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Preliminary observations on MRI correlates of driving independence and performance in persons with heart failure

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Abstract

Purpose/Aim: Heart failure patients often require assistance with activities of daily living, including driving. Recent work shows heart failure patients commit more errors on a simulated driving task relative to controls and cognitive dysfunction contributed to these errors. We sought to extend these findings by examining whether structural magnetic resonance imaging indices correlate with driving independence and performance in heart failure.

Materials and Methods: Forty-nine heart failure patients underwent brain magnetic resonance imaging and performed a battery assessing attention/executive function and memory. A self-report instrument was used to assess independence in transportation. A subset of heart failure participants ($N = 8$) completed a validated driving simulator scenario.

Results: Among the larger sample ($N = 49$), reduced gray matter correlated with greater dependence in transportation and worse attention/executive function; in turn, worse attention/executive function predicted greater assistance with transportation ($p < 0.05$). Among the subset that completed the driving simulator ($N = 8$), reduced gray matter correlated with more stop signs missed and increased white matter hyperintensities correlated with greater collisions, centerline crossings and time out of lane ($p < 0.05$). Poorer attention/executive function was also associated with more time over the speed limit on the driving simulation ($p < 0.05$). Follow-up analyses showed the above effects were largely independent of age.

Conclusions: Reduced structural brain integrity is associated with poorer reported and simulated driving in persons with heart failure. Larger prospective studies that employ on-road testing are needed to clarify brain changes and risk for unsafe driving in heart failure.

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Declaration of Interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

Keywords

heart failure; neuroimaging; cognitive function; driving simulation; transportation

Introduction

Persons with heart failure (HF) frequently require assistance with many daily living tasks, including housekeeping duties, shopping and management of medications and finances [1,2]. Emerging evidence also suggests that this population may be at risk for unsafe driving and some patients may require assistance with transportation. For instance, nearly 10% of HF patients report increased assistance with driving and transportation and a history of heart disease has been linked with self-imposed driving cessation [2,3]. Recent work also shows that HF patients demonstrate worse performance on a simulated driving task relative to controls, including recording greater number of collisions, stop signs missed, centerline crossings and off-road excursions [4].

Cognitive impairment is common in HF and a likely contributor to poor driving ability in this population. For instance, HF patients frequently exhibit deficits in complex cognitive processes required for driving (e.g., attention/executive function) [5,6] and such deficits have indeed been correlated with worse simulated driving performance in this population [4]. Specifically, Alosco and colleagues in 2013 demonstrated that greater impairments on a cognitive composite comprised of measures assessing multitasking, working memory, basic and complex attention, and inhibition predicted greater centerline crossings and increased% of time spent out of the lane [4]. Recent work also demonstrates impaired simulated driving in a heterogenous sample of persons with cardiac disease that was suggested to in part stem from high rates of deficits in driving-related cognitive abilities (e.g., executive dysfunction) [7]. These findings in HF, and cardiovascular disease more broadly, are consistent with the extant evidence that shows the adverse effect of cognitive dysfunction on safe driving in other patient populations (e.g., Alzheimer's disease; Parkinson's disease) [8,9].

Cognitive function did not emerge as a mediator between cardiovascular health and driving performance in a past study among cardiac patients, suggesting that the mechanisms for impaired driving in cardiovascular disease remain unclear and deserves further study [7]. Although not previously examined, the adverse effects of structural and ischemic brain injury on cognitive function in HF patients [10,11] may underlie poor driving ability in this population. When compared with controls, HF patients have been shown to exhibit greater white matter hyperintensities (WMH) and reduced total and regional brain volume [12,13]. Such brain pathology in HF is often found in frontal lobe brain regions that mediate higher-ordered mental abilities necessary for intact driving, such as executive functions [13,14]. This complex region of the brain is indeed at heightened susceptibility to the microvascular and macrovascular physiological effects of HF that ultimately lead to decreased cerebral blood flow and subsequent structural injury. This pattern is unfortunate, as the negative impact of reduced brain volume on cognitive function has been suggested to contribute to impaired driving in elderly individuals [15]. Past work in other patient samples (e.g.,

Alzheimer's disease; vascular disease) also demonstrates that reduced brain perfusion – a significant correlate of WMH in HF – predicts unsafe driving [10,16,17].

