Association Between Objectively Measured Physical Activity and Cognitive Function in Older Adults—The Reasons for Geographic and Racial Differences in Stroke Study

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OBJECTIVES: To examine the relationship between objectively measured physical activity (PA) and cognitive function in white and black older adults.

DESIGN: Cross-sectional.

SETTING: REasons for Geographic and Racial Differences in Stroke (REGARDS) study.

PARTICIPANTS: Older adults who provided valid data from accelerometer and cognitive function tests (N = 7,098).

MEASUREMENTS: Accelerometers provided estimates of PA variables for 4 to 7 consecutive days. PA cut-points of 50 counts per minute (cpm) and 1,065 cpm were applied to differentiate between being sedentary and light PA and between light and moderate to vigorous PA (MVPA), respectively. Prevalence of cognitive impairment was defined using the Six-Item Screener (<4/6). Letter fluency, animal fluency, word list learning, and Montreal Cognitive Assessment (orientation and recall) were used to assess memory and executive function.

RESULTS: Of 7,098 participants (aged 70.1 ± 8.5, 54.2% female, 31.5% black), 359 (5.1%) had impaired cognition within ±12 months of PA measurement. The average proportion of time spent in MVPA (MVPA%) was 1.4 ± 1.9%. Participants in the highest quartile of MVPA% (~258.3 min/wk) were less likely to be cognitively impaired than those in the lowest quartile (odds ratio = 0.65, 95% confidence interval = 0.43–0.97). MVPA% was also significantly associated with executive function and memory z-scores (P < .001). Similar analyses of proportion of time spent in light PA (LPA%) and sedentary time (ST%) showed no significant associations with cognitive function.

CONCLUSION: Higher levels of objectively measured MVPA%, rather than LPA% or ST%, were associated with lower prevalence of cognitive impairment and better performance in memory and executive function in aging people. The amount of MVPA associated with lower prevalence of cognitive impairment is consistent with meeting PA guidelines. J Am Geriatr Soc 63:2447–2454, 2015.

Key words: aging; physical activity; accelerometry; cognitive function

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A growing body of evidence indicates increasing prevalence and incidence of cognitive impairment in older adults in the United States.[1] A national study reported that an estimated 5.4 million people in the United States aged 70 and older had mild cognitive impairment (MCI).[2] Of those who completed follow-up assessments in the study, 11.7% with MCI progressed to dementia annually. A recent study showed that the prevalence of dementia in older adults in the United States in 2010 was 14.7%.[3] The cost of dementia in 2010 was $157 billion to $215 billion, with $11 billion associated with direct medical care. Cognitive impairment is a substantial financial liability on society similar to that of heart disease and cancer. Effective prevention strategies will have significant public health implications by improving quality of life and reducing economic cost and social burden.

Regular physical activity (PA) provides benefits for cognitive health and helps to improve or maintain quality

of life of older adults.[4] Research suggests that more-active individuals have less risk of cognitive impairment or dementia.[5,6] Cognitive impairment was more prevalent in community-dwelling older adults reporting no PA than in those reporting moderate and high PA levels.[7] Higher self-reported PA levels in early life were associated with less risk of MCI in later life,[8,9] although methodological differences in PA assessment preclude comparisons of studies of the optimal pattern of PA to reduce the risk of cognitive decline. Most previous studies were based on self-reported PA assessments,[7,10,11] which are subject to reporting and recall biases. Furthermore, there are important differences in PA between racial groups,[12–14] with blacks significantly understudied in terms of the association between PA and cognitive function.[15]

Thus, the purpose of this study was to investigate the association between objectively measured PA and cognitive function in older adults according to sex and race. It was hypothesized that there would be a significant, positive dose-response association between PA measured using accelerometers and cognitive function in a representative sample of white and black older adults in the United States.

