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# Associations between neighborhood greenspace and brain imaging measures in non-demented older adults: The Cardiovascular Health Study

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## Abstract

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Availability of Data

Researchers can request access to CHS data through the Cardiovascular Health Study, at https://chs-nhlbi.org/.

Code Availability

Not applicable

**Purpose:** Greater neighborhood greenspace has been associated with brain health, including better cognition and lower odds of Alzheimer's disease in older adults. We investigated associations between neighborhood greenspace and brain-based magnetic resonance imaging (MRI) measures and potential effect modification by sex or apolipoprotein E genotype (APOE), a risk factor for Alzheimer's disease.

**Methods:** We obtained a sample of non-demented participants 65 years or older (n=1,125) from the longitudinal, population-based Cardiovascular Health Study (CHS). Greenspace data were derived from the National Land Cover Dataset. Adjusted multivariable linear regression estimated associations between neighborhood greenspace five years prior to the MRI and left and right hippocampal volume and 10-point grades of ventricular size and burden of white matter hyperintensity. Interaction terms tested effect modification by APOE genotype and sex. CHS data (1989–1999) were obtained/analyzed in 2020.

**Results:** Participants were on average 79 years old (standard deviation [SD]=4)), 58% were female, and 11% were non-white race. Mean neighborhood greenspace was 38% (SD=28%). Greater proportion of greenspace in the neighborhood five years before MRI was borderline associated with lower ventricle grade (estimate: −0.30; 95% confidence interval: −0.61, 0.00). We observed no associations between greenspace and the other MRI outcome measures and no evidence of effect modification by APOE genotype and sex.

**Conclusion:** This study suggests a possible association between greater greenspace and less ventricular enlargement, a measure reflecting global brain atrophy. If confirmed in other longitudinal cohort studies, interventions and policies to improve community greenspaces may help to maintain brain health in older age.

### Keywords

Neighborhood; green space; MRI; brain volume; hippocampal; white matter

## Introduction

Cognition among older adults may benefit from greater exposure to greenspaces during early, mid, and late-life [1–9]. In previous studies of cognition, greenspaces were typically defined as public parks/open spaces or overall density of healthy vegetation/greenness, which includes parks/open spaces but also forests, tree canopy, private gardens, and street plantings [1–9]. It has been hypothesized that contact with nature in the form of greenspace has multiple benefits to health including cognitive function [10].

Neighborhoods are smaller geographic communities within a city, suburb, or town. Greenspaces within residential neighborhoods may be particularly important to late-life cognition because they represent everyday greenspace exposures among older adults, who increasingly spend more time in their home and neighborhoods with age due to functional limitations and driving cessation [11].

Among older adults, greenspace has been positively associated with cognition in at least eight studies [3,4,6,12,13–16]. One cohort study showed that among those ≥45 years, higher levels of vegetation in residential neighborhoods was associated with slower cognitive

decline [6]. Another cohort study found that more neighborhood park space in early and mid-life was associated with slower decline on a single measure of intelligence from ages 70 to 76 [4]. In that study, greenspace-cognition associations were stronger for women than men and for apolipoprotein E (APOE) ε4 non-carriers than ε4 carriers, who are at higher risk for Alzheimer's disease [AD]. A third study found that greater neighborhood vegetation, or greenness, was associated with lower AD prevalence among beneficiaries of Medicare, the US national health insurance available to individuals 65 years and older [3]. Yet, other studies found modest, null, or inverse associations between greenspace and cognition or dementia risk [1,17–21].

Greenspace exposure may affect brain health through multiple mechanisms. Physical activity (PA) [22], stress [23], and depression [24] have been associated with brain health in a number of studies. Living in neighborhoods with better access to greenspace may increase neighborhood walking and PA levels [25,26], and spending more time outdoors and increased nature contact may improve mental health outcomes such as anxiety, stress, and depression [27–29]. In addition, recent studies suggest an association between air pollution and cognitive decline [30,31]. Greater neighborhood vegetation may help decrease air pollution [32], thus potentially ameliorating the effect of air pollution on cognition. The benefits of greenspace to brain health may occur throughout life, starting during the period of childhood brain development and protecting against cognitive decline during late-life [4,33–36].

