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Decreased Physical Activity Predicts Cognitive Dysfunction and Reduced Cerebral Blood Flow in Heart Failure

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Abstract

Objective—Cognitive impairment in heart failure (HF) is believed to result from brain hypoperfusion subsequent to cardiac dysfunction. Physical inactivity is prevalent in HF and correlated with reduced cardiac and cognitive function. Yet, no longitudinal studies have examined the neurocognitive effects of physical inactivity in HF. The current study examined whether reduced physical activity increases risk for cognitive impairment and brain hypoperfusion over time in HF.

Methods—At baseline and 12-months later, 65 HF patients underwent neuropsychological testing, transcranial doppler ultrasonography, and were asked to wear an accelerometer for seven days.

Results—Lower baseline step count and less time spent in moderate free-living activity best predicted worse attention/executive function and decreased cerebral perfusion at the 12-month

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follow-up. Decreased baseline cerebral perfusion also emerged as a strong predictor of poorer 12-month attention/executive function.

Conclusions—Lower physical activity predicted worse cognition and cerebral perfusion 12-months later in HF. Physical inactivity in HF may contribute to cognitive impairment and exacerbate risk for conditions such as Alzheimer's disease. Larger studies are needed to elucidate the mechanisms by which physical inactivity leads to cognitive dysfunction in HF, including clarification of the role of cerebral hypoperfusion.

Keywords

Physical activity; heart failure; cognitive function; cerebral blood flow; sedentary; accelerometry; neuropsychology

1. Introduction

A growing body of research demonstrates that heart failure (HF) patients are at heightened risk for cognitive impairment [1,2]. Relative to controls, patients with HF often exhibit poorer performance on tests of executive function, psychomotor speed, and memory [1]. Prospective studies show significant declines in cognitive function over time in HF [3], which is consistent with the elevated risk of dementia in this population [4]. However, the physiological mechanisms for such declines remain unclear.

Cerebral hypoperfusion may be a primary mechanism for cognitive impairment in patients with HF [5,6]. For instance, HF patients exhibit up to 31% reductions in cerebral blood flow [7] and greater decreases in brain perfusion has been linked with poorer cognitive function and the development of neuroimaging abnormalities (e.g., white matter hyperintensities) in persons HF [6,8]. Consistent with this pattern, cerebral hypoperfusion is also a well-documented biomarker of neuropathological disease progression in other cognitively impaired populations (e.g., mild cognitive impairment, Alzheimer's disease) [9,10].

Several HF-related factors, such as increased HF severity, longer disease duration, and greater burden of comorbid medical conditions affect cerebral blood flow [11]. Notably, recent work shows that direct treatment of these risk factors may lead to improved cerebral circulation and better cognitive function. For instance, cerebral perfusion in HF improves after interventions that ameliorate cardiac dysfunction (e.g., heart transplantation, medication) [12,13] and such improvements may lead to better neurocognitive outcomes [14].

Although not previously examined, decreased physical activity may be another modifiable risk factor for reduced cerebral perfusion and cognitive function in HF. Most patients with HF are physically inactive and a recent study showed HF patients averaged >550 minutes per day of sedentary behaviors and just over 3,600 steps per day [15]. As a comparison, relatively healthy older adults have been shown to average close to 10,000 steps per day [16]. This pattern of inactivity is alarming, as increased physical activity is a known promoter of systemic and brain perfusion [17–20] and sedentary lifestyle may exacerbate the impact of the disease. Indeed, cross-sectional studies suggest that physical inactivity is

correlated with poorer cognitive performance and smaller brain volume [21,22]. In addition, prospective studies in other populations (e.g., dementia, healthy elderly) demonstrate the beneficial effects of physical activity on the brain and cognitive function, suggesting physical activity may also improve neurocognitive outcomes in HF [23–26].