METHODS

Design and Procedures

This study was ancillary to the REasons for Geographic and Racial Differences in Stroke study (REGARDS), a national epidemiological study that enrolled and is following a cohort of 30,239 black and white adults to assess the prevalence and incidence of stroke and cognitive decline in the continental United States The cohort was recruited using a combination of mail and telephone contact from January 2003 to October 2007. Risk factors were assessed in a telephone interview, followed by an in-person physical assessment 3 to 4 weeks later. Participants were contacted by telephone every 6 months for incident stroke events, annually for cognitive screening status, and every 2 years for more-detailed cognitive assessments. The detailed design and methods for REGARDS have been described previously.[16]

This ancillary study was conducted from May 2009 to January 2013 during follow-up of the cohort. A question was added to the 6-month telephone follow-up asking participants whether they were willing to wear an accelerometer and complete a daily activity log for 1 week. Upon acceptance, an accelerometer and log sheet were mailed to participants with instructions and then mailed back for processing. The detailed design of and methods for the ancillary study have been described elsewhere.[17] The institutional review boards of Arizona State University, University of South Carolina, University of Georgia, and University of Alabama at Birmingham approved the study.

Baseline information obtained from the parent REGARDS dataset included age, sex, race, region of residence (living within or outside the stroke belt), education, body mass index (BMI), smoking status (self-reported current smoking or not), hypertension (systolic blood pressure ≥140 mmHg, diastolic blood pressure ≥90 mmHg, or self-reported current medication use to control blood pressure),

and diabetes mellitus (self-reported disease or current medication use) for purposes of describing the sample and controlling for possible confounders.

PA Measures

PA monitors (Actical, Mini Mitter Respironics, Inc., Bend, OR) provided real-time estimates of the frequency, intensity, and duration of PA. Accelerometers were attached to a neoprene waistband and worn over the right hip. Participants were asked to put on the device after waking up each morning and take it off just before going to bed each evening and were instructed to wear the device for 7 consecutive days and return the device immediately after. For all participants with valid data, time in sedentary behavior, light PA (LPA), and moderate to vigorous PA (MVPA) and proportions of total wear time spent in sedentary behavior (ST%), light PA (LPA%), and MVPA (MVPA%) were determined. Activity count cut-points of 50 counts per minute (cpm) and 1,065 cpm were applied to differentiate between being sedentary and light PA and between light PA and MVPA, respectively.[18] Details of the accelerometer data management and analysis have been published previously.[17,18]

Cognition Assessment

Cognitive function was assessed during telephone interviews using standardized scripts and scoring methods described previously.[19] Cognitive impairment was defined according to each participant's score on the Six-Item Screener (SIS), a test of global cognitive function with established reliability and validity in community samples and in black and white adults.[20] The SIS included 6 questions: What year is this? What month is this? What is the day of the week? What were the three objects I asked you to remember (apple, table, penny)?" Scores on the SIS range from 0 to 6, with a score of 4 or fewer correct responses indicating cognitive impairment.[20] Sensitivity analyses were conducted,[19] and it was decided to use cognitive assessments within a time range of ±12 months of wearing the accelerometer to obtain the largest sample size and shortest time intervals between PA measurements and cognitive tests.

Four expanded cognitive battery tests with demonstrated usefulness in early identification of Alzheimer's disease or dementia were also used:[21] the Word List Learning (WLL) and semantic fluency (animals fluency, AF) from the Consortium to Establish a Registry for Alzheimer's Disease battery,[21] letter fluency (LF), and the recall and orientation items from the Montreal Cognitive Assessment (MoCA).[22] These tests assess domains of memory (WLL, MoCA recall and orientation) and executive function (AF, LF). Acceptable reliability and validity of these tests have been previously reported.[21,23] Analyses of these measures were restricted to the most-recent results obtained within ±12 months of PA measurement. Composite measures of two cognitive domains (memory and executive function) were created by converting each test into a z-score based on the mean and standard deviation for that specific test's results in all participants. The mean of the z-scores of memory and executive function was calculated as an over-

all cognitive z-score, presenting the average level of memory and executive domains. For participants missing one test score or z-score, the other available records were used to calculate domain and cognitive battery z-scores.