Despite these findings, no study has examined the effects of structural magnetic resonance imaging (MRI) indices on driving ability in patients with HF. Even further, the impact of WMH on driving has yet to be examined, regardless of the patient population. The purpose of the current study was to examine the association among MRI indices (e.g., WMH, total brain volume, total and subcortical gray matter volume), cognitive function and reported independence in transportation among a sample of patients with HF. To help clarify these findings using a more objective assessment of driving performance, we also examined these associations using driving simulation technology among a subset of patients with HF.

Materials and methods

Participants

A sample of 49 participants with HF was recruited from an ongoing National Institute of Health (NIH) study examining neurocognitive function in HF. As part of this NIH study, all participants completed a total of three study sessions over a 1 year period (i.e., at baseline, 3 months and 12 months). The current sample included participants that completed the single time baseline study assessment and had complete baseline neuroimaging data. To minimize possible confound, strict inclusion and exclusion criteria were implemented for entry into the larger NIH funded study. Specifically, the inclusion criteria were age of 50–85 years, English as a primary language and a diagnosis of New York Heart Association (NYHA) class II, III or IV at the time of enrollment. Individuals were precluded from study entry if they had a history of neurological disorders (e.g., dementia, stroke, multiple sclerosis, etc.), head injury with >10 min loss of consciousness, severe psychiatric disorder (e.g., schizophrenia, bipolar disorder), past or current substance abuse/dependence and stage 5 chronic kidney disease. Participants for the current study were also excluded for any contraindications to MRI.

A subset of HF patients ($N = 21$) was also randomly recruited from the larger NIH funded study to participate in a driving simulation study. Participants were randomly contacted by phone to participate in the driving study. For this sample, additional inclusion criteria required a valid driver's license, currently driving and had at least 10 years of driving experience. All patients were also screened for neurological and psychiatric conditions that may influence cognitive function or restrict their performance of instrumental activities of daily living. Two participants were excluded due to failure to meet inclusion/exclusion criteria, i.e., inactive driver's license or not currently driving. One participant also withdrew from study procedures. The final sample size included a total of 18 patients with HF with complete driving simulation data. However, given the aims of the current study, we only examined HF patients that also had complete MRI data yielding a final sample of eight. Neuroimaging and cognitive data for this subset of HF participants was obtained from their most recent study assessment as part of the larger NIH study's protocol.

Measures

Neuroimaging—Whole-brain, high-resolution 3D T1-weighted images (Magnetization Prepared Rapid Gradient-Echo, MPRAGE) were acquired on a Siemens Symphony 1.5 Tesla magnetic resonance imaging scanner for morphologic analysis. Twenty-six slices were acquired in the sagittal plane with a 230 × 100 mm field of view. The acquisition parameters were as follows: Echo time (TE) = 17, repetition time (TR) = 360, acquisition matrix = 256 × 100 and slice thickness = 5 mm. Whole-brain FLAIR images were also acquired to quantify WMH. For the FLAIR images, 21 5 mm slices were acquired with TR = 8500, TI = 2500, Flip Angle = 150 degrees, TE = 115 and FOV = 220×75.

Morphometric analysis of brain structure was completed with FreeSurfer Version 5.1 (http://surfer.nmr.mgh.harvard.edu). Detailed methodology for regional and total volume derivation has been described in detail previously [18-20]. FreeSurfer was used to perform image preprocessing (e.g., intensity normalization, skull stripping), then to provide both cortical and subcortical volume measures using the surface stream and the subcortical segmentation stream, respectively. FreeSurfer performs such parcellations by registering images to a probabilistic brain atlas, built from a manually labeled training set, and then using this probabilistic atlas to assign a neuroanatomical label to each voxel in an MRI volume. Total brain volume, total gray matter volume and total subcortical gray matter volume were all automatically derived with the subcortical processing stream (i.e., “aseg.stats”).