While studies examining neuropsychological test scores are useful to determine if exposure to greenspace helps maintain and improve cognitive function over time, studies using brain biomarkers such as structural magnetic resonance imaging (MRI) and positron emission tomography (PET) will increase the scientific support for the hypothesis that neighborhood greenspace improves brain health. MRI scans can provide assessment of white matter hyperintensities, areas of axonal degeneration and myelin loss, and ventricular enlargement, a measure of global brain atrophy. The hippocampi, located in the temporal lobes, are responsible for memory and learning. White matter hyperintensity burden, ventricle enlargement, and hippocampal volume, are risk factors for AD and cognitive decline [37,38].

To date, only two known studies has investigated associations between neighborhood built environment and brain biomarkers among older adults [39,40]. The first study concluded that living in more walkable neighborhoods was associated with lower ventricle volumes, greater right hippocampal volumes, and greater gray matter volumes. In addition, greater neighborhood walkability was associated with smaller declines in right hippocampal volume among APOE ε4 carriers than non-carriers [39]. The second study found that a greater amount of neighborhood forest but not urban greenspaces was associated with greater MRI-measured amydala integrity (amydala is brain region responsible for fear/stress response and memory) [40]. Thus far, no known studies of older adults have investigated whether positive associations exist between neighborhood greenspace and other MRI measures. Regional and global brain atrophy and white matter hyperintensities are frequently used measures of brain health and AD [41,42]. Therefore, we used longitudinal cohort data to examine greenspace-MRI associations among non-demented older adults and to determine whether associations

were stronger for women compared to men and stronger for APOE ε4 carriers compared to non-carriers. We hypothesized that individuals in neighborhoods with greater greenspace will demonstrate better MRI outcomes compared to individuals living in neighborhoods with less greenspace.

## Methods

### Study sample

We used data from the Cardiovascular Health Study (CHS), a population-based, longitudinal cohort study designed to investigate factors associated with stroke and coronary heart disease among adults 65 years of age or older. Participants were randomly sampled from residents on Medicare eligibility lists (US national health insurance for older adults) from four sites: Sacramento County, California [CA]; Washington County, Maryland [MD]; Forsyth County, North Carolina [NC]; Pittsburgh, Pennsylvania [PA]. Most participants were enrolled in 1989–1990 (n=5,201), with a smaller, predominantly African American cohort (n=687) enrolled in 1992–1993. Participants had annual clinic visits from enrollment to 1999 to collect data on risk factors, comorbidities, and subclinical cardiovascular disease. Since 1999, participants have been contacted twice annually by phone. Additional details on CHS procedures are published elsewhere [43]. De-identified data were provided by CHS for this study (i.e., not human subjects research). The CHS data for years 1989–1999 were obtained and analyzed in 2020.

For this present study, we restricted to participants with: 1) MRI data available (1997–1999); 2) greenspace data available; and 3) no indication of cognitive impairment or dementia at the time of MRI. Neighborhood greenspace data were not available for those still living at the start of the National Institutes of Health-funded Retail Environment and Cardiovascular Disease [RECVD] study, which created the measures and only had approval to geocode addresses for deceased participants. Cognitive impairment or dementia was ascertained from multiple sources including presence of a dementia ICD-9 code (hospital and outpatient visits); use of dementia medications; cognitive screening tests indicative of significant decline over time (accounting for differences by age, sex, race, and education, which could bias determination of cognitive impairment); or the need for a proxy response due to cognitive difficulty.

### MRI measures

Details about the scanning protocol have been published elsewhere [44–46]. Board-certified neuroradiologists were blinded to diagnostic information. Using an atlas with 40 reference cases, they assessed ventricular size from T1-weighted images and burden of white matter hyperintensities from spin-density weighted axial images in a standard fashion on a 10-point scale. The ventricle and white matter grades ranged from 0 to 9, the least to the most abnormal. A 3D T1-weighted spoiled gradient-recalled echo (SPGR) sequence was employed to derive quantitative total brain volume and regional brain volume measures such as left and right hippocampal volumes. Full details of the voxel-based protocol are available in previous publications [47,48]. We used data from the 1997–1999 MRI scans for white

matter grade and ventricle grade. Measures of left and right hippocampal volume ($mm^3$) came from a subset of these scans on which volumes had been determined.