Participants

Of the REGARDS cohort, 12,146 (60.5%) agreed to complete the accelerometer protocol, 7,312 (36.4%) declined, and 618 (3.1%) were deferred and did not have the opportunity to be asked again during the enrollment period. Of the devices that were mailed, 972 (8.0%) were lost or not returned, 1,187 (9.8%) were returned not worn, 14 (0.11%) were returned and found to be defective such that no data could be downloaded, and 9,973 (82.1%) were returned with data. Of the 9,973 participants who returned and wore the accelerometer, 8,096 (81.1%) provided usable data, after exclusions for device error, missing log sheet, and wear time of less than 4 days or less than 10 hours per day.[17]

Seven thousand ninety-eight of the 8,096 participants were included in the present analyses. Participants were excluded if they self-reported stroke at baseline (n = 264), were identified as cognitively impaired more than 12 months before PA assessment (n = 383), had an incident stroke before wearing the accelerometer (n = 6), or had no record of valid PA measurement associated with SIS assessment within ±12 months of PA assessment (n = 345).

Statistical Analysis

Continuous data expressed as MVPA (min/wk) and MVPA % was extremely skewed (e.g., 20% of the entire sample recorded <1 min/d of MVPA), violating the assumptions of linear regression and not providing a true measure of associations with the dependent variables. Thus, the primary independent variable of MVPA% was divided into quartiles, allowing for group comparisons and investigation of possible dose-response associations in the presence of skewness. Because of inherent variability in daily accelerometer wear time, MVPA% rather than absolute time spent in MVPA was used as the standard for quartiles to render results comparable among individuals. Dependent variables were cognitive status (impairment or not) measured using the SIS and z-scores generated from WLL, AF, LF, and MoCA recall and orientation. Differences in demographic variables between quartiles were tested using analysis of variance (continuous variables) or chi-square tests (categorical variables). Because the SIS was validated using dichotomous outcomes rather than continuous scores,[20] associations between MVPA% and cognitive impairment were examined using multivariable logistic regression models. In the logistic models, Model 1 was unadjusted; Model 2 was adjusted for age, sex, race, region of residence, and education; and Model 3 was adjusted for age, sex, race, region of residence, education, ST%, BMI, hypertension, smoking, and diabetes mellitus. Odds ratios (ORs) and 95% confidence intervals (CIs) were generated. Linear regression models with adjustments for potential confounders similar to those mentioned above were used to assess the association between MVPA% and

z-scores generated from WLL, AF, LF, and MoCA recall and orientation. Differences in z-scores of memory and executive function between quartiles and racial and sex subgroups were examined after full adjustment of confounders. Analyses were conducted using SAS version 9.3 (SAS Institute, Inc., Cary, NC).

RESULTS

Demographic characteristics, PA, and cognitive function are shown in Tables 1 and 2 according to quartiles of MVPA%. Of the 7,098 participants, 54.2% were female, 31.5% were black, 54.9% were living in the Stroke Belt, and 5.1% had impaired cognitive status at the assessment within ±12 months of the PA measurement. The mean time ± standard deviation between PA assessment and each cognitive assessment was 5.4 ± 3.8 months. The mean age of all participants was 70.1 ± 8.5, and they wore the accelerometer for 6.6 ± 0.8. Participants spent most of their wear time in sedentary behavior (69.9 ± 8.1%) and LPA (26.6 ± 7.7%). MVPA% was extremely limited (1.5 ± 1.9%). There were significant differences between quartiles of MVPA% in all variables listed in Table 2 (P < .001). Participants with higher MVPA% were more likely to be male, white, younger, well educated, and nonsmokers; not to have diabetes mellitus, hypertension, or cognitive impairment; and to have lower BMI and systolic and diastolic blood pressure. Participants in the higher MVPA% quartiles also spent more time in LPA and had higher raw WLL, AF, LF, and MoCA recall and orientation scores. Higher MVPA% was associated with lower prevalence of cognitive impairment as measured using the SIS. Fewer individuals had cognitive impairment in the highest MVPA% quartile (2.9%) than in the lowest (15.0%).