Despite these findings, no longitudinal study has examined whether decreased physical activity increases risk for cerebral hypoperfusion and cognitive dysfunction in patients with HF. The current study sought to determine whether baseline levels of physical activity predict cognitive function and cerebral perfusion at a 12-month follow-up in a sample of older adults with HF. We hypothesized that decreased levels of physical activity at baseline would predict worse cognitive function and greater reductions in cerebral perfusion at the 12-month follow-up.

2. Methods

2.1 Participants

The original sample consisted of 145 persons with HF recruited from a prospective study examining neurocognitive outcomes in HF over a one-year period. For the current study, the sample was reduced from 145 patients with HF to 65 following exclusion of participants for missing baseline or 12-month self-report data (n = 1), failure to complete baseline or 12-month cerebral blood flow assessment (n = 13), incomplete actigraphy data due to mechanical issues and/or invalid wear (n = 48), and/or participant attrition (n = 18). Thus, the current sample consisted for all participants that completed baseline and 12-month assessments and had complete data at these time points. Participants excluded did not differ in age ($t(142) = 0.43$, $p = 0.67$) or HF severity ($t(137) = -0.58$, $p = 0.56$) from the sample employed in the study.

Strict inclusion/exclusion criteria were implemented as part of the larger study's protocol in order to capture the independent contribution of HF on cognitive function. For inclusion, participants must have been between the ages of 50–85 years, English speaking, and had a diagnosis of New York Heart Association (NYHA) HF class II, III, or IV at the time of enrollment. Potential participants were excluded for a history or current diagnosis of a significant neurological disorder (e.g. dementia, stroke), head injury with >10 minutes loss of consciousness, severe psychiatric disorder (e.g. schizophrenia, bipolar disorder), substance abuse/dependence, and/or stage 5 chronic kidney disease. Participants averaged 69.77 (SD = 10.06) years of age, were 27.7% female, and medical records revealed an average left ventricular ejection fraction (LVEF) of 41.25 (SD = 14.71). See Table 1 for demographic, medical, and clinical characteristics of the sample.

2.2 Measures

2.2.1 Physical Activity—A GT1M accelerometer (Actigraph, Pensacola, FL) measured physical activity over a 7-day period. GTIM accelerometer is a valid measure of physical activity and reliably estimates step counts and activity energy expenditure across various treadmill walking and running speeds [27]. Participants were instructed in how to wear the accelerometer and also provided with a set of instructions for wear over the 7 days.

Specifically, participants were instructed to place the accelerometer over the right hip, affixed to an elastic belt, and preferably worn under their waistbands. Daily step count was calculated by the accelerometer, and for the current population a daily step count between 0 and 2,499 represented sedentary, 2,500 to 4,999 as limited physical activity, and a 5,000 to 12,000 daily step count was considered to be physically active [28]. Step count was analyzed in conjunction with a diary entry of daily routine.

Because daily step count does not fully account for intensity level, to more thoroughly characterize physical activity in the sample, an Excel macro was used to determine the number of minutes the participants engaged in five intensity activity levels. The activity levels were based on cutoff values from counts per minute, which was derived by dividing total activity counts by total wear time. The levels of activity were as follows: sedentary (<100 counts per minute), light intensity (100–760 counts per minute), Matthews free-living moderate intensity (760 –5,724 counts per minute), Freedson exercise-related moderate activity (1952–5724), and vigorous intensity activity (> 5,724 counts per minute) [29]. Cut points for moderate and vigorous activities were based on their correspondence to energy expenditures of 3–6 metabolic equivalents (METs) for moderate and greater than 6 METs for vigorous activity [30]. An additional cut point of 760 counts per minute was used to more accurately capture free-living moderate intensity activities, as opposed to Freedson's moderate exercise intensity [31].

On average, the sample wore the accelerometer for 832.64 (SD = 82.91) minutes per day. A valid day of wear was considered greater than or equal to 10 hours of wear per day, and the activity data was restricted to participants with at least 3 valid days of accelerometer wear. Average number of minutes per waking hours of the day spent in each activity level was calculated for each participant, as well as average minutes per day of accelerometer wear. Of the sample, 7.7% wore the accelerometer for 3 days of the week, 4.6% for 4 days, 6.2% for 5 days, 20.0% for 6 days, and 61.5% wore the accelerometer all 7 days of the week.

