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Daily and hourly patterns of physical activity and sedentary behavior of older adults: Atherosclerosis risk in communities (ARIC) study

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ABSTRACT

This cross-sectional study of older adults ≥ 65 years describes daily and hourly patterns of accelerometer-derived steps, sedentary, and physical activity behaviors and examines differences by day of the week and sociodemographic and health-related factors to identify time-use patterns. Data were from 459 Atherosclerosis Risk in Communities (ARIC) study participants (60% female; mean ± SD age = 78.3 ± 4.6 years; 20% Black) who wore a hip accelerometer ≥ 4 of 7 days, for ≥ 10 h/day in 2016. We used linear mixed models to examine daily patterns of steps, sedentary, low light, high light, and moderate-to-vigorous intensity physical activity (MVPA). Differences by sex, median age (</≥ 78 years), body mass index, self-rated health, depressive symptoms, and performance in a two-minute walk test were explored. Men (vs women), and those with overweight and obesity (vs normal weight), had significantly higher sedentary minutes and lower minutes of low light per day. For each additional meter walked during the two-minute walk test, sedentary behavior was lower while high light, MVPA, and daily steps were higher. No significant differences in time-use behaviors were found by self-reported race, age, education, self-rated health, or depressive symptoms. Participants were least active (22.5 min MVPA, 95% CI: 11.5, 33.5) and most sedentary (453.9 min, 95% CI: 417.7, 490.2) on Sunday. Most activity was accrued in the morning (before 12 PM) while the evening hours (3–11 PM) were spent ≥ 50% sedentary. Movement patterns suggest opportunities for promotion of activity and reduction in sedentary time on Sundays, in the evening hours, and for those with overweight or obesity.

1. Introduction

The numerous health benefits of regular aerobic physical activity for adults, such as reduced risk of premature mortality and chronic diseases, is well established (U.S. Department of Health and Human Services, 2018; World Health Organization, 2020). Further, there is strong evidence to support the benefits of physical activity for improved physical and cognitive functioning and reduced frailty for older adults (Bull et al., 2020; U.S. Department of Health and Human Services, 2018; World Health Organization, 2015). In contrast, high amounts of sedentary behavior, characterized as energy expenditure ≤ 1.5 metabolic equivalents (METs), while in a sitting, reclining, or lying posture (Tremblay et al., 2017), is associated with poor health outcomes and increased risk of premature mortality and several chronic diseases (Saunders et al., 2020; World Health Organization, 2020).

Despite the evidence, 2017–2018 National Health and Nutrition Examination Survey (NHANES) self-reported physical activity data suggests only half (52.6%) of U.S. older adults meet the aerobic *Physical Activity Guidelines for Americans* recommendation of 150 min of moderate to vigorous intensity physical activity (MVPA) (Whitfield, Ussery,

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Saint-Maurice, & Carlson, 2021). Further, older adults are the least active age group in the U.S. with young adult (18–24 years: 74.7%) and midlife adults (45–64 years: 61.5%) reporting higher physical activity levels (Whitfield et al., 2021). Additionally, although guidelines suggest adults should limit time spent sedentary and "move more and sit less" (U.S. Department of Health and Human Services, 2018; World Health Organization, 2020), older adults self-report spending an average of six hours a day sedentary (2015–2016 NHANES) (Du et al., 2019).

Previous research suggests that physical activity among older adults is often irregular and performed at a lower intensity level than younger adult populations (Harada, Chiu, King, & Stewart, 2001; Westerterp, 2008). Thus, accelerometer-based physical activity and sedentary behavior metrics in studies of older adults provide several advantages over self-reported findings including direct quantification of behavior across domains, contexts, and intensity levels. Particularly, the detection of light intensity physical activity has important implications for health in older adults, such as reduced cardiometabolic risk (LaCroix et al., 2019; LaMonte et al., 2017). Additionally, accelerometer measures do not rely on participants' cognitive ability to recall activities (Troiano, Pettee Gabriel, Welk, Owen, & Sternfeld, 2012). Despite this, most surveillance systems use self-report to measure activity (Omura et al., 2021). In epidemiologic studies that include an accelerometer-based assessment, differences in older adult's overall activity level by age, sex, education level, body mass index (BMI), and self-rated health have been found (Bellettiere et al., 2015; Berkemeyer et al., 2016; Davis et al., 2011; Diaz et al., 2016; Evenson, Buchner, & Morland, 2012; Hansen, Kolle, Dyrstad, Holme, & Anderssen, 2012; Hooker et al., 2016; Jefferis et al., 2014). However, few studies have been conducted among diverse samples and studies typically report these behaviors averaged over the assessment period rather than examine daily time-use patterning and day-to-day variability. Day to day patterning may be useful to inform development of interventions to reduce sedentary time and increase physical activity in older adults.

With more than 20% of the U.S. population projected to be 65 years or older by 2030 (Ortman, Velkoff, & Hogan, 2014), understanding patterns of waking time-use behaviors (e.g., physical activity and sedentary behavior) (Falck et al., 2021; Pedišić, Dumuid, & Olds, 2017; Rosenberger et al., 2019) among older adults is imperative to support health promotion strategies focused on healthy aging. Further, to adequately inform future intervention studies targeting physical activity and/or sedentary behavior modification in older adults, identifying time-use patterns, and when older adults spend significant time in sedentary behaviors are greatly needed. Therefore, the overall purpose of this study was to 1) describe the daily and hourly patterns of steps, physical activity, and sedentary behaviors in a sample of Black and white older adult men and women and 2) examine differences in these behaviors by day of the week and a variety of socio-demographic and health-related factors.

