics, such as APOE genotype, factor

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into individual susceptibility and resilience, it remains unclear which additional mechanisms explain observed differences in pathology and clinical presentation between individuals. Some evidence suggests that lifelong exposures, including socioeconomic status (SES), and history of preventive behaviors such as physical activity and diet contribute to observed differences (Scarmeas et al., 2009; Wilson et al., 2005).

Research suggests that built and social environments may play a role in late-life cognitive functioning (Besser et al., 2017). Built environments consist of the physical, man-made environmental spaces for living, working, and leisure, including parks and greenspaces, buildings, public spaces, roads and highways, and pedestrian and public transportation infrastructure. Lower neighborhood SES is a social environment factor that has been associated with worse late-life cognitive functioning and cognitive decline (Clarke et al., 2012; Sheffield and Peek, 2009). In recent years, the number of studies investigating neighborhood built and social environments and late-life brain health (cognitive function, brain atrophy, and/or neurodegenerative disease pathology) has increased. Although the evidence to date is extremely limited, higher density neighborhoods and built environment features typically associated with greater population density (e.g., public transportation availability, a mix of residential and commercial land uses) have been associated with better cognitive functioning among older adults (Besser et al., 2017).

Neighborhood park space is another built environment feature that may be positively associated with brain health, including maintained or improved cognitive functioning in older age. Research suggests that contact with nature may improve mental health and quality of life (Hartig et al., 2014), but the evidence is limited on whether neighborhood greenspaces, such as parks, can improve/maintain cognition or delay onset of cognitive impairment, particularly in older adults. Greenspace, consisting of public and private areas with vegetation including natural areas, gardens, and parks, has been previously associated with lower AD risk (Brown et al., 2018), lower odds of cognitive impairment (Wu et al., 2017), and slower cognitive decline of over time in older adults (Cherrie et al., 2018; de Keijzer et al., 2018). Studies of children and <65 year olds are also suggestive but inconclusive for neighborhood greenspace-brain health associations (de Keijzer et al., 2016). To date, the strongest evidence for an association between park space and brain health comes from two longitudinal cohorts in the UK. The first showed greater access to park space in the neighborhood in early and mid-life was associated with slower late-life cognitive decline using a single measure of intelligence (Cherrie et al., 2018). While not specifically measuring park space, the other study found that after controlling for multiple confounders including individual and neighborhood-level SES, greater greenspace surrounding the home was associated with slower 10-year cognitive decline on global cognition (de Keijzer et al., 2018).

Mechanisms explaining positive associations between neighborhood park space and cognition may involve increases in physical activity (Dalton et al., 2016; Van Cauwenberg et al., 2015, 2018) or decreases in negative mental health disorders including anxiety/stress and depression (Pun et al., 2018; Sarkar et al., 2018; Wu et al., 2015). Individuals living in neighborhoods with greater access to desirable places to walk and calming greenspaces that buffer against noise may increase neighborhood physical activity and experience improved mental health. In addition, recent studies suggest associations between air pollution and cognitive decline (Cleary et al., 2018; Tonne et al., 2014). Greater neighborhood vegetation may be associated with decreases in air pollution relative to neighborhoods with little vegetation (Hartig et al., 2014), potentially ameliorating impacts of air pollution on cognition.

While evidence to date is suggestive for an association between availability of neighborhood parks and cognition, published studies are limited by a lack of diverse older adults and geographic scope. Neighborhood park space likely has a stronger influence on certain cognitive domains, yet no known studies focused on park space have included specific cognitive domains. For instance, if park space is primarily related to cognitive function via increased physical activity, stronger associations would be expected for cognitive domains more affected by physical activity (i.e., processing speed/executive function (Frederiksen et al., 2015)). Additionally, although built environments are context dependent, no known studies have used a multi-city cohort to examine differences in park-cognition associations by location. Therefore, the aims of this study were to examine: 1) whether having a greater proportion of the neighborhood composed of park space is associated with better cognitive functioning in a diverse, multi-site cohort of older adults, and 2) whether neighborhood park space and cognition associations vary depending on geographic location. Multi-site cohort studies focused on the potential influence of neighborhood characteristics on health less frequently investigate whether associations vary by site/city. However, regional variations are plausible due to differences in development patterns, community resources (e.g., to fund park space amenities), and population differences in culture, preferences, and activity patterns. These site differences may help to explain varying associations observed across studies. Therefore, we aimed to examine potential place-based differences in neighborhood park space and cognition associations using a multi-site US cohort that used standardized methods across sites.