2.2.2 Cognitive Function—A brief neuropsychological test battery was administered to assess global cognitive function as well as attention/executive function and memory. The domains and neuropsychological measures administered include:

Global Cognitive Status: The Modified Mini Mental Status Examination (3MS) was used to characterize the global cognitive status of the sample. It is a well-validated screening measure that taps into a broad collection of mental abilities, including attention, orientation, memory, language, and calculation [32]. Scores on this measure range from 0–100 with higher scores reflective of better performance.

Attention/Executive Function: Trail Making Test parts A and B [33] and the Frontal Assessment Battery (FAB) [34] were used to examine attention/executive function. Trail Making Test A asks participants to connect a series of number as quickly as possible in sequential order. For Trail Making Test B, participants connect a series of numbers and letters in alternating sequential order as quickly as possible. In each case, time to completion served as the dependent variable, which demonstrates strong psychometric properties (e.g., test-retest reliability up to $r = 0.89$) [35]. The FAB is a frontal systems index measure

comprised of six subtests that tests abstract reasoning, mental flexibility, motor programming, executive control, resistance to interference, self-regulation, inhibitory control and environmental autonomy [34]. It is a brief (less than 10 minutes) test that demonstrates good internal consistency (Cronbach's = .78) and inter-rater reliability (r = .87) [34, 36]. Scores range from 0 to 18.

Memory: The California Verbal Learning Test-Second Edition (CVLT-II) short and long delayed free recall [37] was administered to test memory abilities. The CVLT-II exhibits strong psychometric properties and asks participants to learn and immediately recall a 16-item word list. Participants are also instructed to recall the learned list of words following a delay period. The CVLT-II demonstrates strong test-retest reliability (r = 0.80 to r = 0.84) [38].

2.2.3 Cerebral Blood Flow—Transcranial Doppler (TCD) ultrasonography measured cerebral blood flow velocity (CBF-V) using an expanded Stroke Prevention Trial in Sickle Cell Anemia (STOP) protocol [39]. TCD measured CBF-V has been shown to reliably reflect changes in cerebral flow [40] and demonstrates strong concordance validity with MRI measures of brain perfusion (i.e., arterial spin labeling) [41]. The TCD protocol assesses blood flow velocity in the major brain arteries and mean blood flow velocity of the Middle Cerebral Artery (CBF-V of the MCA) operationalized cerebral blood flow in the current study. The MCA irrigates the lateral frontal, temporal, and parietal regions of the cerebrum and is the most sensitive indictor of changes in brain perfusion relative to other arteries measured in TCD evaluation [42] Moreover, CBF-V of the MCA is also a sensitive predictor of neurocognitive outcomes in HF [8] and is affected by physical activity [19].

2.2.4 Depressive Symptoms—The Beck Depression Inventory-II [43] operationalized depressive symptomatology. The BDI-II is a commonly used, well-validated, checklist of affective and somatic depressive symptoms.

2.2.5 Physical Fitness—The 2-Minute Step Test (2MST) was used to provide an estimate of physical fitness and HF severity in the current sample. This brief measure requires participants to march in place lifting his/her knees to a marked target set on the wall set at the midpoint between the kneecap and crest of the iliac for a 2-minute period [44]. The 2MST is a valid measure of physical fitness [45] with greater step count reflecting better physical fitness. Average step count for females between the ages of 50–85 ranges from 71–115, while males range from 60–107.

2.2.6 Demographic and Medical Characteristics—Demographic characteristics and medical history were ascertained through participant self-report and corroborated by medical record review.