## Greenspace measure

Participant addresses were geocoded and greenspace measures were developed as part of the RECVD study. Data from the National Land Cover Dataset [49] (NLCD) (1992, 2001) were used to construct annual greenspace measures in the 1-km and 5-km radial buffers around participants' homes starting from 1990. Using a 30-meter spatial resolution from satellite imagery supplemented with other data sources, the NLCD provides a breakdown of the land and surface uses and types, such as developed land, barren land, deciduous forest, scrub, and wetlands [50]. All land uses corresponding to vegetation were categorized as greenspace, and the amount ($km^2$) and proportion of greenspace were calculated for the radial buffers. Neighborhood greenspace values from 1993 to 1999 were used in this study. As NCLD data were not available for that time period, a linear interpolation of NCLD values between 1992 and 2001 was used to develop the 1993–1999 measures, while accounting for residential addresses changes over time. The primary exposure of interest was greenspace estimated five years before the MRI. Main analyses focused on 1-km (0.6 mi) buffers, as individuals have shrinking life space with age. Individuals walk on average 1/2-mile per trip for recreational purposes, and this distance may be somewhat shorter for ≥65 year olds than 18–64 year olds [51,52].

## Participant characteristics

Baseline sociodemographic data included age, sex, race (White, Black, and other), Hispanic ethnicity, income (≥$25,000/year, <$25,000/year), education (<high school degree, high school degree, some college/vocational school, college degree or beyond), and marital status (married versus never/divorced/separated). For the multivariable analyses, categorical/dummy variables were created for race (non-White versus White) and education (dummy variables comparing higher and lower education to high school degree). APOE genotype (available for participants who provided informed consent), previously determined at University of Vermont's Core Molecular Genetics facility [53], was dichotomized as ≥1 ε4 allele versus no ε4 alleles.

Health status and behavior variables measured at MRI included body mass index calculated from height and weight measurements ($kg/m^2$), total kilocalories (kcal) of PA per week calculated from self-reported physical activities [54], blocks walked per week, and smoking status (current, former, never). Pack-years smoked as of the baseline visit was also included. Comorbidities measured at MRI included hypertension (≥140mmg systolic, ≥90 mm diastolic, or self-reported physician diagnosis plus use of anti-hypertensives), depression score on the 10-item Center for Epidemiological Studies Depression Scale [55] self-reported arthritis or treatment with medication, and diabetes (high glucose level or medication use. Presence of cardiovascular disease (cardiac bypass, congestive heart failure, heart attack, coronary heart disease, angina) and cerebrovascular disease (stroke, transient ischemic attack) at MRI were determined from participant reports confirmed via event adjudication after medical records review [56]. The modified Mini-Mental State examination (3MSE) measured global cognition (0–100, higher being better).

### Neighborhood characteristics

Neighborhood population density (people/km$^2$) and neighborhood median household income at the MRI (1997–1999) were estimated for the 1-km and 5-km radial buffers surrounding each participant's residence. US Census data (1990, 2000) from the Brown Longitudinal Tract Database were used to derive 1997–1999 values of population density using linear interpolation and accounting for residential address changes. Data for US Census tracts were used to create weighted average values within each buffer based on proportion of Census tract covered. Analyses focused on the 1-km buffers.

### Statistical analyses

We used means with standard deviations and frequencies with percentages to describe those included in the analyses, including by both high and low neighborhood greenspace at the time of the MRI dichotomized at the mean percentage (>30% versus ≤30%). We tested for significant differences between participants with high and low amounts of greenspace using chi-square tests or unadjusted linear regression.

Unadjusted and adjusted linear regression examined the association between continuous measures of neighborhood greenspace estimated five years before the MRI (proportion of 1-km buffer composed of greenspace; range: 0–1) and MRI measures of left and right hippocampal volume, white matter grade, and ventricle grade. Multivariable linear regression models were run first controlling for demographics (age, sex, race, income, education), neighborhood median household income, whole brain volume (mm$^3$), and site (a priori confounders). The models were then rerun controlling for variables found to be associated with greenspace, MRI measures, or both in unadjusted regression at $p<0.10$, including comorbidities (hypertension, arthritis, diabetes, cardiovascular disease, cerebrovascular disease), pack-years smoked, and APOE genotype. Linearity assumptions were confirmed using scatterplots and residual-by-predicted plots. Effect modification was assessed in the multivariable models by adding interaction terms between greenspace and APOE genotype or sex.