Total WMH volume was derived by a three-step operator-driven protocol that has been described in detail previously [21]. Briefly, in Step 1, a threshold was applied to each FLAIR image to label all voxels that fell within the intensity distribution of hyperintense signal. In Step 2, gross regions-of-interest (ROIs) were drawn manually to include WMH but to exclude other regions (e.g., dermal fat) that have similar intensity values. The ROIs correspond to WMH in periventricular areas and deep cortical areas. In Step 3, a new image is generated that contains the intersection of voxels labeled in Step 1 and those labeled in Step 2. The resulting image contains labeled voxels that are common in Step 1 and Step 2 and isolated in Step 3 to create totalWMHvolume for periventricular and deep cortical regions [21]. During Step 3, volumes are provided for the ROIs in cm^3 that is based on the number of labeled voxels and voxel dimensions [21]. The number of resulting voxels is summed and multiplied by voxel dimensions to derive a total volume score that is comprised of left and right hemisphere periventricular and deepWMHvalues. The validity and reliability of this approach has been demonstrated previously [21].

Self-reported independence in transportation—Item number six from the self-report version of the Lawton Brody Instrumental Activities of Daily Living Scale was used to assess independence in transportation [22]. Specifically, this is a 5-option multiple-choice question that asks participants to indicate their degree of independence in driving and transportation, ranging from travels independently to does not travel at all. Any response that indicated receiving assistance was deemed impaired and scores ranged from 0 to 2 with a higher total score reflective of greater independence in driving and transportation [22]. This item has been used previously to assess independence in driving among HF patients [2]. The Lawton Brody scale is commonly employed in clinical settings to assess

instrumental activities of daily living and demonstrates strong interrater reliability ($r = 0.85$), and concurrent validity with other measures of functional status that assess physical health, orientation and memory, behavioral and social adjustment, and activities of daily living (ADLs) [23].

Driving simulation—The STISIM Driving Simulator (Build 2.08.03) by Systems Technology Inc. (Hawthorne, CA) was used to provide an objective assessment of driving ability. It is a computer-based, interactive drive simulator software package, and has been configured to control: (a) a high fidelity steering wheel with two analog levers for left/right turn indication; (b) an analog pedal set consisting of an analog brake pedal and another pedal for gas and (c) a 46” High Definition LCD television at an average presentation distance of 4.5 feet. The STISIM driving software was used to devise the driving scenarios that all participants completed.

HF participants first completed a practice scenario with the driving simulation technology in order for drivers to become comfortable with the simulator and practice the tasks they were required to perform during the test trial such as accelerating, decelerating, following the speed limit signs, stopping at stop signs/traffic signals and maintaining lane position. The practice scenario is nearly 3 miles long, lasted approximately 15 min, and assessed driving performance in multiple settings, including city, country and highway environments.

Participants then completed the Kent Multidimensional Assessment Driving Simulation (K-MADS) driving scenario, which is distinct from the practice simulation. All participants were instructed to drive as safe as possible as they normally would on the road. The K-MADS is a roughly 7 mile long driving scenario that takes approximately 20–25 min to complete. It has good psychometric properties (among an adult population, test-retest indices at 2 weeks range from $r = 0.68$ to $r = 0.83$; performance correlated with history of tickets in real world driving, $r = 0.76$). The K-MADS provides an opportunity to measure driving performance in a number of environments including a quiet suburb, a country road, a small town and a busy city, each with its own speed limit restrictions and lane configurations. For a full description and review of the K-MADS course refer to Alosco and colleagues [24]. The K-MADS yields several indices reflective of driving performance, including total collisions, number of stop signs missed, number of centerline crossings, number of road excursions,% of time over the speed limit and % of time out of the lane.

Neuropsychological measures—A brief battery of neuropsychological tests was administered to assess multiple domains of cognitive function. All neuropsychological tests in the current study exhibit excellent reliability and validity. The specific domains and neuropsychological tests administered are as follows:

Attention/executive function.: Trail Making Test A and B [25], Digit Symbol Coding [26,27], Frontal Assessment Battery [28]. These measures tap into a range of higher-order cognitive abilities, including multitasking, psychomotor speed, working memory, abstract reasoning, lexical fluency, inhibitory control, sensitivity to interference, higher-order motor programming and environmental autonomy. These measures employed are sensitive to driving abilities and the Trail Making Test A and B are commonly used, and recommended

by the American Medical Association, to assist in the clinical decision making of fitness to drive, including in cardiac and cognitively impaired populations [29,30].