2. Methods

2.1. Study participants

We used data from the Atherosclerosis Risk in Communities (ARIC) study, a prospective cohort study of cardiovascular disease across a diverse sample of community-dwelling U.S. adults (Wright et al., 2021). Briefly, adults ages 45–64 years were recruited from four field centers across the U.S: Forsyth County, NC; Jackson, MS; Minneapolis suburbs, MN; and Washington County, MD. A total of 15,792 participants were measured at visit 1 (baseline) between 1987 and 1989. Cohort members are followed through in-person examinations, and annual (through 2011) and semi-annual (since 2012) telephone follow-up calls.

For this cross-sectional analysis at ARIC visit 6 (2016–2017), participants were a subsample enrolled in the ARIC Physical Activity and Falls Ancillary Study (N = 539). Data were collected during the sixth in-person examination visit (May-November 2016). The primary goal of the ARIC Physical Activity and Falls Ancillary Study was to examine the association between physical activity and falls among older adults (Pettee Gabriel et al., 2019). Exclusion criteria for the ancillary study included: residing in a total care nursing home, being at higher risk for dementia [determined by a score on the Mini-Mental Status Exam (MMSE) (Folstein, Folstein, & McHugh, 1975) < 22], and unable to complete the 4-meter walk test, a component of the Short Physical Performance Battery (SPPB) (Guralnik et al., 1994) that was integrated into visit 6. During the ancillary study, participants were asked to wear an accelerometer device on the right hip for 7 consecutive days and return the device via mail. Questionnaires pertaining to sociodemographic and health-related variables were collected as part of the parent ARIC visit 6 cohort visit. The study was approved by the institutional review board at each participating center. Informed consent was obtained from all participants.

2.2. Measures

2.2.1. Participant characteristics

Standardized questionnaires and health assessments were used to assess participant characteristics. Visit 1 measures included sex [male, female], self-reported race [Black, White], and education [<high school, high school graduate, at least some college and above]. Visit 6 measures included age [dichotomized at median: < 78 years, ≥ 78 years], body mass index [(BMI); normal weight (18.5 to < 25 kg/m^2), overweight (25 to < 30 kg/m^2), obesity (≥ 30 kg/m^2)], self-reported health [excellent/very good, good, fair/poor], depressive symptoms [measured via Center for Epidemiological Studies-Depression (CES-D) (Radloff, 1977); not at risk (score 0–8), at risk (score ≥ 9)], and two-minute walk test [meters, continuous]. For BMI, height and weight were measured while wearing light clothes and without shoes and calculated as weight (kg) divided by height squared (m^2). The two-minute walk test is a self-paced walk test that measures functional endurance capacity (Butland, Pang, Gross, Woodcock, & Geddes, 1982).

2.2.2. Accelerometer-derived movement

ActiGraph wGT3X-BT devices (*ActiGraph, LLC, Pensacola, FL, USA*) were used to measure movement behaviors. Participants were asked to wear the accelerometer on their right hip via elastic belt for all waking hours for 7 days. Raw (.gt3x) accelerometer files were downloaded in ActiLife 6 and reintegrated into.agd files at 1-minute epochs. Wear and non-wear were determined using the Choi algorithm (Choi, Liu, Matthews, & Buchowski, 2011) with the 'PhysicalActivity' (Choi et al., 2021) R package.

For minutes classified as 'wear', Evenson vector magnitude (VM) threshold values were used to classify the minute as sedentary (< 76 VMct·min^{-1}), low light (76 to < 903 VMct·min^{-1}) intensity, high light (903 to < 2075 VMct·min^{-1}) intensity, and MVPA (≥ 2075 VMct·min^{-1}). The original 15-sec VM thresholds (Evenson et al., 2015) were scaled by multiplying by four to account for the longer epoch (60-sec), with slight adjustments to obtain mutually exclusive threshold ranges (Stewart et al., 2020). These cutpoints were chosen based their development in older adults, ages 60 to 91 years. Steps per day were determined using the manufacturer's step algorithm. Minutes were then aggregated into hours. Hours with ≥ 30 min of non-wear time were removed. Although instructions were to remove the accelerometer device prior to going to bed, some participants wore the devices during sleep, thus inflating sedentary behavior and wear time estimates. Therefore, hours between midnight (0:00) and 6:00 AM were excluded based on visual inspection. Hours (06:00–23:59) were aggregated into day-level estimates. Days were classified as adherent if they had ≥ 600 min of wear time.

Prior to conducting analyses, the first day of accelerometer measurement were excluded since it tended to be a partial day of wear. Second, only estimates from the first day types (i.e., Monday, Tuesday, Wednesday, Thursday, Friday, Saturday, Sunday) were retained. For example, if there were two Tuesdays measured, only the first Tuesday was included in analyses. Participants were included in these analyses if they had at least 4 of 7 days of adherent wear (≥ 600 min).

2.3. Statistical analysis

We conducted descriptive analysis including frequency distributions, means and medians, and measures of variability (standard deviations and ranges). To examine movement patterns, we performed linear mixed models using the R package 'lme4′ (Bates, Maechler, Bolker, & Walker, 2015) in order to account for within- and between-level variability and for nesting of days within individuals. Separate mixed models were used to investigate differences in movement patterns by day of the week and six different time periods of the day (3-hour intervals from 06:00 am to 11:59 pm) by sociodemographic [sex, race, education, age], and health-related factors [BMI, depressive symptoms, self-rated health, two-minute walk test]. All estimates were mutually adjusted for all other factors, in addition to field center and accelerometer wear time. Given previous evidence of differences in behaviors by sex and BMI, we also investigated whether there was a significant interaction with day of the week. As this was a recruited subsample of ARIC visit 6 participants, we additionally examined potential differences in sample characteristics among those included in the analytical sample and those that attended visit 6. All analyses were conducted using R (*R Core Team, Vienna, Austria*) (R Core Team, 2021) version 4.0.4 and RStudio (*RStudio Team, Boston, MA, USA*) (RStudio Team, 2021) version 1.4.1106. Visualizations of hourly patterns of daily movement accumulation were produced using the R package 'ggplot2′ (Wickham, 2016).