We performed a number of sensitivity analyses. The first examined cross-sectional adjusted associations with annual greenspace values at MRI and averaged over five years prior to the MRI (simple average of the annual greenspace values for the five years prior to MRI). Secondly, we reran the adjusted models using 5-km (3.1 mi) buffers to define neighborhood greenspace for all three greenspace estimates. These analyses determined if variation in the definitions of greenspace or neighborhood affected the results. The third assessed if removing the lowest and highest deciles of greenspace values changed the results substantially, to confirm that extreme values did not explain observed associations. The last sensitivity analysis involved rerunning the linear regression models using generalized estimating equations (GEE) clustered on US Census tract to ensure that standard errors were not influenced by correlations within neighborhoods.

## Results

The sample included 1,125 participants after exclusions (Figure 1). At MRI, mean proportion of greenspace in the neighborhood was 29.5% (SD=26.6%). Five years prior to the MRI, overall mean neighborhood greenspace was 38.3% (SD=27.6%), and mean values ranged from 22% in CA to 61% in MD (Table S1). Characteristics of participants are shown in Table 1. Several variables differed significantly by high and low amounts of greenspace, including income, education, study site, and neighborhood characteristics, as detailed in Table 1. Additional characteristics of participants concerning health status and comorbidities are shown in Table 2. Only smoking and 3MSE differed by high and low amounts of greenspace. Mean MRI values are also shown in Table 2 but did not differ by amount of greenspace.

Neighborhood greenspace was not associated with MRI outcomes in the unadjusted analyses (Table S2). In the first set of adjusted models, controlling for demographics, neighborhood household income, whole brain volume, and site, greater neighborhood greenspace measured five years before the MRI was borderline associated with lower ventricle grade (estimate: −0.27, 95% confidence interval [CI]: −0.56, 0.01; p=0.06) (Table 3), and this association remained borderline significant when additionally controlling for comorbidities and presence of ≥1 APOE ε4 allele (estimate: −0.30, 95% CI: −0.61, 0.00; p=0.052). In the adjusted models controlling for comorbidities and APOE genotype, age (estimate: 0.06; 95% CI: 0.04, 0.09) and male sex (0.40, 95% CI: 0.23, 0.57) were strong predictors of higher ventricle grade, consistent with prior findings [57]. Race (non-white versus white) was the strongest confounder. Adding race to the unadjusted model for ventricle grade resulted in a similar finding (greenspace estimate changed to - 0.28; 95% CI: −0.56, 0.00) to the fully adjusted model. No associations were found between neighborhood greenspace and left or right hippocampal volume or white matter grade. APOE genotype and sex did not modify associations between greenspace measured five years before MRI and the MRI outcomes (data not shown).

Our sensitivity analyses of greenspace measured at MRI and 5-year average greenspace (Table S3) and of the 5-km buffers (Table S4) resulted in similar findings to the main analyses. Main findings were unchanged after removing extreme greenspace values and using GEE (data not shown). Lastly, a post hoc analysis controlling for total kcal of PA/week did not attenuate the association between greenspace five years before MRI and ventricle grade (data not shown).

## Discussion

Living in neighborhoods with more greenspace was associated with lower ventricle grade, but with only borderline significance, and was not associated with left or right hippocampal volume or white matter grade. APOE genotype and sex did not modify associations in this study.

The borderline findings for ventricle grade suggest that compared to those with the lowest amount of neighborhood greenspace (0%), ventricle grade was on average 0.30 points

lower (on a 10-point scale) for those with the greatest amount of neighborhood greenspace (100%). In a prior CHS study examining individuals with normal cognition, subtle differences in average ventricular volume were observed at baseline between those who maintained normal cognition over time compared and those progressing to mild cognitive impairment [57]. Our observed borderline association between neighborhood greenspace and slightly lower ventricle grade raises the possibility that residing in neighborhoods with more vegetation may help reduce global brain atrophy. Ventricular enlargement occurs with aging and in neurodegenerative diseases including AD and small differences in ventricular volumes have been suggested as a potential AD biomarker prior to dementia [58].

The only known study investigating neighborhood built environment-brain biomarker associations found more walkable neighborhoods were associated with lower ventricular volumes, an association not mediated by PA [39]. We also found that PA did not mediate the greenspace-MRI associations but were not able to evaluate possible mediation by stress, depression, or air pollution. Future studies are needed to confirm our findings and test mechanisms through which greenspace influences brain health.