Results of logistic regression analyses are displayed in Table 3. In the unadjusted model (Model 1), participants in the highest MVPA% quartile were 63% less likely to have cognitive impairment than those in the lowest quartile. After adjustment for age, sex, race, region of residence, and education (Model 2), this association remained significant. Participants in the highest quartile were 36% less likely to have cognitive impairment (OR = 0.64, 95% CI = 0.44–0.93). There were no significant interactions (age*MVPA%, sex*MVPA%, race*MVPA%, education *MVPA%, region*MVPA%), so these were not included in the analytical models. In the fully adjusted model (Model 3), results were consistent with Model 2, with participants in the highest MVPA% quartile 37% less likely to have cognitive impairment (OR = 0.63, 95% CI = 0.43–0.93). Similar analyses with LPA% and ST% did not reveal any significant associations (P > .05) with the odds of cognitive impairment. Additionally, logistic regression analysis categorizing participants as accumulating more or less than 150 min/wk of MVPA indicated that older adults were 36% less likely to have cognitive impairment if they accumulated 150 min/wk or more of MVPA (OR = 0.64, 95% CI = 0.44–0.91) after full adjustment. Subgroup logistic analyses were conducted for each race and sex group, but significance was not maintained. When using MVPA% as a continuous variable, there was no significant association between MVPA% and prevalence of

Table 1. Characteristics of Participants According to Level of Moderate to Vigorous Physical Activity (N = 7,098)

Characteristics	Quartile 1	Quartile 2	Quartile 3	Quartile 4	Total
Female, n (%)	1,164 (65.7)	1,026 (57.8)	904 (51.0)	750 (42.1)[a]	3,844 (54.2)
African American, n (%)	749 (42.3)	611 (34.4)	495 (28.0)	379 (21.3)[a]	2,234 (31.5)
Stroke belt, n (%)	991 (56.0)	1,001 (56.4)	989 (55.8)	913 (51.3)[a]	3,894 (54.9)
Education, n (%)					
<High school	203 (11.5)	111 (6.3)	85 (4.8)	48 (2.7)	447 (6.3)
High school graduate	544 (30.7)	445 (25.1)	366 (20.7)	263 (14.8)	1,618 (22.8)
Some college	486 (27.4)	561 (31.6)	469 (26.5)	385 (21.6)	1,901 (26.8)
≥College graduate	538 (30.4)	659 (37.1)	851 (48.1)	1,084 (60.9)[a]	3,132 (44.1)
Smoking, n (%)	255 (14.4)	219 (12.3)	165 (9.3)	112 (6.3)[a]	751 (10.6)
Hypertension, n (%)	1,224 (69.1)	987 (55.6)	831 (46.9)	657 (36.9)[a]	3,699 (52.1)
Diabetes mellitus, n (%)	454 (25.6)	308 (17.3)	215 (12.1)	162 (9.1)[a]	1,139 (16.1)
Age, mean ± SD	75.2 ± 8.1	70.9 ± 7.7	68.1 ± 7.8	66.3 ± 7.7[a]	70.1 ± 8.5
Body mass index, kg/m^2, mean ± SD	30.1 ± 6.4	29.3 ± 5.8	28.3 ± 5.3	26.9 ± 4.6[a]	28.6 ± 5.7
Systolic blood pressure, mmHg, mean ± SD	130.1 ± 16.3	126.4 ± 15.5	124.4 ± 14.7	121.5 ± 14.3[a]	125.6 ± 15.6
Diastolic blood pressure, mmHg, mean ± SD	76.4 ± 9.6	76.3 ± 9.5	76.3 ± 9.0	75.8 ± 8.8[a]	76.2 ± 9.2

Quartiles are proportion of total time spent in moderate to vigorous physical activity.
[a]Significant difference between quartiles (*P* < .001), tested using analysis of variance (continuous variables) or chi-square tests (categorical variables).
SD = standard deviation.

Table 2. Physical Activity and Cognitive Function According to Level of Moderate to Vigorous Physical Activity (MVPA) (N = 7,098 Unless Otherwise Noted)