3. Results

Out of the 539 participants that returned an accelerometer device, 9 participants were excluded due to incorrect ID labeling during device initialization. After removing those without adherent wear time (n = 64) and those that were classified as underweight (n = 5), a total of 459 participants were included in the analysis. Underweight participants were removed due to the association with negative health outcomes and possible confounding with prevalent, but unmeasured, diseases (Berrington de Gonzalez et al., 2010; Di Angelantonio et al., 2016). Participants had a mean age (± standard deviation [SD]) of 78.3 ± 4.6 years (range: 71–92 years). The majority were female, white, and had at least some college or above education (Table 1). Compared to the ARIC cohort at visit 6, participants in the analytic sample were more likely to be younger, white, have some college and above, self-rate their health as excellent/very good, and had the ability to walk a longer distance in the two-minute walk test (i.e., had better functional endurance capacity) than participants at visit 6 ($p < 0.05$) (Supplemental Table 1).

The devices were worn for an average (±SD) of 831.0 ± 106.6 min per day. Wilcoxon rank sum tests indicated that wear time did not differ by sex (p = 0.28) or age category (p = 0.38). On average, participants spent 449.8 ± 126.6 min sedentary, 235.8 ± 81.5 min in low light intensity activity, 113.9 ± 54.8 min in high light intensity, and 31.5 ± 34.5 min in MVPA, equating to 54.2%, 28.4%, 13.7%, and 3.8% of the average wear day, respectively.

Adjusted means and 95% confidence intervals (CI) of the linear mixed models are presented in Table 2. When examining movement patterns across the week, the participants were most sedentary (453.9 min/day, 95% CI: 417.7, 490.2), least active (MVPA: 22.5 min/day, 95% CI: 11.5, 33.5), and had the lowest number of steps (2999.7, 95% CI: 2275.3, 3724.1) on Sunday (Table 2 and Figs. 1 and 2). Also, more time was spent in high light intensity activities on any other day, relative to Sunday. Furthermore, participants also had higher minutes of low light intensity physical activity on Tuesday, Thursday, Friday, and Saturday, compared to Sunday. Hourly patterns (Table 3) show most activity occurred in the mornings between 06:00 09:00 and 09:00 and12:00 pm when 42.7 and 41.6% of the wear day was spent sedentary and 5.6 and 5.1% was spent in MVPA, respectively. Compared to the hours between 09:00–12:00, all other hour intervals, except for hours between 06:00–09:00, had a higher percentage of the time spent in sedentary behaviors and a lower percentage of time spent in low light, high light, and MVPA and also had a lower number of average steps taken.

Table 1
Characteristics of the Atherosclerosis Risk in Communities (ARIC) participants with adherent accelerometer wear (N = 459).

		Overall % (n)	Male % (n)	Female % (n)
Sociodemographic Factors				
Sex		–	40.3 (185)	59.7 (274)
Age[a] (years)	Mean (SD)	78.3 (4.6)	78.8 (4.7)	77.9 (4.5)
Self-reported Race	Black	19.8 (91)	14.1 (26)	23.7 (65)
	White	80.2 (368)	85.9 (159)	76.3 (209)
Education	< High School	6.5 (30)	4.9 (9)	7.7 (21)
	High School	36.8 (169)	30.8 (57)	40.9 (112)
	Some college and above	56.2 (258)	63.2 (117)	51.5 (141)
	Missing	0.4 (2)	1.1 (2)	–
Co-Morbidities				
Body Mass Index[a]	Normal weight, 18.5 to < 25 kg/m^2	28.8 (132)	24.9 (46)	31.4 (86)
	Overweight, 25 to < 30 kg/m^2	39.9 (183)	42.2 (78)	38.3 (105)
	Obesity, ≥ 30 kg/m^2	30.5 (140)	31.9 (59)	29.6 (81)
	Missing	0.9 (4)	1.1 (2)	0.7 (2)
Self-rated Health[a]	Excellent/Very good	55.3 (254)	51.4 (95)	58.0 (159)
	Good	39.0 (179)	42.7 (79)	36.5 (100)
	Fair/poor	4.6 (21)	5.4 (10)	4.0 (11)
	Missing	1.1 (5)	0.5 (1)	1.5 (4)
Depressive Symptoms[a,b]	At Risk	5.9 (27)	5.4 (10)	6.2 (17)
	Not At Risk	92.6 (425)	93.0 (172)	92.3 (253)
	Missing	1.5 (7)	1.6 (3)	1.5 (4)
2-Minute Walk Test[a], m	Mean (SD)	140.6 (28.2)	145.6 (28.3)	137.0 (27.6)
	Missing, % (n)	8.3 (38)	2.2 (10)	6.1 (28)

[a]Measured at visit 6 (2016–2017); otherwise measured at baseline (1987–1989).
[b]Measured via Center for Epidemiological Studies-Depression (CES-D): At risk (score ≥ 9).

Examining differences in daily movement patterns by sex, males had higher minutes of daily sedentary time (β = 54.2, 95% CI: 37.1, 71.4) and lower minutes of daily low light intensity activity (β = -37.7, 95% CI: −48.9, −26.6) and high light intensity activity (β = -19.9, 95% CI: −27.5, −12.3) compared to females. There were no significant differences detected between males and females for minutes per day spent in MVPA (β = 3.4, 95% CI: −1.8, 8.6, p = 0.201) or daily steps (β = 2.4, 95% CI: −340.7, 345.4, p = 0.989). There were no differences in hourly pattern intervals between males and females (Fig. 3).