2.3 Procedures

The local Institutional Review Boards (IRB) approved the study procedures and all participants provided written informed consent prior to study enrollment. During a single baseline assessment, participants completed demographic and medical history questionnaires

and a brief neuropsychological test battery was administered. Participants then received an accelerometer and were instructed to wear the device each day for seven days from the moment they wake until they go to sleep. On a separate study visit, but within 2 weeks of baseline testing, participants also underwent TCD. These same procedures were performed at a 12-month follow-up.

2.4 Statistical Analyses

To facilitate clinical interpretation and maintain directionality across scales, neuropsychological measures assessing attention/executive function and memory were converted to T-scores adjusting for age; memory indices were also corrected for gender. A T-score of 35 was considered reflective of clinically-meaningful levels of cognitive impairment (i.e., 1.5 SD below the mean of normative values). Composite scores were computed for attention/executive function and memory and consisted of the mean of the T-scores of the neuropsychological measures that comprise these domains.

Repeated measures analysis of variance examined changes in each of the cognitive composite scores (e.g., attention/executive function, memory) in addition to CBF-V of the MCA over the one-year period. A series of regression analyses with and without covariates were then conducted to examine the predictive validity of baseline physical activity on 12-month attention/executive function, memory abilities, and CBF-V of the MCA. For all models, baseline values of the dependent variable were entered in block 1 and baseline daily step count was then entered in block 2. For models with covariates, block 1 also consisted of medical, clinical, and demographic variables, including age, years of education, depressive symptoms (as assessed by the BDI-II), and diagnostic history of hypertension, type 2 diabetes mellitus (T2DM), sleep apnea, and myocardial infarction (1 = positive diagnostic history; 0 = negative diagnostic history). These covariates were carefully selected based on the extant literature that demonstrates their effects on neurocognitive function and physical activity. Inclusion of such covariates was conducted to help to clarify the independent effects of physical activity on cognition and cerebral perfusion.

To clarify the above analyses, we also performed a series of follow-up regressions to determine the effects of intensity of physical activity on 12-month attention/executive function, memory abilities, and CBF-V. Using the above-described adjusted models, regression analyses were conducted for each of the following activity levels that were individually entered in block 2: light intensity, Matthews free-living moderate intensity, Freedson's moderate exercise activity, and vigorous intensity activity.

Finally, regression analyses were conducted to examine whether baseline CBF-V of the MCA predicted 12-month cognitive function. For these analyses, baseline cognitive test performance and age were included as the only covariates in block 1. Age was included as a covariate in light of its critical role in disrupted cerebral hemodynamics and cognitive outcomes in older adult populations [46]. Block 2 included baseline CBF-V of the MCA and the dependent variables consisted of 12-month attention/executive function and memory.

3. Results

3.1 Descriptive Statistics of Physical Activity

Table 2 presents descriptive statistics of physical activity in the current sample. Participants exhibited low levels of physical activity, averaging 594.17 (SD = 74.80) minutes per day of sedentary behaviors. According to daily step count cutoffs, 30.8% of participants were classified as sedentary, 46.2% as having limited physical activity, and just 23.1% as being physically active. Participants also demonstrated minimal time spent in Freedson's moderate exercise intensity activity and nearly no time spent in vigorous activity.

Consistent with the above, baseline physical fitness levels in the sample fell in the low and below average range for both males (mean (SD) = 63.70 (24.21) and females (mean (SD) = 61.65 (21.39) at baseline and remained stable over time (males: $F(1, 40) = 1.95$, $p = 0.17$; females: ($F(1,13) = 0.00$, $p = 0.98$). Increased baseline daily step count was correlated with greater baseline physical fitness levels ($r(58) = 0.46$, $p < 0.001$). Of note, independent samples *t*-tests showed no between sex group differences on attention/executive function or CBF-V of the MCA ($p > 0.05$ for all).