The regression estimates for ventricle grade remained consistent regardless of the time period used to measure greenspace (five years before MRI, at MRI, or 5-year average before MRI) and neighborhood scale (1-km or 5-km buffers). In the field of environmental research focused on neighborhoods, built environment, and greenspace, the methods employed to define exposures of interest and to delineate neighborhood boundaries are often not standardized [59,60]. Therefore, sensitivity analyses were essential to examine potential variation in associations depending on study definitions. Additional research is needed to assess associations between earlier life exposures to greenspace and brain biomarkers and whether brain health is influenced by greenspace changes over time and by residential moves between neighborhoods with different amounts of greenspace.

Hippocampal atrophy and the burden of white matter hyperintensities are risk factors for cognitive decline and Alzheimer’s disease and related disorders (ADRD), and individuals with ADRD who have these brain biomarkers demonstrate faster disease progression. Depression and PA have been associated with greenspace, hippocampal atrophy [61], and white matter hyperintensities, and therefore, neighborhood greenspace is plausibly related to these MRI measures via these mechanisms. However, no such associations were observed in this study. The lack of an association with hippocampal volume may be in part due to the reduced sample size of participants with hippocampal measures (n=612), in comparison to the number with ventricle grade scores (n=1,121), possibly limiting power to detect associations. In addition, future studies would benefit from examining the association of greenspace with atrophy in other brain regions such as the frontal lobe [8] and occipital lobe [62]. Walking in the neighborhood environment requires decision-making, attention, and navigation -- tasks that correspond to frontal and occipital lobe function.

## Limitations

This study has limitations. We did not include CHS participants who developed dementia because they likely represented a select sample with dementia that did not drop out and that volunteered for an MRI. In addition, individuals developing dementia may move

to assisted living or nursing homes with greenspace environments differing from their usual neighborhood surroundings prior to dementia (e.g., urban to suburban), which would misclassify exposure and also bias findings. Nonetheless, the exclusion of individuals with dementia may have resulted in the borderline associations, due to a lack of statistical power to test subtle differences in ventricle grade among non-demented individuals. Our borderline findings could also be explained by the lack of a real association between neighborhood greenspace and ventricle grade. Cognitive tests or other biomarkers may be better than ventricle grade at detecting greenspace-brain health associations. In the only other known study investigating greenspace and MRI outcomes in older adults, the authors posited that observed positive associations between greater forest coverage and amygdala integrity may have been due to reverse causality [40]. Future studies will need account for potential self-selection into neighborhoods (i.e., reverse causality) that could explain our borderline, positive associations between greenspace and ventricle grade.

Greenspace was quantified by the amount of neighborhood vegetation, without distinguishing among types or quality of the greenspace (e.g., condition of greenspace, gardens versus open spaces, trees versus grasses). Additional studies will be needed to investigate associations based on greenspace type, diversity, and quality [63], as well as associations with greenspaces outside the neighborhood, which could be important for the subset of older adults with greater mobility. Measures of access to and time spent in greenspaces are needed to confirm that any observed greenspace-MRI associations are not spurious/due to residual confounding. Greenspace data were missing for 10% of participants, which may have biased the results. Brain volume measures were only available for a single time point and therefore associations between greenspace and longitudinal change in MRI measures were not the focus of this study. In addition, the number of participants with hippocampal volume data was approximately half that of those with white matter and ventricle grade, possibly limiting our power to detect associations. Four MRI outcomes were examined and thus findings may be affected by multiple comparisons. However, we observed consistent results across different definitions of greenspace and neighborhood suggesting a possible association between greenspace and ventricle grade. This study was not designed to evaluate mediating factors that help explain greenspace-MRI measure associations such as social engagement [64], although our post hoc analysis of PA and its association with greenspace and ventricle grade provided no evidence that PA explains the observed associations. Additionally, as 89% of the sample were white, future studies will need to examine these associations in other races and ethnicities.

Strengths of the study include the use of a population-based, longitudinal cohort that provides a representative and large sample size with which to examine associations with MRI outcomes. Standardized clinical and MRI scanning protocols were employed to ensure data quality and consistency over time. The sample was restricted to individuals without dementia, and longitudinal data were available on the amount of greenspace in participants' neighborhoods in the five years prior to the MRI, ensuring temporal order between greenspace exposure and MRI outcomes.