For BMI, those with overweight (β = 28.0, 95% CI: 8.8, 47.2) and those with obesity (β = 73.0, 95% CI: 51.0, 95.1) had higher minutes of daily sedentary time, compared to participants with normal weight. Participants with overweight (β = -20.8, 95% CI: –33.3, −8.4) and with obesity (β = -48.6, 95% CI: −62.9, −34.3) also had significantly lower minutes of daily low light intensity activity than participants with normal weight. Additionally, participants with obesity had significantly lower daily minutes of high light intensity activity (β = –22.7, 95% CI: –32.5, −13.0) and daily steps (β = -589.0, 95% CI: −1029.2, −148.9) than participants with normal weight. There were no significant

Table 2
Daily accelerometer-determined activity estimates [adjusted means (95% CI)] by participant characteristics.

	Sedentary behavior	Low light intensity activity	High light intensity activity	Moderate-to-vigorous intensity activity (MVPA)	Steps
Sex					
Female (Ref)	403.4 (366.6, 440.2)	277.4 (253.6, 301.2)	127.4 (111.2, 143.6)	25.6 (14.4, 36.7)	3420.7 (2686.6, 4154.8)
Male	457.7 (421.1, 494.2) ***	239.7 (216.0, 263.3) ***	107.5 (91.4, 123.6) ***	29.0 (17.9, 40.1)	3423.1 (2694.2, 4152.0)
Self-reported Race					
White (Ref)	463.7 (428.5, 498.9)	225.4 (202.6, 248.2)	113.8 (98.3, 129.3)	30.9 (20.3, 41.6)	3591.6 (2888.7, 4294.4)
Black	397.4 (308.9, 485.8)	291.7 (234.4, 349.0)	121.1 (82.2, 160.0)	23.6 (-3.1, 50.4)	3252.2 (1488.1, 5016.3)
Age					
<78 years (Ref)	426.1 (390.5, 461.7)	258.8 (235.7, 281.9)	119.4 (103.7, 135.1)	29.6 (18.8, 40.3)	3599.5 (2889.1, 4310.0)
≥78 years	435.0 (397.5, 472.6)	258.3 (233.9, 282.6)	115.5 (99.0, 132.1)	25.0 (13.6, 36.4)	3244.2 (2494.9, 3993.5) *
Education					
< High School (Ref)	428.3 (382.4, 474.3)	261.1 (231.3, 290.8)	121.1 (100.9, 141.4)	23.3 (9.4, 37.3)	3301.9 (2384.6, 4219.2)
High School	422.4 (384.9, 460.0)	266.5 (242.2, 290.8)	117.5 (100.9, 134)	27.4 (16.1, 38.8)	3408.4 (2659.7, 4157.2)
Some college and above	440.9 (405.2, 476.6)	248.0 (224.9, 271.2)	113.8 (98.1, 129.5)	31.1 (20.3, 41.9)	3555.3 (2842.6, 4268.0)
BMI Category					
Normal (Ref)	396.9 (358.6, 435.2)	281.7 (256.9, 306.5)	127.5 (110.7, 144.4)	27.7 (16.1, 39.3)	3629.9 (2865.6, 4394.2)
Overweight	424.9 (388.1, 461.6) **	260.8 (237.0, 284.7) **	120.0 (103.8, 136.2)	28.1 (17.0, 39.2)	3594.9 (2861.8, 4327.9)
Obesity	469.9 (432.3, 507.5) ***	233.1 (208.7, 257.5) ***	104.8 (88.3, 121.4) ***	26.0 (14.6, 37.4)	3040.9 (2290.3, 3791.5) **
Self-rated Health					
Excellent/Very good (Ref)	435.4 (398.0, 472.7)	252.8 (228.6, 277.0)	116.5 (100.1, 133)	29.1 (17.8, 40.4)	3560.6 (2815.6, 4305.7)
Good	429.9 (393.3, 466.5)	252.6 (228.9, 276.4)	120.7 (104.5, 136.8)	30.6 (19.5, 41.7)	3541.6 (2811.5, 4271.8)
Fair/poor	426.3 (375.5, 477.2)	270.2 (237.2, 303.1)	115.2 (92.8, 137.6)	22.2 (6.8, 37.6)	3163.4 (2148.9, 4177.8)
Depressive Symptoms					
Not at risk (Ref)	430.4 (396.9, 464.0)	259.0 (237.3, 280.8)	117.2 (102.4, 131.9)	27.2 (17.0, 37.3)	3524.4 (2855.8, 4193.0)
At risk	430.6 (383.9, 477.4)	258.0 (227.8, 288.3)	117.7 (97.1, 138.3)	27.4 (13.3, 41.6)	3319.3 (2387.2, 4251.5)
2-Minute Walk Test (continuous, per meter)	−0.8 (-1.2, −0.5) ***	0.0 (-0.2, 0.2)	0.4 (0.3, 0.6) ***	0.4 (0.3, 0.5) ***	32.7 (26.3, 39.2) ***
Day					
Sunday (Ref)	453.9 (417.7, 490.2)	249.3 (225.8, 272.8)	108.1 (92.0, 124.1)	22.5 (11.5, 33.5)	2999.7 (2275.3, 3724.1)
Monday	431.9 (395.5, 468.2) ***	254.1 (230.5, 277.6)	118.3 (102.2, 134.3) ***	29.7 (18.6, 40.7) ***	3484.2 (2758.1, 4210.2) ***
Tuesday	424.7 (388.3, 461.0) ***	260.6 (237.1, 284.2) **	118.4 (102.3, 134.5) ***	30.1 (19.1, 41.2) ***	3626.0 (2899.5, 4352.6) ***
Wednesday	435.0 (398.7, 471.4) ***	256.0 (232.4, 279.6)	115.7 (99.6, 131.7) **	27.1 (16.1, 38.1) **	3531.0 (2804.7, 4257.3) ***
Thursday	429.2 (392.8, 465.5) ***	257.8 (234.2, 281.3) *	118.7 (102.6, 134.8) ***	28.3 (17.2, 39.3) **	3545.7 (2819.9, 4271.6) ***
Friday	415.7 (379.4, 452.1) ***	267.5 (244.0, 291.1) ***	123.8 (107.7, 139.9) ***	26.7 (15.7, 37.7) *	3466.4 (2740.3, 4192.5) ***
Saturday	423.4 (387.2, 459.7) ***	264.4 (240.9, 287.9) ***	119.3 (103.3, 135.3) ***	26.7 (15.7, 37.7) *	3300.1 (2576.0, 4024.3) **

Note. All mixed effects estimates were mutually adjusted for all other factors under study, in addition to field center and accelerometer wear time.
p-values denoted as * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

differences for time spent in MVPA for participants with overweight (β = 0.4, 95% CI: −5.4, 6.2, p = 0.897) or with obesity (β = -1.7, 95% CI: −8.4, 5.0, p = 0.622) compared to normal weight participants. There were no differences in hourly pattern intervals between those with normal weight, overweight, or obesity (Fig. 4).