Memory.: California Verbal Learning Test-Second Edition (CVLT-II) long delayed free recall and total recognition hits [31]. This measure assesses ability to store and recall information at a later time point and was employed given past work that suggests memory may play an important role in driving abilities [32].

Demographic and medical history—Demographic and medical characteristics were ascertained through participant self-report and medical record review.

Procedures

The local Institutional Review Board (IRB) approved the study procedures and all participants provided written informed consent prior to study enrollment. As part of the larger NIH study procedures, a medical record review was performed and participants completed demographic and medical history and psychosocial self-report measures, including the Lawton Brody Instrumental Activities of Daily Living Scale. A brief neuropsychological test battery was also administered to all HF patients. The total study time for this single time baseline assessment was approximately 90 min. All participants then underwent MRI at a separate study visit, but within 2 weeks of cognitive testing. A sample of HF participants that completed the above procedures was also randomly recruited to complete the 20–25 min brief driving simulation task.

Statistical analyses

All neuropsychological measures were converted to *T*-scores using normative data that accounted for the effects of age; memory was also adjusted for gender in addition to age. Consistent with clinical interpretation, a *T*-score < 35 (i.e., 1.5 SD below the mean of normative standards) was considered to reflect impaired test performance. Attention/executive function and memory composites were computed that consisted of the mean *T*-scores of the measures that comprise their respective domains. One case exhibited missing data on Digit Symbol Coding, and for this instance, attention/executive function consisted of the mean of the remaining measures that comprise this domain.

Among the larger sample ($N = 49$), partial correlation analyses controlling for intracranial volume and HF severity were performed to examine the association amongMRI indices (e.g., WMH, total brain volume, total gray matter volume and total subcortical gray matter volume) with attention/executive function and memory as well as reported independence in transportation. Partial correlations adjusting for LVEF also investigated the impact of attention/executive function and memory on reported independence in transportation.

Among the subset of HF participants ($N = 8$), bivariate correlation analyses were performed to examine the association betweenWMHand brain volume indices (i.e., total brain, total gray matter and total subcortical gray matter volume) with the driving simulation indices, including total collisions, number of stop signs missed, number of centerline crossings, number of road excursions,%of time over the speed limit and % of time out of the lane.

Bivariate correlations also examined the association between attention/executive and the above listed driving simulation indices. No covariates were included in the correlation models among the subset of HF participants in light of the reduced sample size for these analyses. However, analyses were performed to examine the association between medical conditions and driving simulation performance.

Results

Sample characteristics

Participants averaged 69.12 (SD = 8.27) years of age, and were 51.0% female. Medical chart review revealed that the sample had an average left ventricular ejection fraction (LVEF) of 46.27 (SD = 14.81) and 42 of the 49 participants were in NYHA class II. Medical comorbidities were prevalent in the larger sample, including hypertension (75.5%), diabetes (30.6%), sleep apnea (24.5%) and elevated total cholesterol (63.3%). See Table 1 for demographic and medical information.

Among the subset of participants that completed the driving simulation task ($N = 8$), participants averaged 65.13 (SD = 8.95) years of age and were 12.5% female and had an average LVEF of 43.63 (SD = 12.18). All but one participant was in NYHA class II. In terms of medical comorbidities, 75.0% had a history of hypertension, 25.0% of diabetes, 12.5% of sleep apnea and 75.0% had elevated total cholesterol.

For both samples, independent sample *t*-tests and chi-square analyses showed no associations between any of the medical comorbidities and self-reported independence in transportation or driving simulation performance ($p > 0.05$ for all).