## Conclusions

Our study suggests that residing in neighborhoods with greater amounts of greenspace may be associated with less ventricular enlargement among non-demented older adults. However, the observed association was of borderline significance, and the findings will need to be replicated in future longitudinal studies. If our findings were confirmed and expanded, the hope would be that future interventions and policies would be enacted to increase and improve neighborhood greenspace with the goal of promoting brain health in older adults.

## Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Declarations

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Conflict of interest:

Lilah Besser has no conflict of interest.

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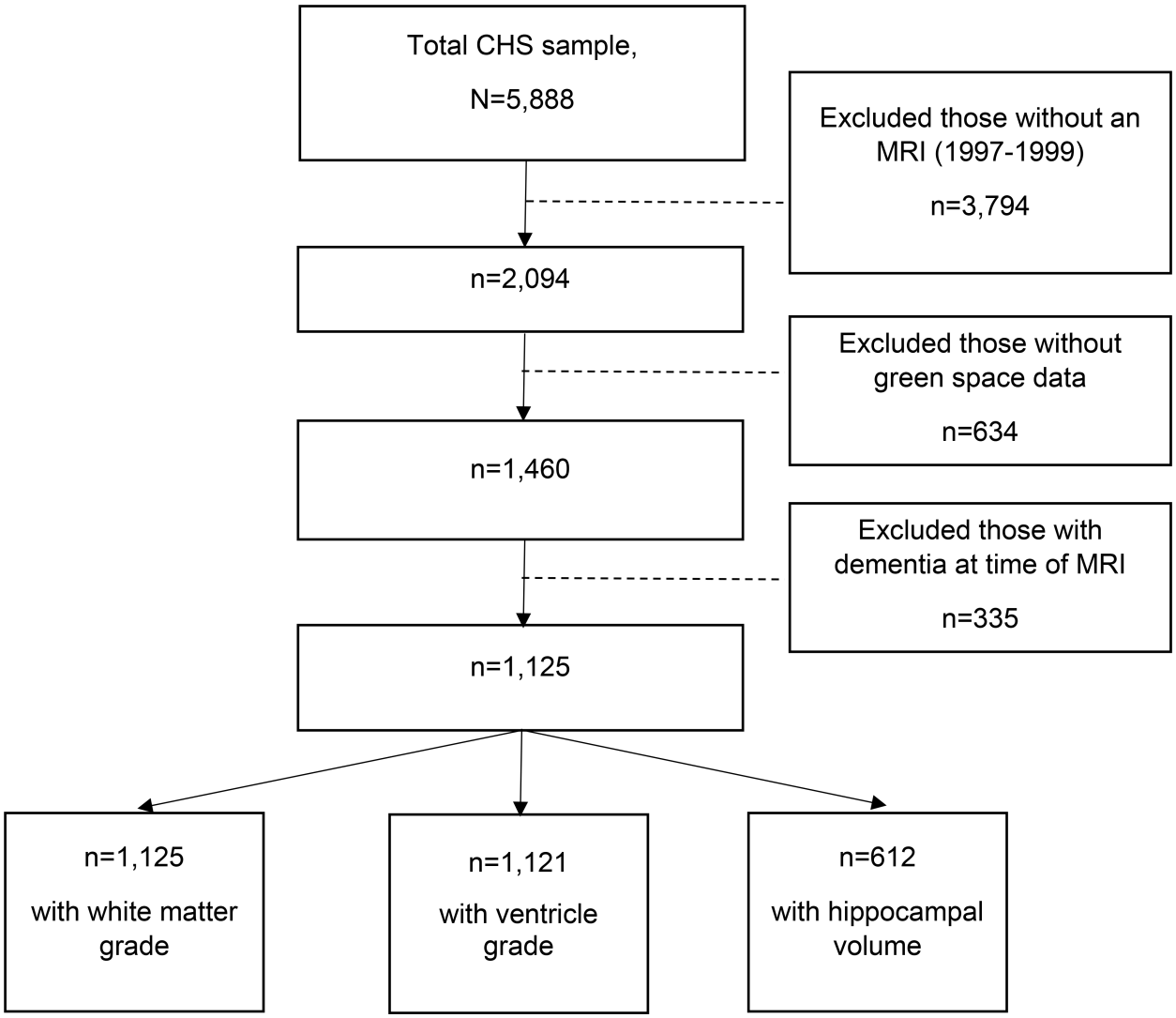