Higher functional capacity (measured via two-minute walk test) was negatively associated with daily sedentary time and positively associated daily high light intensity and MVPA. For each additional meter walked during the two-minute walk test, daily minutes spent sedentary was lower by 0.8 min (95% CI: −1.2, −0.5) while minutes per day spent in high light intensity physical activity (β = 0.4, 95% CI: 0.3, 0.6),MVPA (β = 0.4, 95% CI: 0.3, 0.5), and daily steps (32.7, [26.3, 39.2]) were higher, when controlling for the other sociodemographic and health-related factors.

No significant differences were found by self-reported race, age, education, self-rated health, or depressive symptoms for daily time spent sedentary or within any of the physical activity intensity categories when adjusting for all factors under study. However, older adults had lower daily steps 3244.2 (95% CI: 2494.9, 3993.5) Additionally, there were no significant interactions found between day of the week or

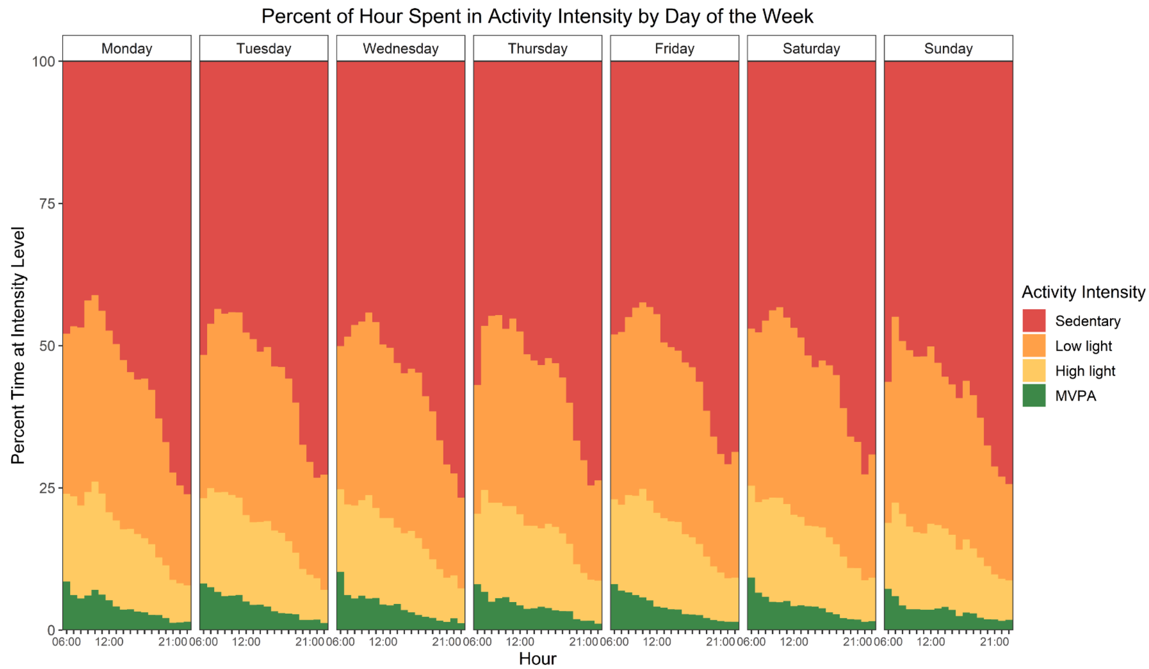

Fig. 1. Daily patterns of accelerometer-determined activity estimates for the overall sample.