2. Materials and methods

2.1. Sample

Cross-sectional data were obtained from the Multi-Ethnic Study of Atherosclerosis (MESA), a population-based longitudinal cohort study of subclinical cardiovascular disease. In 2000–2002 (Exam 1), MESA participants without known cardiovascular disease aged 45- to 84-years old were enrolled at six study sites across the US (Forsyth County, North Carolina; New York, New York; Baltimore, Maryland; St. Paul, Minnesota; Chicago, Illinois; Los Angeles, California). Individuals of African American, Chinese, and Hispanic race/ethnicity were oversampled. Additional details on MESA are published elsewhere (Bild et al., 2002; Fitzpatrick et al., 2015).

This study focuses on non-demented participants completing MESA Exam 5 (2010–2012) (n = 4716). We excluded 632 participants who were missing all cognitive test scores, missing data on percent park space in the neighborhood, and had either an International Classification of Disease (ICD-9) dementia diagnosis determined from hospitalization or death records (Fujiyoshi et al., 2016), used medication for dementia (acetylcholinesterase inhibitor or N-methyl-D aspartate receptor blocker), or had a Cognitive Abilities Screening Instrument (CASI) < 20 (lacks face validity) (Supplemental Figure 1). Participants were asked to bring their prescription medications to the visit to assist in filling out a medication questionnaire.

2.2. Cognitive measures

MESA conducted three cognitive tests at Exam 5. The CASI (version 2) (Teng et al., 1994), measures global cognition based on a brief assessment of multiple domains: concentration, orientation, short-term memory, long-term memory, language, visual construction, verbal fluency, abstraction, and judgment (range: 0–100). The cognitive assessment also included Digit Span, a subtest of Wechsler Adult Intelligence Scale (WAIS-III (Wechsler, 1997)) that measures memory, and Digit Symbol Coding (DSC), a subtest of WAIS-III that measures processing speed (range: 0–133). We analyzed the two Digit Span subscales (Forward [DSF], range: 0–16, and Backward [DSB], range: 0–14), separately as they measure different facets of memory (short-term auditory memory/attention versus working memory). For all tests, higher scores indicate better cognition. All four raw cognitive test scores were converted into standardized z-scores for each test using the sample's mean and standard deviation, and the z-scores were used in all regression analyses.

2.3. Neighborhood built environment measures

Percentage park space in participants' neighborhoods, neighborhood SES, and neighborhood population density were previously calculated using geographic information systems (GIS) as part of the ancillary MESA Neighborhood Study (Jones et al., 2015). Data on publicly accessible parks were obtained from 36 counties in the six MESA cities, including municipal/county and commercial sources (ESRI) for GIS shapefiles of park boundaries and names. Park amenities were determined by searching online resources, contacting municipal/county departments, and in some cases visiting parks in order to focus on parks offering physical activity opportunities and exclude parks that were only ornamental or dog parks. The neighborhood park space variables were then operationalized and calculated based on the percentage of the land surrounding participants' homes that was composed of parks (calculated for multiple radial buffers; e.g., ½- and 1-mile radius around the home). Further details on how the park data were derived are published elsewhere (Evenson and Wen, 2013; Jones et al., 2015). We hypothesized that the area closer to the home (e.g., within a ½ mile versus one mile) better represented the neighborhood area frequented by older adults, who may experience shrinking life spaces and increased disability/frailty with age. In addition, previous research suggests adults walk approximately half a mile to get to neighborhood destinations (de Keijzer et al., 2018).

Neighborhood socioeconomic status (SES) was calculated for the participants' US Census tracts (proxy for neighborhood) using US Census American Community Survey data (2007–2011). A principal components analysis was conducted to develop a single measure based on seven variables: neighborhood median home value, percentage rental income, and median household income, as well as percentage of neighborhood residents with a high school degree, a bachelor's degree, an annual household income >$50,000, and a managerial occupation. Neighborhood population density was calculated for multiple radial buffers surrounding the participants' homes based on the 2010 Census population density at the block level. The population density for the radial buffer was calculated from proportional weighting of population based on land area within each radial buffer, assuming a uniform distribution of people across each block. For this study, the ½-mile radial buffer was used.

2.4. Covariates

Participant characteristics included age at Exam 5 (years), sex, education (<high school degree, high school degree, some college, bachelor's degree or higher), race/ethnicity (White/Caucasian, Chinese, Black/African American, Hispanic), marital status, family income (≥$30,000/year versus <$30,000/year), and having ≥1 apolipoprotein ϵ4 allele (APOE ϵ4), a genetic risk factor for AD (Yu et al., 2014). Self-reported health indicators and conditions included current smoking; diabetes, arthiritis, cardiovascular disease, cerebrovascular disease, hypercholesterolemia, or depression (Center for Epidemiological Studies Depression Scale (Radloff, 1977) [CES-D] score ≥16); diabetes, arthritis, cardiovascular disease, cerebrovascular disease, hypercholesterolemia, or depression; medication use for hypertension; and transportation walking (minutes to get places) and total minutes/week spent walking (exercise or transport) determined from a validated physical activity questionnaire (LaMonte et al., 2001). Height and weight measurements were used for body mass index (BMI) calculation (kg/m^2).