MRI indices and cognitive function ($N = 49$)

Clinically meaningful impairments on cognitive test performance were common in the sample, particularly in attention/executive function. Specifically, 12.2% exhibited impairments on Trail Making Test B and 30.6% on the Frontal Assessment Battery. Memory impairments were also evident, as 10.2% demonstrated a *T*-score < 35 on the CVLT-II Long Delayed Free Recall and 22.4% on total recognition hits. See Table 2 for a full summary of cognitive test performance.

MRI indices demonstrated significant associations with cognitive function in the sample. Specifically, partial correlations showed reduced total gray matter volume ($p = 0.01$) and subcortical gray matter volume ($p = 0.03$) were associated with decreased attention/executive function, even after accounting for intracranial volume and LVEF. These same analyses also showed marginal significance between reduced total gray matter volume ($p = 0.06$) and total brain volume ($p = 0.07$) with poorer memory abilities. No associations emerged for WMH ($p > 0.05$). See Table 3.

MRI indices, cognitive function and reported independence in transportation ($N = 49$)

Of the sample, 8.2% reported requiring some assistance with transportation needs. See Table 4 for correlations examining the association between MRI indices and reported independence in transportation. Partial correlations adjusting for LVEF revealed

a significant association between attention/executive function and reported independence in transportation ($t(46) = 0.30$, $p = 0.04$). Decreased attention/executive function was associated with greater assistance with transportation. No such findings were found for memory ($t(46) = 0.04$, $p = 0.79$).

After controlling for intracranial volume and LVEF, there was a significant association between total gray matter volume ($p = 0.01$) and marginal significance for total subcortical gray matter volume ($p = 0.06$) with reported independence in transportation. In each case, reduced brain volume was associated with greater reported assistance with transportation. No such pattern emerged for total brain volume or WMH ($p > 0.05$ for all).

MRI indices, cognitive function and driving simulation performance (*N* = 8)

HF participants frequently committed errors on the driving simulation task. Specifically, the sample averaged 2.50 (SD = 1.41) total collisions, 4.63 (SD = 3.66) centerline crossings and 3.25 (SD = 4.53) off-road excursions. In addition, 50.0% of the sample missed at least one stop sign, and on average spent 11.52% (SD = 10.49) of the time over the speed limit, and 2.96% (SD = 2.22) of the time out of the lane. Poorer cognitive function was associated with poorer driving simulation performance. Reduced attention/executive function correlated with greater amount of time spent over the speed limit ($t(6) = -0.70$, $p = 0.05$). No other associations between the cognitive domains and driving simulation indices emerged ($p > 0.05$). Of note, all participants that completed the driving simulation reported being fully independent in driving.

Refer to Table 5 for bivariate correlations examining the associations between MRI and driving simulation indices. Reduced total ($p = 0.03$) and subcortical gray matter volume ($p = 0.03$) were associated greater number of stop signs missed. Increased WMH was also associated with greater number of total collisions ($p = 0.02$), higher number of centerline crossing ($p = 0.01$), greater time spent out of the lane ($p = 0.02$) and a trend for greater number of off-road excursions ($p = 0.07$). Trends also emerged between smaller total brain volume with greater number of stop signs missed ($p = 0.07$) and % of time spent out of the lane ($p = 0.07$). Follow-up scatter plots showed that these effects were largely independent of age. Specifically, these scatter plots were stratified by age in order to determine whether older age is driving the current findings. However, the scatter plots demonstrated a strong relationship between the MRI indices and driving simulation performance even among younger individuals and thus suggest minimal confound from the effects of age in this study.

Discussion

Cognitive dysfunction has recently been identified as a contributor to poor simulated driving in HF. The mechanisms for these findings are not entirely clear, though the current study extends past work by showing a significant association among structural MRI indices, cognitive function and reported and simulated driving ability in HF. Several aspects of these findings deserve further discussion.