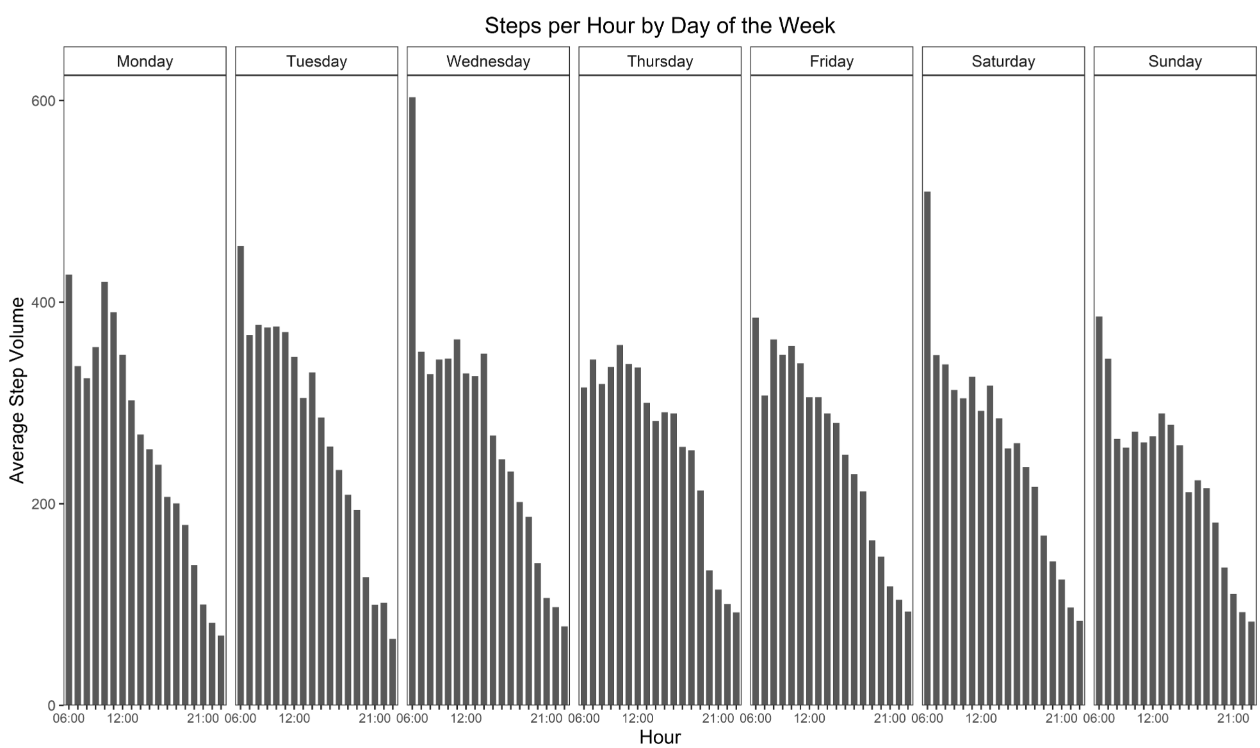

Fig. 2. Daily step estimates for the overall sample.

hourly intervals and sex or BMI (Supplemental Figs. 1 and 2), thus the interaction term was removed from all models.

4. Discussion

We examined time-use patterns of accelerometer-determined steps and minutes of sedentary behavior, low and high light intensity physical activity, and MVPA in a sample of U.S. older adults between the ages of 71–92 years. Time-use encompasses the amount of time spent sleeping, in sedentary behavior, and in physical activity and examining these patterns can be useful for preventing unhealthy time-use patterns and potential health consequences (Pedišić et al., 2017). We found that older adult men and those with overweight or obesity had significantly lower minutes of low light and high light intensity physical activity than older adult women and those with normal weight. Correspondingly, the lower minutes of physical activity were displaced by spending more minutes in sedentary behaviors, as men, compared to women, and participants with overweight or obesity, compared to those with normal weight, had

Table 3
Proportion of time and number of steps spent in accelerometer-determined activity estimates [adjusted percentage (95% CI)].

	Sedentary behavior	Low light intensity activity	High light intensity activity	Moderate-to-vigorous intensity activity (MVPA)	Steps
06:00 to 09:00	42.7 (38.4, 47.0)	34.7 (31.8, 37.6) *	17.2 (15.2, 19.4)	5.5 (4.2, 6.8)	406.4 (276.1, 536.8) ***
09:00 to 12:00 (Ref)	41.6 (37.2, 45.9)	35.8 (32.9, 38.7)	17.5 (15.6, 19.4)	5.1 (3.9, 6.4)	910.4 (780.8, 1040.0)
12:00 to 15:00	46.3 (42.0, 50.6) ***	34.1 (31.2, 37.0) ***	15.6 (13.7, 17.5) ***	4.0 (2.7, 5.3) ***	877.6 (748.0, 1007.2)
15:00 to 18:00	50.3 (45.9, 54.6) ***	32.2 (29.3, 35.1) ***	14.4 (12.4, 16.3) ***	3.1 (1.9, 4.0) ***	701.7 (572.1, 831.3) ***
18:00 to 21:00	58.0 (53.7, 62.4) ***	28.7 (25.8, 31.6) ***	11.2 (9.3, 13.1) ***	2.0 (0.7, 3.3) ***	462.7 (333.1, 592.3) ***
21:00 to 00:00	68.5 (64.2, 72.9) ***	22.3 (19.4, 25.2) ***	7.9 (6.0, 9.9) ***	1.2 (-0.1, 2.5) ***	83.2 (-46.8, 213.3) ***

Note. Mixed effects estimates adjusted for age, sex, self-reported race, education, BMI category, self-rated health, depressive symptoms, 2-Minute Walk test, and field center.
p-values denoted as * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

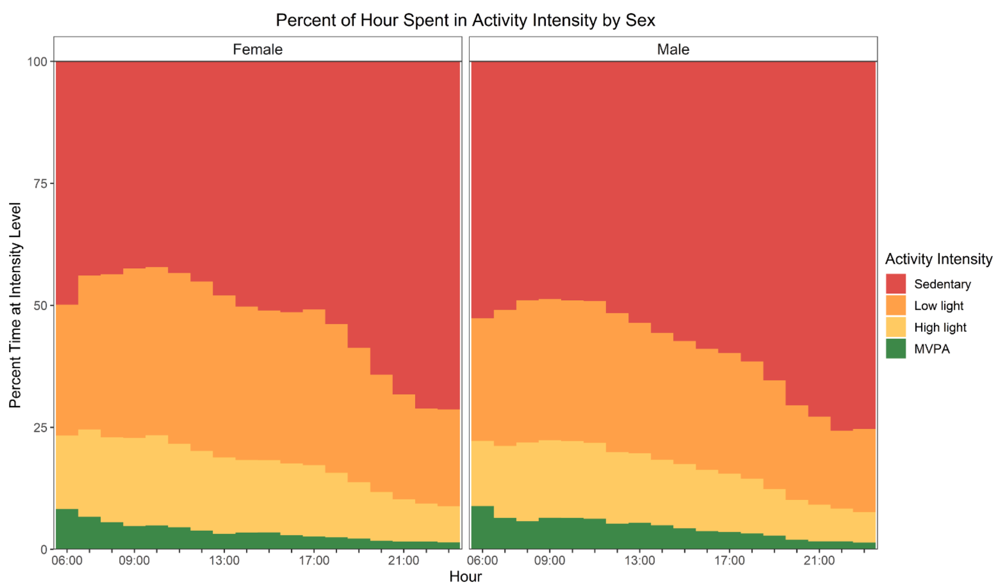

Fig. 3. Hourly patterns of accelerometer-determined activity estimates by sex.

significantly more minutes of daily sedentary time and fewer daily steps with no significant differences found for minutes spent in MVPA. This has important health consequences as greater accelerometer-determined sedentary time is associated with an increased risk for cardiovascular disease (Bellettiere et al., 2019), poor cardiorespiratory fitness (Santos et al., 2012) and physical functioning, all-cause mortality (Diaz et al., 2017; Ekelund et al., 2020), and cancer-related mortality (Gilchrist et al., 2020) among older adults.