As part of each MESA exam, participants were asked to complete a questionnaire that asked about perceptions of neighborhood psychosocial and physical environments, including four questions on neighborhood social environment (e.g., "people in this neighborhood are willing to help their neighbors"), three questions on neighborhood safety and crime (e.g., "violence is a problem in my neighborhood"), three questions on neighborhood walkability (e.g., "in my neighborhood it is easy to walk places"), and four questions on neighborhood aesthetics (e.g., "my neighborhood is attractive")(Multi-Ethnic Study of Atherosclerosis). Participants were asked to agree with the statements about their neighborhood on a 5-point scale (1 = strongly agree to 5 = strongly disagree). An index measure was created for each category by a simple sum of the scores for questions within that category.

2.5. Statistical analyses

Participant demographics, APOE genotype, and clinical characteristics were described using means and standard deviations or frequencies and percentages for the overall sample, and by MESA site. Mean raw (non-standardized) cognitive test scores were provided for the overall sample and by city/county, and differences in mean test scores by city/county were tested using analysis of variance (ANOVA) accounting for multiple comparisons (Tukey). Percentage neighborhood park space, and other neighborhood characteristics (population density, neighborhood SES), and transportation and total walking minutes were calculated overall and by city/county. Means (and standard deviations) for each individual question and the index scores for neighborhood perceptions were calculated for each MESA city/county.

Prior to running regression analyses, we produced scatterplots and residual plots and verified that the relationship between park space and cognition in the overall sample appeared linear. We estimated associations in the overall sample between continuous neighborhood park space and each of the four cognitive tests using unadjusted and adjusted multilevel linear regression models (accounting for correlated data within US Census tracts). We ran separate models for each cognitive test (z-scores), and repeated models stratified by city/county. We stratified by study site instead of including site as a random effect because we specifically aimed to determine if associations varied by city. If comparable associations are observed in other studies of these cities, specific place-based characteristics could be investigated to help explain observed associations. Adjusted multilevel linear regression models controlled for age, education, income, race/ethnicity, neighborhood SES, city/county (only models for overall sample), neighborhood population density, presence of ≥1 APOE ε4 allele, perceptions of neighborhood safety when walking and neighborhood crime, total walking (minutes), and comorbidities including arthritis, cardiovascular and cerebrovascular disease, diabetes, and depression. These covariates were chosen a priori based on previous studies demonstrating their associations with cognition and/or expected associations with time spent in the neighborhood (e.g., those with arthritis may have functional limitations associated with less frequent neighborhood walking). Since some MESA cities lacked participants of a certain race/ethnicity, each model controlled only for the applicable races/ethnicities. The same unadjusted and adjusted models were then repeated using a dichotomous (≥6% versus <6%, cutpoint based on sample mean) instead of a continuous park space measure.

To examine whether associations between park space and the four cognitive measures varied based on transport and total (transport and exercise) walking in minutes/week, we included interaction terms between park space and transport/total walking minutes/week (≥7 versus <7 h/week) in the adjusted models. The walking measures served as a crude proxy for time spent in the neighborhood (we lacked measures of park-based walking/physical activity). Our examination of interaction by the walking measures aimed to determine if associations were stronger for those who walked more (i.e., spent more time in their neighborhoods/parks).

Several sensitivity analyses were performed. First, we reran regression analyses using 1-mile buffers to define the neighborhood (versus ½-mile buffers used in main analyses) to determine if results depended on the area used to define the neighborhood. Second, we repeated regression analyses additionally controlling for the three neighborhood measures for perceptions of social environment, walkability, and aesthetics. These factors could potentially account for elements of the neighborhood's social and physical environment that influences how frequently an individual walks in the neighborhood. Lastly, we repeated the regression analyses additionally controlling for number of residential moves from Exam 1 to Exam 5, to examine whether differences between movers and non-movers helped to explained observed associations.

3. Results

The sample consisted of 4084 participants who were a mean of 70 years old at Exam 5 (Table 1, Supplemental Figure 1). Almost half were men; 69% had at least some college education; 11% were Chinese, 27% were Black/African American, and 21% were Hispanic; and 27% had ≥1 APOE ε4 allele. The age, sex, education, and race distribution of the analytic sample is similar to the entire sample from Exam 5 (n = 4716) (Multi-Ethnic Study of Atherosclerosis, 2020). Approximately 15% had depression, 34% were obese (≥30 kg/m^2), 32% had arthritis, and 27% reported walking ≥7 h per week to get places.