The current study found that reduced brain volume and greater WMH were associated with poorer simulated driving performance and/or greater dependence in transportation. HF

patients frequently exhibit accelerated brain atrophy and greater WMH relative to controls [13,33]. While past work in elderly samples supports reduced brain volume as a correlate of unsafe driving [15], this study is the first to demonstrate the adverse effects of WMH on driving ability. WMH frequently accompany increasing age [34] and are believed to precede brain atrophy in many persons [35]. HF patients may be at even greater risk for unsafe driving relative to their peers due to heightened risk of WMH and brain atrophy stemming from exacerbated reductions in systemic and brain perfusion in this population [10,13,33,36,37]. Indeed, past work shows reduced cerebral blood flow is predictive of impaired driving in patients with Alzheimer's disease, perhaps a result of ischemic related brain changes (i.e., WMH) [16]. It is possible that WMH in HF interfere with activation and communication of key neuronal pathways among brain networks (e.g., visual and spatial areas to the prefrontal cortex) necessary for the performance of safe driving behaviors [38]. Future studies that employ on-road testing and neuroimaging modalities such as diffusion tensor imaging would help clarify the effects of WMH and brain atrophy on neuronal integrity and subsequent risk for unsafe driving.

Reduced brain volume was associated with poorer attention/executive function; in-turn, reduced attention/executive function correlated with poorer reported driving independence and performance. Cognitive impairment, notably reduced attention/executive function, is a significant risk factor for impaired on-road driving in elderly individuals [39]. Impairment in attention/executive function is also an important predictor of reduced functional independence in HF and a key contributor to reduced driving simulation performance [4,40]. Safe driving requires complex cognitive processes that involve attention/executive mental abilities such as planning, multitasking and execution of driving actions in response to changes in the environment [15]. Based on the current findings, WMH and/or smaller brain volume in HF [12,13] may compromise such cognitive abilities in HF to negatively impact driving ability. Supporting this notion is recent work in elderly drivers that demonstrates a significant association among smaller gray matter volume, lower executive function and risky driving tendencies [15]. Moreover, relative to controls, regions of the brain that regulate attention/executive functions (e.g., frontal lobes) are particularly susceptible to brain injury in HF [14,41]. Prospective studies should examine driving skills over time in HF, particularly as they correspond with brain atrophy and accompanying cognitive decline.

Interestingly, WMH was not associated with cognitive test performance in this sample, but still predicted poorer simulated driving. The exact reason for this finding is not entirely clear, although it is possible that WMH yield subclinical deficits in cognition that impact driving performance but were not captured by the current cognitive test battery. Alternatively, we did not examine WMH location effects and the global WMH quantification methodology in this study may have lacked sensitivity to cognitive impairments. For instance, WMH have been shown to be common in the frontal lobe regions in patients with HF [13] and insult to this specific brain region may account for a significant amount of the variance between executive function and driving abilities in HF. Lastly, increased WMH may reflect greater disease severity and thus other mechanisms may mediate the association between WMH and impaired driving in HF such as fatigue and/or psychological factors (e.g., depression). Future studies that examine WMH location effects are much needed to better elucidate the role of brain abnormalities in the risk for unsafe driving in HF.

The generalizability of the current findings is limited in several ways. Most notably, the current study did not employ a demographically matched healthy control group and future work that does so is much needed to confirm the validity of our findings. However, this concern is at least partially attenuated in the current study through the use of normative data that accounts for the influence of age and/or gender among the cognitive variables and follow-up analyses that found the effects of MRI variables on driving simulation performance to be largely independent of age. In addition, past work also shows that HF patients exhibit worse driving performance relative to healthy controls [4]. Independence in transportation was assessed using self-report and does not assess actual driving ability. Although past studies suggest a strong association between reported and objective driving abilities [42], it cannot be certain whether loss of driving independence was related to actual reduced ability in the current sample. While driving simulation technology was used to help corroborate the self-report findings, the sample size was small and thus reduces the external validity of these findings. Interestingly, the subset of HF participants that completed the driving simulation all reported being fully independent in driving and transportation despite committing frequent errors on the driving simulation task. Similar to other cognitively impaired populations (e.g., Alzheimer's disease) [43,44], HF patients may not be fully aware of their deficits in driving or of the cognitive deficits that might place them at risk for harm to them-selves or others while driving. Future studies should explore this possibility and studies with larger samples are also needed to confirm our findings and determine the prevalence of impaired driving across the HF severity continuum.