**Fig 1.**
Sample size flow diagram

**Table 1.**

Participant characteristics stratified by greenspace at time of imaging, dichotomized at mean percentage

| Characteristic[a] | Total n=1,125 | >30% greenspace at MRI n=455 | ≤30% greenspace at MRI n=670 | p-value[d] |
|---|---|---|---|---|
| Age[c], mean (SD) | 79.1 (4.1) | 78.9 (4.1) | 79.2 (4.2) | 0.20 |
| Female, n (%) | 647 (57.5%) | 273 (60.0%) | 374 (55.8%) | 0.16 |
| Race, n (%) | | | | 0.42 |
| White | 1001 (89.0%) | 413 (90.8%) | 588 (87.8%) | |
| Black | 121 (10.8%) | 40 (8.8%) | 81 (12.1%) | |
| Other | 3 (0.3%) | 2 (0.4%) | 1 (0.2%) | |
| Hispani[c], n (%) | 14 (1.3%) | 4 (0.9%) | 10 (1.5%) | 0.42 |
| Married, n (%) | 819 (72.9%) | 333 (73.4%) | 486 (72.5%) | 0.76 |
| Income, ≥$25,000/year[b], n (%) | 493 (46.7%) | 170 (39.2%) | 323 (52.0%) | **<.0001** |
| Education, n (%) | | | | **<.0001** |
| < High school degree | 226 (20.1%) | 116 (25.5%) | 110 (16.4%) | |
| High school degree | 333 (29.6%) | 148 (32.5%) | 185 (27.6%) | |
| Some college/vocational school | 276 (24.5%) | 103 (22.6%) | 173 (25.8%) | |
| ≥College degree | 290 (25.8%) | 88 (19.3%) | 202 (30.2%) | |
| ≥1 APOE ε4 allele, n (%) | 224 (21.2%) | 92 (21.4%) | 132 (21.1%) | 0.91 |
| Study site, n (%) | | | | **<.0001** |
| Forsyth County, NC | 236 (21.0%) | 138 (30.3%) | 98 (14.6%) | |
| Sacramento County, CA | 366 (32.5%) | 65 (14.3%) | 301 (44.9%) | |
| Washington County, MD | 226 (20.1%) | 174 (38.2%) | 52 (7.8%) | |
| Pittsburgh, PA | 297 (26.4%) | 78 (17.1%) | 219 (32.7%) | |
| Neighborhood population density[c], people/km$^2$, mean (SD) | 1,448 (1292) | 433 (466) | 2083 (1237) | **<.0001** |
| Neighborhood median HH annual income (in $1,000)[c], mean (SD) | 59.7 (21.1) | 64.3 (19.6) | 56.8 (21.5) | **<.0001** |
| Urban vs. suburban/rural[c], n (%) | 174 (15.5%) | 4 (0.9%) | 171 (25.5%) | **<.0001** |

Abbreviations: SD = standard deviation; APOE = apolipoprotein E; HH = household; NC = North Carolina; CA = California; MD = Maryland; PA = Pennsylvania

[a]Missing data: Hispanic, n=2; married, n=1; income, n=70; education, n=1; APOE, n=70; Left/right hippocampal volume, n=513; white matter grade, n=0; ventricle grade, n=4

[b]Measured at baseline visit

[c]Measured at time of MRI

[d]Unadjusted linear regression or chi-square test

**Table 2.**

Health status and comorbidities stratified by greenspace at time of imaging, dichotomized at mean percentage