Participants had a mean CASI score of 87.6, a mean DSF score of 9.6, a mean DSB score of 5.6, and a mean DSC score of 50.5 (Table 2). Comparing raw cognitive test scores by MESA city/county demonstrated variation ($p < 0.0001$), with the significant city-by-city differences listed in Table 2. Mean CASI scores ranged from 84.3 in New York to 89.7 in Forsyth County; mean DSF scores ranged from 8.9 in Forsyth County to 10.7 in Baltimore; mean DSB scores ranged from 5.2 in New York to 6.2 in Chicago; and mean DSC scores ranged from 43.2 in New York to 62.3 in St. Paul.

The mean percentage park space in the neighborhood for the overall sample was 5.5% (SD = 8.8%), but varied widely from 1.3% in Los Angeles to 14.8% in New York (Table 3). Neighborhood population density also varied substantially by city/county, from 699 persons/km^2 in Forsyth County to 27,071 persons/km^2 in New York. Neighborhood SES was lowest (and comparable on average) in Forsyth County, St. Paul, and Los Angeles, and was the highest in New York. Cities/counties with more neighborhood park space (New York and Chicago) also had the highest amount of total walking in minutes/week. The city/county with the lowest mean neighborhood park space (Los Angeles) also had the lowest amount of walking per week. Neighborhood social and psychosocial environments also varied by city/county (Supplemental Table 1).

In unadjusted analyses, greater park space was associated with worse DSC scores, and associations between park space and cognitive tests varied by city/county (Supplemental Table 2). In the main adjusted analyses, the continuous park space measure was not associated with cognition in the overall sample (Table 4). However, greater park space was associated with worse CASI scores (estimate: -2.66; 95% CI: -4.70, −0.62) in Los Angeles and worse DSC scores in Forsyth County (estimate: 0.72, 95% CI: 1.37, −0.08). Borderline associations were observed between greater park space and better CASI scores in St. Paul (estimate: 0.94; 95%: -0.00, 1.89) and better DSC scores in New York (estimate: 0.69; 95% CI: -0.04, 1.41). Using the dichotomous measure, having ≥6% park space in the neighborhood was associated with better CASI scores in St. Paul (estimate: 0.21; 95% CI: 0.05, 0.38) and better DSC scores in New York (estimate: 0.19, 95% CI: 0.04, 0.35), but worse CASI scores in Los Angeles (estimate: -0.44; 95% CI: 0.83, −0.05) (Table 5). The directions of the associations for Los Angeles, Forsyth County, St. Paul, and New York were consistent when comparing the results using the dichotomous and continuous park space measures.

For CASI, DSF, and DSB, associations between park space and cognitive test scores did not vary based on total or transport minutes walking (data not shown). For DSC, the interaction terms between park space and total walking and between park space and transport walking indicated effect modification ($p = 0.01$), suggesting those with higher levels of walking have stronger associations between park space and DSC score (e.g., estimate for ≥7 h/week transport walking: 0.43; CI: -0.19, 1.04; estimate for <7 h/week: -0.04; CI: 0.50, 0.42).

Sensitivity analyses using 1-mile buffers to define neighborhood park space showed associations between greater park space and higher DSC scores in the overall sample (estimate: 0.48; 95% CI: 0.03, 0.92) and in New York (estimate: 1.87; 95% CI: 1.07, 2.67), but lower DSC scores in Forsyth County (estimate: -1.43; 95% CI: 1.07, 2.67) (Supplemental Table 4). Additionally controlling for perceptions of neighborhood social environment, walkability, and aesthetics (Supplemental Table 4) and number of residential moves during follow-up (Supplemental Tables 5-6) resulted in minimal differences in the regression estimates.

Table 1
Demographics and clinical characteristics.

Characteristic[a]	
Sample size, n	4084
Age at Exam 5, mean (SD)	69.6 (9.3)
Men, n (%)	1894 (46.4%)
Education, n (%)	
< High school degree	563 (13.8%)
High school degree	723 (17.7%)
Some college, no bachelor's degree	1196 (29.3%)
Bachelor's degree or higher	1595 (39.2%)
Married, n (%)	2579 (63.8%)
Race/ethnicity, n (%)	
White/Caucasian	1648 (40.4%)
Chinese-American	464 (11.4%)
Black/African American	1108 (27.1%)
Hispanic	864 (21.2%)
Family income ≥$30,000/year, n (%)	2649 (67.3%)
≥1 APOE ε4 allele, n (%)	1029 (26.9%)
Depression (CES-D score ≥16), n (%)	582 (14.6%)
Current smoker, n (%)	298 (7.4%)
Body mass index (kg/m^2), n (%)	
<18.5 (underweight)	34 (0.8%)
18.5–24.9 (normal)	1140 (28.0%)
25–29.9 (overweight)	1514 (37.2%)
≥30 (obese)	1387 (34.0%)
Diabetes (self-reported), n (%)	438 (10.8%)
Hypertension (taking medication), n (%)	2257 (55.3%)
Taking depression medication, n (%)	556 (13.6%)
Arthritis (self-reported), n (%)	1306 (32.3%)
Cardiovascular disease, n (%)	310 (7.6%)
Cerebrovascular disease (stroke/TIA), n (%)	120 (2.9%)
Frequently walk places (≥7 h/week), n (%)	1108 (27.4%)