Variable	Quartile 1	Quartile 2	Quartile 3	Quartile 4	Total
Adherence, days with valid wear, mean ± SD	6.4 ± 0.9	6.6 ± 0.8	6.6 ± 0.7	6.7 ± 0.7[d]	6.6 ± 0.8
Total wearing time, min/d, mean ± SD	868.3 ± 117.0	885.4 ± 104.1	897.8 ± 99.7	910.1 ± 92.9[d]	890.4 ± 104.9
Moderate to vigorous physical activity, min/d, mean ± SD	0.4 ± 0.4	3.3 ± 1.5	11.1 ± 3.8	36.9 ± 19.5[d]	12.9 ± 17.5
Light physical activity, min/d, mean ± SD	117.0 ± 58.3	181.9 ± 60.7	213.8 ± 68.3	235.0 ± 69.7[d]	186.9 ± 78.4
Sedentary time, min/d, mean ± SD	750.9 ± 119.5	700.2 ± 108.5	672.9 ± 105.9	638.3 ± 107.1[d]	690.5 ± 117.8
Percentage of wear time in MVPA, mean ± SD	0.05 ± 0.05	0.37 ± 0.15	1.23 ± 0.39	4.05 ± 2.10[d]	1.42 ± 1.91
Percentage of wear time in light physical activity, mean ± SD	13.6 ± 6.6	20.7 ± 6.9	24.0 ± 7.5	26.0 ± 7.7[d]	21.1 ± 8.6
Percentage of wear time in sedentary behavior, mean ± SD	86.4 ± 6.6	78.9 ± 6.9	74.8 ± 7.5	69.9 ± 8.1[d]	77.5 ± 9.5
Cognitively impaired, n (%)[a]	134 (7.6)	103 (5.8)	70 (4.0)	52 (2.9)[d]	359 (5.1)
Letter fluency score, mean±SD (n = 3,405)	10.3 ± 4.3	11.2 ± 4.5	11.4 ± 4.5	12.3 ± 4.8[d]	11.3 ± 4.6
Animal fluency score, mean ± SD (n = 4,353)	14.9 ± 5.1	16.7 ± 5.0	17.6 ± 5.6	19.4 ± 5.7[d]	17.1 ± 5.6
Word list learning sum score, mean ± SD (n = 3,847)[b]	16.4 ± 5.1	17.7 ± 5.1	18.9 ± 4.8	19.5 ± 4.5[d]	18.1 ± 5.0
Montreal Cognitive Assessment[c] recall and orientation, mean ± SD (n = 5,160)	9.6 ± 1.6	10.0 ± 1.3	10.1 ± 1.2	10.2 ± 1.2[d]	10.0 ± 1.4

Quartiles are proportion of total time spent in MVPA.
[a]≤4 correct responses on six-item screener consisting of a three-item recall and three-item temporal orientation.
[b]From the Consortium to Establish a Registry for Alzheimer's Disease battery (range 0–30).
[c]Five-word delayed memory recall test and six-item orientation test.
[d]Significant difference between quartiles (*P* < .001) tested using analysis of variance (continuous variables) or chi-square test (categorical variables).

cognitive impairment when adjusted for confounders in Models 2 and 3 (*P* > .05).

Four thousand four hundred forty-one participants had at least one test of AF or LF in the domain of executive function (with 3,412 (77%) of those having both tests), and 5,178 participants had at least one test of WLL or MoCA items in the domain of memory (with 3,977 (77%) of those having both tests). Additionally, 5,188 participants had at least one *z*-score of memory or executive function (with 4,431 (85%) of those having both tests). Linear regression models (Table 4) revealed a significant association (*P* < .001) between MVPA% and both cognitive function domains in the unadjusted model. These relationships remained significant when controlling for age, sex, race, region of residence, and education, and there

were no significant interactions between MVPA% and these confounders (*P* > .05). When analyses were further adjusted for BMI, hypertension, smoking, and diabetes mellitus, MVPA% remained significantly associated with of executive function and memory *z*-scores and their average combined score for overall cognitive function. Linear regression models using MVPA% as a continuous variable were also developed. Significance was maintained for the association between MVPA% and executive function, memory, and overall cognitive function *z*-scores in all models (*P* < .05).