The current study is limited in several other ways. While driving simulators are valid, cost-effective and maintain participant safety, on-road testing is required to replicate this study and confirm and increase the ecological validity of the current findings. Lastly, the overarching goal of the larger NIH study from which this sample was recruited was not to assess driving performance in HF and thus comprehensive driving assessments were not administered. Future work that employs more detailed assessments of driving (i.e., number of crashes, tickets, years of driving), as well as more diverse neuropsychological batteries are much needed to better elucidate the effects of neurocognitive impairment on driving abilities in HF. For example, previous work among a larger sample of HF patients [4] shows that attention/executive dysfunction predicted a different pattern of simulated driving impairments (i.e., greater centerline crossing, % of time spent out of lane) relative to the current study. The reasoning for this discrepancy appears to be largely related to differences in cognitive tests employed and neuropsychological measures assessing distinct aspects of attention/executive dysfunction likely exhibit differential sensitivity to various driving abilities.

Conclusions

In brief summary, MRI structural indices are associated with reported and simulated driving ability in HF. This study provides further evidence for HF to be an at-risk population for unsafe driving. Larger prospective studies that employ on-road testing are needed to clarify brain changes in HF and corresponding risk for impaired driving.

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Table 1.

Demographic and medical characteristics of 49 adults with heart failure.

Demographic characteristics	
Age, mean (SD) years	69.12 (8.27)
Education, mean (SD) years	13.82 (2.59)
Female (%)	51.0
Race (% Caucasian)	83.7
Medical characteristics	
LVEF, mean (SD)	46.27 (14.81)
Hypertension (% yes)	75.5
Diabetes (% yes)	30.6
Sleep apnea (% yes)	24.5
Elevated total cholesterol (% yes)	63.3

Abbreviations: LVEF = left ventricular ejection fraction.

Table 2.

Cognitive test performance of 49 adults with heart failure.

	***T*-score, mean (SD)**	**(%) *T*-score < 35**
Attention/executive function		
Trail making test A	51.64 (8.96)	8.2
Trail making test B	45.90 (18.80)	12.2
Frontal assessment battery	41.79 (21.69)	30.6
Digit symbol coding	48.60 (9.41)	8.3
Memory		
CVLT-II long delayed free recall	47.24 (11.28)	10.2
CVLT-II total recognition hits	44.08 (14.20)	22.4

Abbreviations: CVLT-II = California Verbal Learning Test.

Table 3.

Partial correlations examining the association between MRI indices and cognitive function ($N = 49$).

	Attention/ executive function	Memory
Neuroimaging indices		
Total brain volume	0.23	0.27 ($p = 0.06$)
Total gray matter volume	0.36*	0.27 ($p = 0.07$)
Total subcortical gray matter volume	0.31*	0.18
White matter hyperintensities	−0.02	−0.06

Note. *$p < 0.05$.

Analyses were adjusted for intracranial volume and left ventricular ejection fraction.

Table 4.

Correlations examining the association between MRI indices and reported transportation independence (N = 49).

	Reported transportation independence
Neuroimaging indices	
Total brain volume	0.10
Total gray matter volume	0.40 *
Total subcortical gray matter volume	0.28 (p = 0.06)
White matter hyperintensities	0.10

Note. *p < 0.01

Analyses were adjusted for intracranial volume and left ventricular ejection fraction.

Table 5.

Bivariate correlations examining the association between MRI and driving simulation indices ($N = 8$).

	Total collisions	Stop signs missed	Number of centerline crossings	Number of road excursions	% of time over the speed limit	% of time out of the lane
Neuroimaging indices						
Total brain volume	−0.14	−0.67 ($p = 0.07$)	0.03	−0.22	−0.66 ($p = 0.07$)	−0.09
Total gray matter volume	−0.32	−0.76 *	0.00	−0.18	−0.25	−0.01
Subcortical gray matter volume	−0.13	−0.74 *	0.09	−0.20	−0.09	−0.07
White matter hyperintensities	0.79 *	0.35	0.81 *	0.66 ($p = 0.07$)	−0.11	0.78 *

Note. *$p < 0.05$.