There have been similar previous findings that men and those with overweight and obesity have more sedentary time and less light intensity activity than women and those with normal weight (Davis et al., 2011; Diaz et al., 2016; Giné-Garriga et al., 2020). This study furthers these findings in a racially diverse sample. In addition, these findings are supported when controlling for a range of other health-related correlates and when utilizing accelerometer cutpoints developed specifically for use in older adults. Applying accelerometer threshold values developed for use in a similar age group is important as intensity thresholds may differ depending on cardiorespiratory fitness (Ozemek, Cochran, Strath, Byun, & Kaminsky, 2013; Siddique et al., 2020) which declines over age (Fleg et al., 2005). As frequently done in prior studies, the use of intensity cutpoints developed in younger adults in older adult populations should be cautioned (Schrack et al., 2016). However, it should be noted that functional status can vary largely in older adult populations, thus relative intensity cutpoints may be more appropriate (Schrack et al., 2018). This may be one reason we observed differences in activity patterns by two-minute walk test but did not observe differences by age as, for example, two older adults of the same age can vary greatly in terms of their functional ability and speed of movement.

We also are one of the first studies to examine physical activity and sedentary behavior patterns across days of the week in older adults. Older adult retired populations are unique in that employment, which can be a significant setting for physical activity and/or sedentary behavior accumulation for adults (Gabriel, Morrow, & Woolsey, 2012) is no longer a factor. We found days of the week tended to be similar, however Sunday was the least active and most sedentary day compared to other days of the week, with older adults spending about 7.6 (95% CI: 7.0, 8.2) hours in inactive, sedentary behaviors. When examining hourly patterns, a greater proportion of time was spent in sedentary behaviors during Sunday morning hours (8 AM-12 PM) than were typically accrued on the other days of the week. This may be due to church or other worship services (Pew Research Center, 2015); however, we are unable to examine this directly within our study given contextual information was not assessed. Future studies in older adults should consider time-use questionnaires or simultaneous collection of accelerometers and global positioning system (GPS) device data to further understand spatial-based behaviors, if possible, in order to understand

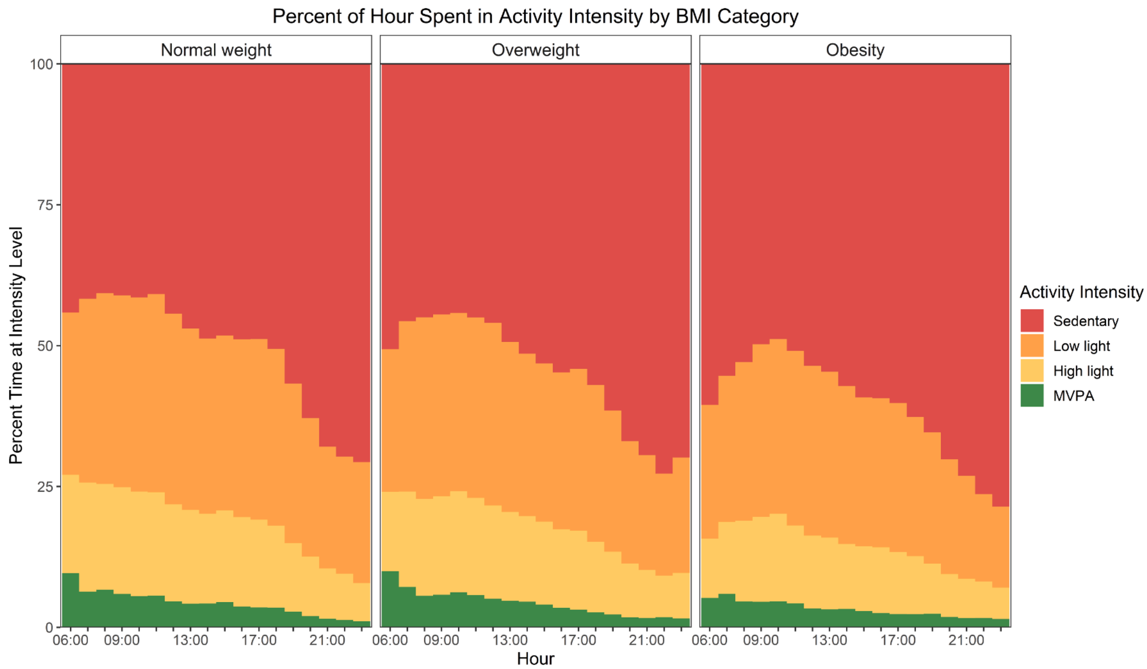

Fig. 4. Hourly patterns of accelerometer-determined activity estimates by Body Mass Index (BMI) category.

where and how older adults move within the built environment (Krenn, Titze, Oja, Jones, & Ogilvie, 2011).