Abbreviations: SD = standard deviation; APOE = apolipoprotein E; CES-D = Center for Epidemiologic Studies Depression scale; TIA = transient ischemic attack; SD = standard deviation; APOE = apolipoprotein E.

[a] Missing data: income, n = 150; education, n = 7; married, n = 42; APOE, n = 254; CES-D, n = 83; current smoker, n = 67; BMI, n = 9; diabetes, n = 21; arthritis, n = 46; cardiovascular disease, n = 2; cerebrovascular disease, n = 2; frequently walk places, n = 34.

4. Conclusions

Our findings of cross-sectional associations between neighborhood park space and cognition were mixed. For the entire sample, we observed no associations between greater park space and cognition when defining neighborhood as the ½-mile surrounding the home. However, a greater percentage of neighborhood park space in the mile surrounding the home was associated with better processing speed (DSC). In addition, greater park space in the ½-mile surrounding the home was associated with worse global cognition in Los Angeles and worse processing speed in Forsyth County, but better global cognition in St. Paul and better processing speed in New York. Overall, the observed associations depended on place, even after controlling for important confounders previously associated with both park access and cognition in other studies, including individual-level demographics and socioeconomic status and neighborhood characteristics including population density and socioeconomic status.

A greater percentage of park space was associated with better processing speed when defining neighborhood using a 1-mile buffer surrounding the home. When focused on the entire sample, associations

Table 2
Raw cognitive test scores by study site.

Measure[a]	Mean (SD)							
	All sites	Forsyth County, North Carolina n = 671	New York, New York n = 692	Baltimore, Maryland n = 591	St. Paul, Minnesota n = 689	Chicago, Illinois n = 768	Los Angeles, California n = 673	Site differences p-value[b]
CASI	87.6 (8.7)	89.7 (7.5)	84.3 (9.8)	88.1 (8.2)	88.3 (8.4)	89.3 (8.5)	85.7 (8.6)	<.0001[c]
DSF	9.6 (2.8)	8.9 (2.1)	9.2 (2.6)	10.7 (2.5)	9.0 (2.5)	10.0 (2.7)	10.1 (3.7)	<.0001[d]
Digit Span Backward	5.6 (2.4)	5.4 (2.0)	5.2 (2.5)	6.1 (2.6)	5.4 (2.3)	6.2 (2.2)	5.4 (2.6)	<.0001[e]
Digit Symbol Coding	50.5 (18.6)	50.5 (16.7)	43.2 (19.5)	48.4 (16.1)	62.3 (18.6)	55.4 (17.1)	52.4 (20.0)	<.0001[f]

Abbreviations: CASI = Cognitive Abilities Screening Instrument; DSF = Digit Span Forward; DSB = Digit Span Backward.
[a] Missing data: CASI, n = 8; DSF, n = 16; DSB, n = 16; Digit Symbol Coding, n = 387.
[b] ANOVA test for differences in means, adjusting for multiple comparisons (Tukey).
[c] Site by site comparisons different at $p < 0.05$ except Baltimore versus St. Paul; and Chicago versus Forsyth County, St. Paul, and Baltimore.
[d] Site by site comparisons different at $p < 0.05$ except Forsyth County versus New York and St. Paul; New York versus St. Paul; and Chicago versus Los Angeles.
[e] Site by site comparisons different at $p < 0.05$ except Chicago versus Baltimore; St. Paul versus Forsyth County, New York, and Los Angeles; Forsyth County versus New York and Los Angeles; and New York versus Los Angeles.
[f] Site by site comparisons different at $p < 0.05$ except Forsyth County versus Baltimore, St. Paul, and Los Angeles; and St. Paul versus Los Angeles.

Table 3
Neighborhood characteristics and time walking to get places by study site.