3.2 Baseline and 12-Month Cognitive Function

Table 3 presents cognitive test performance in the current sample at baseline and the 12-month follow-up. The average baseline 3MS score in the current sample was 93.09 (SD = 5.35) and 21.5% scored below a 90. A 3MS score of 90 has indeed been suggested to be clinically meaningful [47]. Many participants exhibited baseline impairments on cognitive measures assessing attention/executive function and memory abilities (see Table 3). Repeated measures analyses showed that participants demonstrated significant improvements on the 3MS ($F(1,64) = 5.50$, $p = 0.02$) and memory composite scores ($F(1,64) = 25.51$, $p < 0.001$) from baseline to the 12-month follow-up. No such pattern was found for attention/executive function ($F(1,64) = 0.06$, $p > 0.50$).

3.3 Physical Activity and 12-Month Cognitive Function

Analyses adjusted only for baseline cognitive test performance showed that reduced baseline daily step count was a significant predictor of worse 12-month attention/executive function ($\beta = 0.18$, $p = 0.04$; b = 0.001, 95% CI = 0.000–0.002). This pattern did not emerge for memory abilities ($p > 0.05$). Indeed, after controlling for baseline cognitive test performance and medical, clinical, and demographic factors, reduced baseline daily step count (marginal significance; $\beta = 0.17$, $p = 0.057$; b = 0.001, 95% CI = 0.000–0.002) predicted worse 12-month attention/executive function. Again, there was no such pattern for memory ($p > 0.05$).

To clarify these findings, regression analyses examining baseline physical activity intensity levels and 12-month cognitive function were performed. Less time spent in Matthews free-living moderate activity at baseline predicted worse 12-month attention/executive function ($\beta = 0.19$, $p = 0.049$; b = 0.06, 95% CI = 0.00–0.12). Time spent in light activity, Freedson's moderate exercise activity, or vigorous activity at baseline did not predict 12-month attention/executive function ($p > 0.05$ for all). Refer to Table 4 for a full summary of

adjusted regression analyses examining the predictive validity of baseline physical activity on 12-month cognitive function.

3.4 Physical Activity and 12-Month Cerebral Perfusion

Repeated measures ANOVA showed CBF-V of the MCA declined over time, but such findings did not reach significance ($p > 0.05$; see Table 1). Analyses adjusted only for baseline CBF-V of the MCA and no demographic or medical covariates showed marginal significance for the predictive validity of decreased baseline daily step count on reduced 12-month CBF-V of the MCA ($\beta = 0.17$, $p = 0.06$; b = 0.001, 95% CI = 0.000–0.003). This pattern remained after adjustment for demographic, medical, and clinical variables ($\beta = 0.18$, $p = 0.05$; b = 0.001, 95% CI = 0.000–0.003). Follow-up analyses showed less time spent in Matthews moderate free-living activity ($\beta = 0.19$, $p = 0.05$; b = 0.07, 95% CI = 0.000–0.15) at baseline predicted worse CBF-V of the MCA at the 12-month follow-up, even after controlling for baseline CBF-V of the MCA and demographic, medical, and clinical variables. This pattern did not emerge for light intensity activity or Freedson's moderate exercise activity ($p > 0.05$). See Table 4.

3.5 Cerebral Perfusion and Cognitive Function

Regression analyses controlling for baseline cognitive test performance and age showed that baseline CBF-V of the MCA was a strong predictor of 12-month attention/executive function (F change (1,61) = 3.61, $p = 0.06$, $\beta = 0.18$; b = 0.16, 95% CI = −0.01–0.32). Worse baseline CBF-V of the MCA predicted decreased 12-month attention/executive function. Baseline CBF-V of the MCA did not predict 12-month memory abilities (F change (1,61) = 0.29, $p = 0.60$).

4. Discussion

Physical activity is associated with better cardiac function [48] and has recently been identified as an important correlate of cognitive function in HF [15]. The present study extends such findings by demonstrating that physical activity predicts cognitive function and cerebral blood flow over time in patients with HF. The current findings also provide initial evidence for the contribution of reduced cerebral blood flow to worse cognitive function at a 12-month follow-up in HF. Several aspects of these findings warrant brief discussion.