The association between MVPA% and memory and executive function varied across different racial and sex subgroups (Table 5). For white men, memory and executive function *z*-scores were significantly positively associ-

Table 3. Likelihood of Cognitive Impairment According to Level of Moderate to Vigorous Physical Activity (MVPA)

MVPA	Model 1[a]	Model 2[b]	Model 3[c]
	Odds Ratio (95.0% Confidence Interval)		
Percentage of time spend in MVPA (reference Q1 (low)			
Q2	0.76 (0.58–0.99)	0.99 (0.75–1.31)	0.97 (0.71–1.31)
Q3	0.52 (0.39–0.70)	0.78 (0.56–1.07)	0.74 (0.51–1.07)
Q4 (high)	0.37 (0.27–0.51)	0.64 (0.44–0.93)	0.63 (0.43–0.93)
Weekly MVPA ≥150 minutes[d]	0.43 (0.31–0.61)	0.63 (0.44–0.89)	0.64 (0.44–0.91)

[a]Unadjusted regression model.
[b]Adjusted for age, sex, race, region of residence, and education.
[c]Adjusted for age, sex, race, region of residence, education, proportion of time spent in sedentary behavior, body mass index, hypertension, smoking, and diabetes mellitus.
[d]The U.S. Physical Activity Guidelines recommend that older adults perform ≥150 minutes of MVPA per week.[24]

ated with MVPA% ($P < .001$). For white women, significant differences existed between Quartiles 1 and 3 and between Quartiles 1 and 4 for executive function ($P < .001$). For black men, significant differences existed between Quartiles 1 and 3 and between Quartiles 1 and 4 for memory ($P < .001$). No significant differences were observed between any domains for black women ($P > .05$).

DISCUSSION

To the knowledge of the authors, this is one of the first studies to examine the dose-response relationship between objectively measured PA and cognitive function in a large and diverse older population. Objectively measured MVPA (absolute min/wk and MVPA%) was independently associated with cognitive impairment and continuous measures of cognitive function in a population of 7,098 older white and black adults. The odds of cognitive impairment were lowest in those in the highest MVPA% quartile (36.9 min/day (258.3 min/wk) of MVPA, above that recommended in U.S. national guidelines (>150 min/wk)).[24] Older adults with a greater proportion of accelerometer wear time spent in MVPA also had better memory and executive function than their less-active peers.

Cross-sectional and prospective studies[5,6] using self-reported PA measurements suggest that more-active individuals may be less likely to develop cognitive impairment and dementia. A metaanalysis of 16 prospective studies using self-reported PA indicated that the relative risks of incident dementia and Alzheimer's disease in the highest PA category were 28% and 45% lower, respectively, than in the lowest PA category,[25] although the bias of self-report measures of PA have limited most previous studies of the relationship between PA and cognitive function, and these studies have had difficulty identifying effects of LPA and sedentary time on cognitive function.

A few studies with objectively measured data have also reported that active older adults may have a lower

Table 4. Linear Regression Model Indicating Association Between Moderate to Vigorous Physical Activity and Z-scores of Expanded Cognitive Battery Tests

Cognitive Function	Model 1[a]	Model 2[b]	Model 3[c]
	Beta (Standard Error) P-Value		
Average overall cognitive z-score (reference Q1 (low)) (N = 5,188)[d]			
Q2	0.32 (0.03) <.001	0.13 (0.03) <.001	0.15 (0.03) <.001
Q3	0.46 (0.03) <.001	0.19 (0.03) <.001	0.16 (0.03) <.001
Q4 (high)	0.63 (0.03) <.001	0.27 (0.03) <.001	0.23 (0.03) <.001
Executive function z-score (reference Q1 (low) (N = 4,441)[e]			
Q2	0.30 (0.04) <.001	0.13 (0.03) <.001	0.11 (0.03) .003
Q3	0.46 (0.04) <.001	0.17 (0.03) <.001	0.13 (0.04) .001
Q4 (high)	0.71 (0.04) <.001	0.29 (0.04) <.001	0.25 (0.04) <.001
Memory z-score (reference Q1 (low)) (N = 5,178)[f]			
Q2	0.32 (0.03) <.001	0.20 (0.03) <.001	0.19 (0.03) <.001
Q3	0.46 (0.03) <.001	0.21 (0.03) <.001	0.19 (0.04) <.001
Q4 (high)	0.63 (0.03) <.001	0.26 (0.04) <.001	0.24 (0.04) <.001