Measure[a]	Mean (SD)						
	All sites	Forsyth County, North Carolina n = 671	New York, New York n = 692	Baltimore, Maryland n = 591	St. Paul, Minnesota n = 689	Chicago, Illinois n = 768	Los Angeles, California n = 673
Percent neighborhood parkspace[b]	5.5% (8.8%)	1.9% (4.6%)	14.8% (11.3%)	4.2% (9.0%)	3.2% (5.4%)	7.0% (8.4%)	1.3% (2.7%)
Population density[b] (per km^2)	7487 (10,135)	699 (380)	27,071 (9148)	2619 (1736)	2141 (902)	7269 (4853)	4116 (2230)
Neighborhood SES[c]	−0.54 (1.25)	−0.01 (0.85)	−1.13 (1.44)	−0.30 (0.86)	0.01 (0.64)	−1.62 (1.30)	−0.05 (1.03)
Neighborhood safe to walk[d]	2.16 (0.96)	1.93 (0.98)	2.17 (0.91)	2.32 (1.05)	2.23 (1.01)	2.25 (1.01)	2.09 (0.75)
Neighborhood safe from crime[d]	2.79 (1.02)	2.51 (1.05)	3.00 (0.99)	2.95 (1.01)	2.76 (1.02)	2.88 (1.07)	2.66 (0.87)
Minutes per week walking for exercise or transport	547.2 (681.0)	528.7 (671.5)	801.6 (845.1)	539.2 (699.0)	475.9 (645.4)	611.8 (622.9)	312.2 (452.7)

Abbreviations: SES = socioeconomic status.
[a] Missing data: safe to walk, n = 62; safe from crime, n = 62; neighborhood SES, n = 92.
[b] Measured in ½ mile radius of participant's home.
[c] Higher (more positive) value = worse SES.
[d] 1 = strongly disagree; 5 = strongly agree.

were not observed for the other cognitive domains. Processing speed may be improved with greater levels of physical activity (Frederiksen et al., 2015) and impaired with higher levels of stress (Korten et al., 2017), and physical activity and stress have been associated with park exposure (Fan et al., 2011). Therefore, neighborhood park exposure is plausibly related to processing speed.

Our results suggest that park space-cognition associations vary by US geographical region. Greater percentage of park space was associated with worse cognition in Los Angeles and Forsyth County but better cognition in New York and St. Paul. These conflicting findings could have at least a few explanations, including differences in park quality or available park amenities by city/county. Variation in the aesthetics such as landscaping, cleanliness of facilities, types of facilities offered (e.g., tennis and basketball courts, play fields, playgrounds) and upkeep of walking trails could help explain regional differences in park use (Cohen et al., 2016; McCormack et al., 2010) and any potential resulting park space-cognition associations. Park use can be affected if a mismatch exists between park offerings and individual and cultural park preferences. One study found that parks of similar size in Los Angeles had up to a 10-fold difference in park use, and attributed the disparity to differences in services/programming and outreach (Han et al., 2014). Variation in park preferences is likely also to extend across US regions. Future work will need to tease apart the differences in park offerings and quality within and between cities/regions to determine how much these contribute to regional variation in park space-cognition associations.

Residual confounding by other neighborhood social or built environment characteristics may also help explain the regional variation. For instance, although we controlled for population density, neighborhoods in New York and Forsyth County are not easily compared because of the disparate ranges of population density. Although perceptions of neighborhood safety, aesthetics, walkability, and social environment were controlled for in this study, residual confounding is possible if the measures do not fully capture differences in the neighborhood characteristics that are associated with both park space and cognitive functioning. In particular, harmful neighborhood exposures across the life course, which may not have been fully measured/controlled for in this study (e.g., crime, socioeconomic status), may help explain the negative associations between park space and cognition in Los Angeles and Forsyth County. Additional studies are needed to ensure adequate control for all important confounders, including life course neighborhood exposures.

Lastly, the percentage of park space varied significantly by city/

Table 4
Adjusted association between continuous neighborhood park space measure (1/2-mile buffer) and cognition.

	Adjusted estimate (95% Confidence Interval)[a,b]			
	CASI	DSF	DSB	DSC
All sites	−0.15 (−0.53, 0.24)	0.21 (−0.15, 0.58)	0.00 (−0.36, 0.36)	0.11 (−0.28, 0.50)
Forsyth County, NC	−0.47 (−2.40, 1.45)	−1.16 (−2.79, 0.47)	−0.11 (−1.20, 0.98)	−0.72 (−1.37, −0.08)*
New York, NY	−0.29 (−1.00, 0.42)	−0.06 (−0.63, 0.52)	−0.20 (−0.82, 0.43)	0.69 (−0.04, 1.41)
Baltimore, MD	−0.18 (−0.95, 0.59)	0.45 (−0.33, 1.22)	0.46 (−0.25, 1.18)	0.22 (−0.66, 1.09)
St. Paul, MN	0.94 (−0.00, 1.89)	0.13 (−0.91, 1.17)	0.01 (−1.06, 1.08)	0.08 (−0.81, 0.98)
Chicago, IL	0.17 (−0.60, 0.95)	0.23 (−0.76, 1.21)	−0.27 (−1.04, 0.50)	−0.49 (−1.14, 0.15)
Los Angeles, CA	−2.66 (−4.70, −0.62)*	1.93 (−0.46, 4.32)	−0.60 (−2.92, 1.73)	−1.70 (−3.84, 0.44)