| **Characteristic at MRI (unless otherwise indicated)**[a] | **Total n=1,125** | **>30% greenspace at MRI n=455** | **≤30% greenspace at MRI n=670** | **p-value**[d] |
|---|---|---|---|---|
| Body mass index (kg/m$^2$), mean (SD) | 26.7 (4.3) | 26.8 (4.5) | 26.6 (4.3) | 0.32 |
| Hypertension, n (%) | 787 (70.0%) | 312 (68.6%) | 475 (70.9%) | 0.40 |
| Total kcals physical activity/week, mean (SD) | 1456 (1792) | 1421 (1896) | 1479 (1719) | 0.60 |
| Blocks walked per week, mean (SD) | 34.6 (54.9) | 33.2 (53.0) | 35.6 (56.1) | 0.47 |
| Smoking, n (%) | | | | **0.0005** |
| Current | 86 (7.6%) | 41 (9.0%) | 45 (6.7%) | |
| Former | 494 (44.0%) | 168 (36.9%) | 326 (48.7%) | |
| Never | 545 (48.4%) | 246 (54.1%) | 299 (44.6%) | |
| Smoking pack years[b], mean (SD) | 15.8 (23.8) | 13.8 (21.9) | 17.2 (24.9) | **0.02** |
| Arthritis, n (%) | 535 (47.8%) | 233 (51.3%) | 302 (45.4%) | 0.05 |
| 10-item CES-D (depression) scale, mean (SD) | 5.1 (4.5) | 5.1 (4.5) | 5.1 (4.5) | 0.97 |
| Diabetes, n (%) | 195 (17.5%) | 91 (20.1%) | 104 (15.7%) | 0.06 |
| Fasting glucose (mg/dL), mean (SD) | 101.3 (29.8) | 102.3 (30.2) | 100.6 (29.5) | 0.37 |
| Cardiovascular disease[c], n (%) | 312 (27.7%) | 120 (26.4%) | 192 (28.7%) | 0.40 |
| Cerebrovascular disease (stroke/TIA), n (%) | 87 (7.7%) | 39 (8.6%) | 48 (7.2%) | 0.39 |
| 3MSE (cognitive screening test), mean (SD) | 94.0 (5.4) | 93.6 (5.8) | 94.3 (5.2) | **0.03** |
| MRI measure | | | | |
| Left hippocampus, mm$^3$ | 1713 (347) | 1685 (207) | 1728 (401) | 0.14 |
| Right hippocampus, mm$^3$ | 2476 (507) | 2430 (367) | 2501 (566) | 010 |
| White matter grade (0–9) | 2.59 (1.60) | 2.61 (1.62) | 2.58 (1.58) | 0.77 |
| Ventricle grade (0–9) | 3.51 (1.26) | 3.47 (1.27) | 3.53 (1.25) | 0.46 |

Abbreviations: SD = standard deviation; CES-D = Center for Epidemiological Studies Depression; 3MSE = modified Mini Mental State Exam; TIA = transient ischemic attack

[a]Missing data: Body mass index, n=39; kcal physical activity, n=13; pack years, n=39; glucose, n=55; 3MS, n=6; arthritis, n=6; diabetes status, n=11; depression score, n=2

[b]Measured at baseline visit (not available at time of MRI)

[c]Cardiac bypass, congestive heart failure, heart attack, coronary heart disease, angina

[d]Unadjusted linear regression or chi-square test

**Table 3.**

Adjusted association between proportion neighborhood greenspace (continuous measure) and imaging measures

| Time frame of proportion greenspace measure[a] | MRI outcome | Controlling for demographics, total brain volume, neighborhood HH income[b,c] | | Additionally controlling for comorbidities and APOE[d] | |
|---|---|---|---|---|---|
| | | b estimate (95% CI) | p-value | b estimate (95% CI) | p-value |
| Five years prior to MRI | Left hippocampus | 15.6 (−54.6, 85.8) | 0.66 | −5.5 (−79.3, 68.3) | 0.88 |
| | Right hippocampus | 48.4 (−54.4, 151.2) | 0.36 | 34.0 (−79.1, 143.1) | 0.54 |
| | White matter grade | −0.17 (−0.52, 0.20) | 0.37 | −009 (−0.48, 0.30) | 0.65 |
| | Ventricle grade | −0.27 (−0.56, 0.01) | 0.06 | −0.30 (−0.61, 0.00) | 0.05 |

Abbreviations: MRI =Magnetic resonance imaging; Confidence interval = Confidence interval; HH = household; APOE = apolipoprotein E

[a]Greenspace measurements taken from 1 km around participants' residences

[b]Controlling for age, sex, race (non-white versus white), income, education, neighborhood median household income, site

[c]Models for left and right hippocampus (not white matter or ventricle grade) included total brain volume as covariate

[d]Comorbidities (diabetes, arthritis, hypertension, cardiovascular disease, cerebrovascular disease), pack-years smoked, body mass index, APOE genotype