Quartiles are quartiles of proportion of total time spent in moderate to vigorous physical activity.
[a]Unadjusted regression model.
[b]Adjusted for age, sex, race, region of residence, and education.
[c]Adjusted by age, sex, race, region of residence, education, proportion of time spent sedentary, body mass index, hypertension, smoking, and diabetes mellitus.
[d]Average cognitive z-score refers to average of mean executive score and mean memory score.
[e]Executive z-score refers to average of standardized scores of letter fluency and animal fluency tests. For participants with only one executive test, the mean score would be the result of that test.
[f]Memory z-score refers to average of standardized scores of word list learning and Montreal Cognitive Assessment five-word delayed memory recall and six-item orientation tests. For participants with only one executive test, the mean score would be the result of that test.

prevalence of cognitive impairment or dementia.[26–29] One cross-sectional study of 2,735 older women showed that daytime PA measured using accelerometers was associated with lower odds of cognitive impairment.[26] Another cross-sectional study of 217 older adults indicated a dose-response relationship between objectively measured PA intensity and cognitive function, with a stronger association between MVPA and cognitive function.[27] Another study[5] reported that a higher level of total daily PA, measured using accelerometers, was significantly associated with lower risk of Alzheimer's disease in 716 white individuals aged 55 and older during 4 years of follow-up. Higher baseline aerobic fitness levels predicted better performance on measures of attention and executive function 6 years later in 349 adults aged 5 and older.[28] Nevertheless, the sample sizes of studies with objective PA assessment were small and included fewer nonwhite participants.

Table 5. Adjusted Z-Scores for Cognitive Battery Tests and Prevalence of Cognitive Impairment According to Level of Moderate to Vigorous Physical Activity, Race, and Sex

Variable	Quartile 1	Quartile 2	Quartile 3	Quartile 4	P-Value
	Mean (Standard Error)				
Average overall cognitive z-score (N = 5,188)[a]					
Black male	−0.70 (0.05)	−0.49 (0.05)	−0.35 (0.05)	−0.40 (0.06)	<.001[d]
Black female	−0.35 (0.04)	−0.21 (0.04)	−0.27 (0.05)	−0.15 (0.06)	.30
White male	−0.44 (0.04)	−0.28 (0.04)	−0.22 (0.03)	−0.14 (0.03)	<.001[d]
White female	−0.08 (0.03)	0.06 (0.03)	0.01 (0.04)	0.08 (0.04)	.06
Executive function z-score (N = 4,441)[b]					
Black male	−0.56 (0.07)	−0.38 (0.07)	−0.35 (0.07)	−0.32 (0.08)	.50
Black female	−0.48 (0.05)	−0.42 (0.05)	−0.49 (0.06)	−0.39 (0.08)	.99
White male	−0.32 (0.05)	−0.18 (0.05)	−0.08 (0.04)	0.01 (0.04)	<.001[e]
White female	−0.13 (0.04)	−0.03 (0.04)	−0.02 (0.05)	0.14 (0.05)	<.001[d]
Memory z-score (N = 5,178)[c]					
Black male	−0.74 (0.07)	−0.48 (0.06)	−0.32 (0.07)	−0.38 (0.07)	<.001[d]
Black female	−0.23 (0.04)	−0.03 (0.05)	−0.10 (0.06)	0.01 (0.08)	.27
White male	−0.52 (0.05)	−0.32 (0.04)	−0.26 (0.04)	−0.20 (0.04)	<.001[d]
White female	−0.02 (0.04)	0.14 (0.04)	0.05 (0.04)	0.08 (0.05)	.14

Adjusted for age, region, education, proportion of time spent sedentary, body mass index, hypertension, smoking, and diabetes mellitus.

Cognitive impairment is defined as a score of ≤4 correct responses on six-item screener (three-item recall and three-item temporal orientation).

Quartiles denote proportion of total time spent in moderate to vigorous physical activity.

[a]Average cognitive z-score refers to average of mean executive score and mean memory score. The reference of the z-score is the mean and standard deviation (SD) of the total sample.

[b]Executive z-score refers to average of standardized scores of letter fluency and animal fluency tests. For participants with only one executive test, mean score would be the result of that test. The reference of the z-score is the mean and SD of the total sample.

[c]Memory z-score refers to average of standardized scores of word list learning and Montreal Cognitive Assessment five-word delayed memory recall and six-item orientation tests. For participants with only one executive test, the mean score would be the result of that test. The reference of the z-score is the mean and SD of the total sample.