Abbreviations: CASI = Cognitive Abilities Screening Instrument; DSF = Digit Span Forward; DSB = Digit Span Backward; DSC = Digit Symbol Coding.
*p < 0.05; **p < 0.01; **p < 0.001.
[a] Controlling for: age, education, income, race/ethnicity, neighborhood socioeconomic status, study site (for analyses of total sample), neighborhood population density, APOE e4 carrier, neighborhood perception of safety walking day or night and crime, arthritis, cardiovascular and cerebrovascular disease, diabetes, depression, total minutes walking per week.
[b] Park space unit of measure is proportion of neighborhood composed of park space (sample range: 0 to 0.56; i.e., 0–56% of neighborhoods composed of park space).

Table 5
Adjusted association between dichotomous neighborhood park space measure (≥6% vs <6%) and cognition.

	Adjusted estimate (95% Confidence Interval)[a]			
	CASI	DSF	DSB	DSC
All sites	0.01 (−0.07, 0.09)	0.02 (−0.06, 0.10)	0.03 (−0.05, 0.11)	0.04 (−0.03, 0.11)
Forsyth County, North Carolina	0.05 (−0.17, 0.28)	−0.02 (−0.28, 0.25)	0.12 (−0.07, 0.32)	−0.10 (−0.24, 0.04)
New York, New York	0.02 (−0.17, 0.21)	−0.03 (−0.19, 0.14)	−0.03 (−0.19, 0.12)	0.19 (0.04, 0.35)*
Baltimore, Maryland	0.03 (−0.18, 0.24)	0.14 (−0.03, 0.31)	0.19 (−0.04, 0.43)	0.15 (−0.06, 0.36)
St. Paul, Minnesota	0.21 (0.05, 0.38)*	−0.00 (−0.18, 0.18)	0.04 (−0.12, 0.21)	0.08 (−0.10, 0.26)
Chicago, Illinois	−0.04 (−0.17, 0.10)	−0.02 (−0.22, 0.17)	−0.06 (−0.25, 0.12)	−0.06 (−0.17, 0.06)
Los Angeles, California	−0.44 (−0.83, −0.05)*	0.13 (−0.25, 0.50)	−0.20 (−0.56, 0.15)	−0.20 (−0.67, 0.17)

Abbreviations: CASI = Cognitive Abilities Screening Instrument; DSF = Digit Span Forward; DSB = Digit Span Backward; DSC = Digit Symbol Coding.
*p < 0.05; **p < 0.01; **p < 0.001.
[a] Controlling for: age, education, income, race/ethnicity, neighborhood socioeconomic status, study site (for analyses of total sample), neighborhood population density, APOE ε4 carrier, neighborhood perception of safety walking day or night and crime, arthritis, cardiovascular and cerebrovascular disease, diabetes, depression, total minutes walking per week.

county. For instance, 25% of the Los Angeles sample had >2% park space in the ½-mile surrounding the home, compared to >90% of the New York sample. This suggests that differences in the amount of neighborhood park space by region may be an important consideration when evaluating the presence or absence of park space-cognition associations. Overall, this study highlights the need to critically evaluate geographic differences and whether data can be pooled when park space and neighborhood attributes and cultural preferences for park spaces diverge greatly between regions.

Two other studies have investigated associations between neighborhood park space and cognition in older adults. A cross-sectional study of ≥50 year olds in Chicago, Illinois, found no association between park area (in each US Census tract) and Telephone Instrument for Cognitive Status scores (TICS; global cognition screening test) (Clarke et al., 2012). In contrast, a longitudinal study of 70- to 76-year-olds in Scotland found that presence of greater neighborhood park space in childhood and early/mid-adulthood years was associated with slower decline on the Moray House Test (Cherrie et al., 2018).

Direct comparisons of these two studies to the current study are hampered due to differing methods and samples. Similar to the current study, the Chicago study examined cross-sectional associations, was based on a diverse sample (37% African American, 18% Hispanic), and controlled for neighborhood SES, an important confounder. Unlike the Chicago study and the current study, the Scottish study measured life-course exposures to park space and longitudinal change in late-life cognition, and was presumably more homogeneous regarding race/ethnicity (cohort was born in Scotland in 1936). Although the Scottish study controlled for early- and late-life SES, it did not control for neighborhood SES.