The current study suggests that decreased daily physical activity predicts poorer attention/executive function at a 1-year follow up in patients with HF. These findings are consistent with past work in older adult populations linking physical inactivity and neuropsychological outcomes [25, 49]. The current sample exhibited nearly 600 minutes of sedentary behavior per day, which is perhaps not surprising given lack of physical activity is the most common self-care failure in HF populations [50]. Interestingly, recent findings show that higher levels of daily physical activity are associated with decreased risk for Alzheimer's disease among elderly patients [51]. Persons with HF are at elevated risk for Alzheimer's disease [4] and the current findings suggest that physical inactivity may exacerbate this risk. It is also possible that the high rates of sedentary behaviors rather than reduced levels of physical activity may alone introduce unique physiological mechanisms to negatively impact

cognition. For instance, individuals who spend more time sedentary have been shown to be at heighted risk for metabolic syndrome, a significant risk factor of cognitive decline [52,53]. In sum, exercise and physical activity programs may attenuate cognitive decline or the development of dementia in this population and future work should explore this possibility.

The current study also shows that reduced physical activity predicts lower cerebral blood flow at 12-months. These findings are consistent with past work in older adults and cardiovascular disease patients [18,54]. Physical activity helps maintain cerebral autoregulation through its beneficial effects on several physiological processes, including improved cerebrovascular endothelium, enhanced cardiac functioning, reduced inflammatory processes, among others [45,55–57]. While the combination of age and HF is believed to disrupt the cerebral autoregulatory system [5,11], altered cerebral hemodynamics may be exacerbated by sedentary behaviors. This is noteworthy, as decreased cerebral perfusion is an identified contributor to the pathogenesis of neurodegenerative conditions (e.g., Alzheimer's disease) [10,58] and believed to underlie brain pathology and cognitive impairment in HF [8]. In-turn, the mechanisms underlying the adverse effects of physical inactivity on cognitive function in HF may involve additive detriments to cardiorespiratory fitness—a key correlate of cognition in HF—resulting in exacerbated reductions in cerebral perfusion [45]. Taken together, it is possible that physically inactive HF patients may be at heightened risk for structural brain changes (e.g., white matter hyperintensities) due to further reductions in cerebral blood.

Global cognitive function and memory improved in the overall sample. Longitudinal studies reveal mixed evidence for both cognitive improvement and cognitive decline in HF patients [3,59] and such inconsistencies are likely a manifestation of the identified sub-groups of neurocognitive outcomes in HF [60]. This pattern is likely occurring in the current sample. For instance, on average, cerebral blood flow levels in the sample remained relatively unchanged over the one year period. However, it is likely that a small subset of patients within the sample are exhibiting significant reductions in brain perfusion—perhaps the unhealthiest of participants—and it is these persons driving the effects of cerebral hypoperfusion on reduced cognitive function. The current results between physical inactivity and poor neurocognitive outcomes may also be accounted for by a subgroup of the most sedentary HF participants; however, the reduced sample sizes precluded any form of subgroup analyses. As an example, Miller and colleagues (2012) [60] identified three cognitive subgroups in a sample of HF patients: cognitively intact, memory impaired, and globally impaired. Interestingly, this study showed that decreased physical fitness level was an important contributor to classification of being cognitively impaired. If confirmed, the higher rates of cognitive deficits that may be present in physically inactive HF patients could interfere with successful completion of recommended exercise training programs that can help preserve cognitive function given the complex demands associated with these programs [61,62].

Reduced physical activity predicted attention/executive function, but no such pattern emerged for memory. Impairment in attention/executive function is a common manifestation of vascular-related disorders [63,64] and past work in other cardiovascular disease patients

(i.e., stroke) shows this domain is sensitive to the effects of exercise [65]. As previously noted, physical inactivity is a correlate of cerebral hypoperfusion and this may in part explain the differential effects on attention/executive function. The regions of the brain that mediate attention/executive (i.e., frontal lobes) are particularly sensitive to reductions in cerebral perfusion and possibly subsequent ischemic injury [63]. Further supporting this notion is the current findings that demonstrate a significant association between cerebral blood flow and attention/executive function. The sensitivity of the frontal brain regions to drops in cerebral perfusion may also lead to irreversible brain damage (e.g., white matter hyperintensities) that may perhaps partially explain the lack of improvement observed in this domain over time in the present study.