[d]P < .05 between Quartiles 1 and 3 and Quartiles 1 and 4.

[e]P < .05 between Quartiles 1 and 3.

To the knowledge of the authors, the association between PA and cognitive function remains robust in older adults when adjusted for race, sex, education, and age,[30–32] but few investigations have investigated the relationship between PA and cognitive function in specific racial and sex subgroups. Although interaction terms were nonsignificant, exploratory analyses (Table 5) indicated that the association between MVPA% and memory and executive function may vary according to racial and sex subgroups. Additional prospective and intervention studies are needed to investigate the contributions of race and sex to the association between PA and cognitive function in diverse older adults.

These findings regarding LPA% and ST% revealed no relationships to cognitive function. MVPA% was the only PA element displaying a significant dose-response relationship with cognitive function in this population, suggesting that intensity may be an important factor influencing the relationship between PA and cognitive function in older adults. This finding was consistent with previous studies using self-reported PA.[33,34] Only one study using accelerometers has reported intensity of PA as important in the association between PA and cognitive function in older adults, with participants in the highest tertile of PA intensity performing better than those in the lowest tertile on cognitive tasks related to memory and executive function.[35]

The influence of LPA and sedentary behavior on cognitive function is not fully known. One cross-sectional study documented that LPA was not significantly associated with memory and executive function in older adults after adjustments for confounders.[27] Another longitudinal study in Japan determined that self-reported LPA and sedentary time were associated with cognitive impairment after 8 years of follow-up.[36] Previous research also indicated that diverse types of sedentary behaviors might be differently associated with cognitive function.[37] Amount of computer use was positively associated with memory and executive function, whereas television viewing time was negatively associated with cognitive function in older adults.[38,39] It was not possible to record the type of sedentary behavior in the current study. Additional investigations are necessary to more fully explore the effect of sedentary behavior and LPA on cognitive function in older adults because this is how they spend the vast majority of their time.

PA may be related to cognitive function through different mechanisms. Research suggests that PA is associated with greater brain volume in specific areas related to executive function and memory (e.g., hippocampus volume),[40,41] higher brain-derived neurotrophic factor levels,[42,43] greater cerebrovascular function, and lower vascular risk associated with hypertension, type 2 diabetes mellitus, and obesity.[44] Moreover, studies suggest that significant changes in cardiorespiratory fitness may affect cognitive function and risk of dementia.[45]

This study had several strengths. First and most important, an objective measure of PA was used to examine the

association between PA and cognitive function in a large population of older adults. This allowed for analyses with absolute amount and proportion of time spent in PA of varying intensity. Second, this is one of the first studies to examine the association between objectively measured PA and cognitive function in a diverse population, providing more-detailed analyses for older white and black women and men. Finally, it was possible to explore the relationship between accelerometer-derived PA and sedentary behavior in specific domains of memory and executive function in addition to odds of impairment in global cognitive status.

The findings of this study were also subject to limitations. First, the study was an attempt to characterize participants' habitual PA using accelerometers. A limitation of using accelerometers is that type of PA activity and upper body movements are not captured. Second, because this was a cross-sectional analysis, causality cannot be inferred. Third, because of the potential for unaccounted confounding factors and random errors or noise in the dataset, the results should be interpreted with caution. Last, because of the excessive skewness of MVPA (min/wk) and MVPA% as continuous variables, it was not possible to identify a precise threshold for reducing the risk of cognitive impairment or the degree of risk reduction associated with a minor increase in daily or weekly MVPA. It is possible that a MVPA level higher than of participants in Quartile 3 (11.1 min/d) and less than that observed for Quartile 4 (36.9 min/d) is adequate to reduce the risk of cognitive decline in older adults. Further studies are warranted in this arena to help refine PA guidelines.

In summary, higher levels of objectively measured MVPA% were independently associated with less likelihood of cognitive impairment and better performance in memory and executive function for white and black older adults. In addition, there was a dose-response relationship between MVPA% and cognitive function in older adults, with the highest level of MVPA% associated with better cognitive function. The amount of MVPA associated with lower prevalence of cognitive impairment is consistent with meeting U.S. PA guidelines. Neither LPA% nor ST% was associated with any measure of cognitive function in this cohort, which warrants further investigation.

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