Additionally, neighborhood boundary definitions and cognitive tests differed by study. The Chicago study used US Census tracts, the Scottish study used 1500 m buffers (0.93 miles) surrounding the home, and the current study used ½- and 1-mile buffers around the residence. The TICS, used in the Chicago study, is limited as it is telephone-based, is considered only a screening test, and is not considered a measure of specific cognitive domains (e.g., memory). The Moray House Test, used in the Scottish study, is a measure of intelligence. Although previously validated, it is not frequently used to identify cognitive decline consistent with neurodegenerative diseases such as AD. Cognitive testing to detect late-life cognitive decline typically involves a battery of tests assessing multiple cognitive domains, including episodic memory, visuospatial abilities, language, executive function, processing speed and attention. The current study advances beyond the two prior studies by measuring global cognition and two specific cognitive domains, working memory and processing speed. Both domains are pertinent to the study of park space-cognition associations, as they have been associated with greenspace exposure and physical activity (Dadvand et al., 2015; Frederiksen et al., 2015; Moriya et al., 2016).

The current study has limitations. Causality could not be addressed due to the study's cross-sectional nature, and evidence is insufficient as few related studies have been conducted to date. Data were not available on park usage, and thus future studies of park space-cognition associations would ideally capture GPS-based measures of the time spent in parks and the locations, as well as detailed information on park activities (e.g., walking, social engagement). Future studies also will need to evaluate longer-term/life course exposure to park space and longitudinal change in multiple cognitive domains. Residual confounding by factors such as individual- or neighborhood-level socioeconomic status, which we may not have been able to fully account for in our models, or neighborhood social connectedness (measure not available) may have affected results. Data on park quality (e.g., amenities) and use will be important to examine in future studies to possibly explain the observed regional differences in associations. Although the cognitive tests were an improvement upon previous studies, future work could incorporate tests targeting other cognitive domains that plausibly relate to neighborhood exposures such as visuospatial function. We found limited evidence of an interaction between neighborhood park space and amount of total walking or transport walking. The walking measures were based on a validated self-reported physical activity questionnaire (LaMonte et al., 2001), but future studies may want to confirm if interactions are present based on objective physical activity measurements. Our study was not designed to address mechanisms (e.g., physical activity, stress reduction/depression, air pollution exposure) relating park space and cognition. Future studies are needed to investigate causal mechanisms through mediation analyses and how the mechanisms may differ depending on geographic region. Perception of safety walking in the neighborhood, but not neighborhood crime, social environment, walkability, or aesthetics, was associated with cognition in adjusted analyses. Future research could study whether perceived neighborhood safety when walking moderates park space-cognition associations. Our results may be biased if individuals more likely to use parks or have better cognition self-selected into neighborhoods with greater park access. Missing data resulted in approximately 10% of the sample missing from the adjusted regression analyses for the CASI, DSF, and DSB tests (i.e., from listwise deletion), but approximately 20% missing for the models focused on DSC, which may have biased findings or resulted in reduced power to detect associations. The choice of a cutpoint for defining high versus low neighborhood proportion park space was based on the sample mean, as there is no established cutpoint relevant to cognitive outcomes, and because a higher cutpoint would exclude all participants from certain sites with low amounts of park space (e.g., fewer Los Angeles participants had ≥6% neighborhood park space). Lastly, we performed multiple comparisons and found that none of the associations were significant at $p < 0.001$. However, a stringent significance level to account multiple testing could be considered conservative, and overall, our results are suggestive of associations that must be replicated in future studies.

Study strengths include the diverse sample and availability of data from six US regions, allowing for examination of geographic variations in associations. Presence of dementia was determined from ICD-9 diagnosis codes from hospitalization/death records and from medication use for dementia, when participants brought their medications to the visits, which reduced the chance of including individuals with dementia in our sample. The park space and cognitive measures were developed/collected in a standardized manner, aiding comparisons across city/county. In addition, we evaluated associations using different buffer sizes (½- and 1-mile), which is significant given the lack of a standardized or best practices definition of neighborhoods for older adults.

Our study demonstrated associations between park space and global cognition and processing speed. However, the directions of associations varied by city/county, suggesting that park space exposure may be beneficial to cognition in certain circumstances and detrimental in others. Plausible explanations for the discrepancies by geographic region, which should be investigated in future studies, include differences in park quality, amenities, and services/outreach that affect park use, and/or residual confounding by neighborhood level factors such as socioeconomic status or social environment. Although preliminary, if our findings are replicated, this study suggests caution when pooling data from multiple sites to examine park space-cognition associations.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.healthplace.2020.102459.

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