The results of the current study should be interpreted in the context of several limitations. First, while moderate levels of intense free-living physical activity predicted cognitive function and cerebral blood flow, no such pattern emerged for moderate or vigorous exercise activity. These findings are unexpected given physical activity and its associated health benefits are believed to have a dose-response relationship, particularly as it relates to cardiovascular disease [45]. A likely explanation may involve range restriction, as participation in moderate exercise activity was minimal (mean = 5.31 minutes per day) and nearly no time was spent in vigorous activities for the group (mean = 0.31 minutes per day). Larger studies that include an exercise intervention are needed to better characterize the possible benefits of higher intensity physical activity in persons with HF and identify the intensity level necessary to produce neurocognitive benefits. Cerebral blood flow was operationalized using transcranial Doppler ultrasonography, which is a valid and reliable estimate of brain perfusion [40]. The use of more reliable measures of cerebral perfusion (e.g., arterial spin labeling) would help clarify the association among physical activity, cognition, and cerebral blood flow. Finally, the short follow-up period employed may not have been sensitive to changes in cerebral perfusion. Future studies with extended follow-ups are needed to examine the trajectories of cognitive function and cerebral blood flow over time in HF and determine whether physical inactivity accelerates cognitive decline or dementia-related processes possibly due to negative effects on the cerebral circulatory system.

Conclusions

In brief summary, the current study found that reduced physical activity at baseline predicts poorer cognitive function and cerebral blood flow 12 months later in older adults with HF. Such findings suggest that physical inactivity is common in HF and contributes to cognitive impairment in HF. Indeed, one possible mechanism for this relationship may involve cerebral hypoperfusion, though this awaits empirical testing among larger samples of older adults with HF. Prospective work is needed to determine whether exercise programs in HF can promote better neurocognitive outcomes in this population.

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Table 1

Demographic, Medical, and Clinical Characteristics of 65 Older Adults with Heart Failure at Baseline and 12-Month Follow-up

Demographic Characteristics	Baseline	12-Months
Age, mean (SD)	69.77 (10.06)	70.51 (10.18)
Sex (% Women)	27.7	--
Race (% Caucasian)	92.3	--
Education, mean years (SD)	13.60 (2.52)	--
Medical and Clinical Characteristics		
CBF-V of the MCA, mean (SD) cm/s	40.53 (12.90)	38.47 (13.58)
Diabetes (%)	26.2	26.2
Hypertension (%)	63.1	69.2
Sleep Apnea (%)	18.5	24.6
Myocardial Infarction (%)	53.8	55.4
Beck Depression Inventory-II	7.25 (6.73)	7.05 (6.74)

Note. CBF-V of the MCA = Cerebral blood flow velocity of the middle cerebral artery

Table 2

Objectively Measured Physical Activity in Older Adults with HF (*N* = 65) Activity Level

Wear Time, mean (SD)	832.64(82.91)
Daily Step Count, mean (SD)	3,723.90(1866.92)
Light Intensity, mean (SD)	187.88(59.10)
Matthew's Moderate Intensity, mean (SD)	50.29(34.82)
Freedson Moderate Intensity, mean (SD)	5.86(6.77)
Vigorous Intensity, mean (SD)	0.31(1.62)
Sedentary Time, mean (SD)	594.17(74.80)

Note. Wear Time = Average minutes per day of accelerometer wear; Daily Step Count = Average daily steps per day; Light Intensity = Average minutes per day of light intensity activity; Matthew's Moderate Intensity = Average minutes per day of free-living moderate intensity activity; Freedson Moderate Intensity = Average minutes per day of moderate exercise intensity activity; Vigorous Intensity = Average minutes per day of vigorous intensity activity; Sedentary Time = Average minutes per day of sedentary time