We observed that a large proportion of older adults' day was spent in low light and high light intensity physical activity. Low light intensity physical activities occur between 1.6 and 2.2 METs and include activities such as washing and drying dishes, whereas high light intensity physical activities are between 2.3 and 2.9 METs and include activities such as laundry, mopping, and walking 1.5 miles per hour (mph). While higher intensity physical activity (i.e., MVPA, $\geq$ 3 METs) have been typically studied for health benefits and for physical activity recommendations and guidelines, evidence suggests there are protective health benefits of light intensity physical activity (Amagasa et al., 2018; Gilchrist et al., 2020; LaCroix et al., 2019; LaMonte et al., 2017). For example, a previous study utilizing hypothetical time replacement scenarios (e.g., isotemporal substitution models) in older adults, mean age = 69.8 (SD 8.5) years, found that replacing 30 min of sedentary time with light intensity physical activity would reduce the risk of cancer mortality by 8% (Gilchrist et al., 2020) over a 5-year follow-up. In another study using the Evenson VM threshold values for determining time spent in low light and high light intensity activities, there were significant reductions in predicted cardiovascular disease risk scores and cardiometabolic risk factors for both low light and high light intensity in older adult women (LaMonte et al., 2017). Further, the strongest relation for reductions in predicted cardiovascular disease risk scores was seen for high light physical activity even when controlling for time spent in MVPA. Although older adults in our study did spend a large part of their day in light intensity activity, most of this activity occurred in the morning and mid-afternoon periods. Pattern visualization shows that the evening hours between 4 and 11 PM, were largely spent engaged in sedentary behaviors for more than 50% of the hour. Given the evidence of the benefits of light intensity physical activity, interventions could focus on engaging older adults to increase both their low and high light activities, especially in the evening hours, such as an after-dinner walk. However, given potential functional limitations, including vision, may preclude older adults in engaging in activity after dark, older adults should also be encouraged to look for opportunities in the morning to add movement and replace sedentary behaviors with any type of physical activity. Replacing sedentary behavior with activity at any intensity would lead to more daily steps which has been shown to have a dose–response relation with all-cause mortality (Paluch et al., 2022).

The findings that there were no significant differences in daily MVPA by BMI may be due to using population-based absolute intensity threshold values for accelerometer-derived intensity estimates. Relative intensity cutpoint thresholds for individuals with overweight and obesity have been found to be lower than individuals with normal weight (Raiber, Christensen, Randhawa, Jamnik, & Kuk, 2019). Thus, the use of absolute intensity threshold values may result in misclassification of MVPA as low light or high light intensity among individuals with overweight or obesity. Nevertheless, compared to those with normal weight, those with overweight and obesity had significantly higher minutes of sedentary behavior. Particularly, those with obesity had over an hour (β = 73.0, 95% CI: 51.0, 95.1) extra time of daily sedentary behaviors than those with normal weight. Thus, promotion of light intensity and MVPA and reduction in sedentary time is still needed among this population.

4.1. Limitations

Although this study was conducted within a large cohort of Black and white men and women, participants had to enroll in the accelerometer ancillary substudy and meet ancillary specific inclusion criteria (i.e., not residing in a total care nursing home, not at higher risk of dementia, and able to complete the 4-meter walk test of the SPPB). Participants were younger, more likely have higher educational attainment, and less likely to self-report their overall health as fair or poor than the overall ARIC cohort at visit 6. Despite this, by using this well-characterized cohort, we were able to explore and adjust for several potential confounders. In addition, hip worn accelerometers were worn only during waking periods, thus we are unable to examine the patterns of physical activity and sedentary behaviors in relation to daily sleep. However, by using Evenson VM thresholds to derive the sedentary and physical activity intensity metrics, we were able to examine the patterns of both low light and high light intensity activity which have important implications for health of older adults. But, as noted previously, accelerometer threshold values based on absolute intensity may have limitations compared to threshold values based on relative intensity (Schrack et al., 2018), individual level calibration (Brage et al., 2007), or examining activity patterns without the use of cutpoints (Shiroma, Schrack, & Harris, 2018) due to potential of large differences in functional status within older adult populations. Despite this, Evenson VM thresholds were developed and evaluated as part of a calibration study consisting of older women (Evenson et al., 2015). While differences in patterns were statistically significant, overall differences between days may be marginal within the context of a 24-hour period. However, research and public health guidelines suggests every minute counts and adults should move more and sit less for health benefits (U.S. Department of Health and Human Services, 2018). Finally, it should be noted that waist-worn ActiGraph accelerometers are limited in measuring stationary behavior, as the device does not measure posture or context, as defined by the consensus definition provided by the Sedentary Behaviour Research Network (SBRN) (Tremblay et al., 2017). Further investigation of sedentary behavior findings is warranted and would be enhanced with the inclusion of devices that capture postural positions or by classifying sedentary patterns and sedentary behavior from hip-worn ActiGraph devices using machine learning algorithms (Greenwood-Hickman et al., 2021).

5. Conclusions

Older adults are the least active age group in the U.S., therefore efforts are needed to explore daily and hourly activity and sedentary behavior patterns for health promoting benefits. Although older adults typically engage in activity of lower intensity, accumulation of activity at any threshold above sedentary behavior has the potential for health benefits. Supporting physical activity in older adults is paramount with the rapidly aging U.S. population and increasing life expectancy (Medina, Sabo, & Vespa, 2020). Findings of time-use movement patterns of older adults suggests there are continued opportunities for promotion of physical activity and reduction in sedentary behaviors on Sundays, in the evening hours, and for men and those who have overweight or obesity.

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CRediT authorship contribution statement

Erin E. Dooley: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing, Visualization. **Lisa A. Pompeii:** Funding acquisition, Investigation, Writing – review & editing. **Priya Palta:** Writing – review & editing. **Pablo Martinez-Amezcua:** Writing – review & editing. **Bjoern Hornikel:** Writing – review & editing. **Kelly R. Evenson:** Writing – review & editing. **Jennifer A. Schrack:** Writing – review & editing. **Kelley Pettee Gabriel:** Funding acquisition, Investigation, Data curation, Project administration, Conceptualization, Writing – review & editing, Supervision.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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