Table 3

Baseline and 12-Month Neuropsychological Test Performance (N = 65)

	Baseline Mean (SD)	**% T-score < 35**	**12-month Mean (SD)**	**% T-score < 35**	***F*-statistic**
Global Cognition					
3MS	93.09 (5.35)	--	94.17 (4.57)	--	5.50*
Attention/Executive Function (T-scores)					
TMTA	51.37 (8.70)	7.7	51.21 (10.59)	10.8	0.03
TMTB	47.28 (12.84)	12.3	46.99 (14.59)	13.8	0.04
FAB	42.90 (22.62)	24.6	44.19 (16.18)	26.2	0.30
Memory					
CVLT LDFR	47.92 (10.30)	7.7	52.85 (11.25)	3.1	18.59**
CVLT SDFR	48.08 (11.17)	6.2	53.72 (11.62)	3.1	23.36**

Note.

* $p < 0.05$;

** $p < 0.01$

Abbreviations—3MS = Modified Mini Mental State Examination; TMTA = Trail Making Test A; TMTB = Trail Making Test B; FAB = Frontal Assessment Battery; CVLT = California Verbal Learning Test; LDFR = Long Delay Free Recall; SDFR = Short Delayed Free Recall

Table 4

Predictive Validity of Baseline Physical Activity on 12-Month Cognitive Function and Cerebral Blood Flow (N = 65)

	Attention/Executive Function		Memory		CBF-V of the MCA	
	β	SE b	β	SE b	β	SE b
Block 1						
Age	0.03	0.10	0.16	0.10	−0.22*	0.13
Education	0.18*	0.39	0.19	0.41	−0.16	0.48
Hypertension	0.10	2.07	0.03	2.15	−0.08	2.53
Diabetes	0.18	2.45	0.01	2.50	0.01	3.02
Sleep Apnea	−0.08	2.61	−0.03	2.75	−0.15	3.27
MI	0.05	2.08	0.00	2.29	−0.12	2.56
BDI-II	−0.15	0.15	−0.08	0.15	0.15	0.18
Baseline***	0.72**	0.08	0.69**	0.10	0.63**	0.11
R^2	0.54		0.48		0.53	
F	10.26**		8.36**		9.97**	
Block 2 Model 1						
Step Count	0.17ϕ	0.00	0.05	0.00	0.18*	0.00
R^2	0.56		0.47		0.55	
F for ΔR^2	3.79ϕ		0.22		3.39*	
Block 2 Model 2						
Light Intensity	0.14	0.02	0.04	0.02	0.09	0.02
R^2	0.55		0.47		0.53	
F for ΔR^2	2.58		0.17		0.99	
Block 2 Model 3						
Matthew's Moderate	0.19*	0.03	0.09	0.03	0.19*	0.04
R^2	0.56		0.48		0.55	
F for ΔR^2	4.10*		0.72		3.87*	

	Attention/Executive Function		Memory		CBF-V of the MCA	
	β	**SE b**	**β**	**SE b**	**β**	**SE b**
Block 2 Model 4						
Freedson's Moderate	0.13	0.15	0.08	0.16	0.08	0.19
R^2	0.55		0.48		0.53	
F for ΔR^2	2.14		0.72		0.75	
Block 2 Model 5						
Vigorous Intensity	0.01	0.64	0.02	0.65	−0.12	0.76
R^2	0.53		0.47		0.60	
F for ΔR^2	0.01		0.04		1.65	

Note.

* $p < 0.05$;

** $p < 0.01$; $p = 0.057$;

*** Baseline test performance of the 12-month dependent variable was entered as a covariate

Abbreviations: 3MS = Modified Mini Mental State Examination; CBF-V of the MCA = Cerebral Blood Flow Velocity of the Middle Cerebral Artery; MI = Myocardial infarction; BDI-II = Beck Depression Inventory-II