



Associations of accelerometer-determined sedentary behavior and physical activity with physical performance outcomes by race/ethnicity in older women

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ABSTRACT

To determine the cross-sectional associations of accelerometer-measured time spent in physical activity intensity categories (sedentary, low and high light intensity, or moderate to vigorous intensity physical activity (MVPA) with physical performance outcomes [stair climb ascent, 40 foot walk test, and short physical performance battery (SPPB)] in older women and examine differences by race/ethnicity. Data were from 1,256 Study of Women's Health Across the Nation (SWAN) participants [aged 64.9 (2.7) years at Visit 15 (2015–16); 54.1% non-White]. Three sets of adjusted multivariable linear or logistic regression models were built to test the study objectives using the backward elimination approach to identify relevant covariates. In the full analytic sample, a 10 min increment in MVPA was related to faster performance on the stair climb [$\beta = -0.023$ (95% CI: $-0.04, -0.005$) seconds] and 40 foot walk test [$\beta = -0.066$ (95% CI: $-0.133, -0.038$) seconds], and a 9% lower odds [OR: 0.91; 95% CI: 0.87, 0.96; $p = 0.004$] of limitations based on the SPPB. Statistically significant differences by race/ethnicity were found for the stair climb ascent time as MVPA was associated with better performance for White, Chinese, and Japanese participants while high light intensity physical activity, but not MVPA, was deemed beneficial in Black women. Findings from the isotemporal substitution models were consistent. Findings further support the importance of MVPA on physical performance outcomes in older women. Further research is needed to examine the complex associations between physical (in)activity and physical performance outcomes by race/ethnicity to provide more targeted recommendations.

1. Introduction

More than one-quarter of U.S. adults aged ≥ 65 years reported a mobility disability (Courtney-Long et al., 2015). Sex differences in the prevalence of disability (Courtney-Long et al., 2015) across the

lifecourse (Leveille et al., 2000) have also been shown. Specifically, the prevalence of mobility disability was 22% in women aged 70 compared to 15% in similarly aged men; a gender gap that becomes more pronounced by age 85 (Leveille et al., 2000). As the U.S. population continues to age and become more racially/ethnically diverse (Population

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Reference Bureau, 2015), prevention strategies are needed to reduce the public health burdens associated with physical impairment and mobility disability; particularly among women (Freedman et al., 2008; Sternfeld et al., 2020; Ylitalo et al., 2013).

Mobility disability has been described as a highly dynamic process (Gill et al., 2006) and engaging in habitual physical activity (PA) has been shown to improve physical functioning and reduce risk of mobility loss (LaCroix et al., 1993). While the 2018 PA Guidelines Advisory Committee (U.S. Department of Health and Human Services, 2018) (2018 PAG Committee) indicated strong scientific evidence supporting the benefits of PA to optimize physical function across the lifecourse, important research gaps remain.

First, the majority of studies reviewed and summarized by the 2018 PAG Committee (U.S. Department of Health and Human Services, 2018) utilized report-based methods to quantify PA, which has known limitations (Troiano et al., 2012). Most questionnaires focus exclusively on estimating moderate to vigorous intensity PA (MVPA) during leisure-time. Light intensity physical activities (LPA), defined as activity types between 1.6 and 2.9 metabolic equivalents of task (MET) (Pate et al., 2008), are often omitted from questionnaires because they are more sporadic and less salient; making them more cognitively challenging to recall accurately (Troiano et al., 2012). This has limited our understanding of the potential health benefits of LPA to maintain or improve physical functioning. Technological advances in wearable devices has improved our ability to examine the potential benefits of PA across intensity categories, including sedentary time (U.S. Department of Health and Human Services, 2018).

Second, there is currently limited evidence on whether the association between PA and physical functioning varies by race/ethnicity (U.S. Department of Health and Human Services, 2018). In the Study of Women's Health Across the Nation (SWAN), differences in both PA (report- and accelerometer-based (Stewart et al., 2020)) and physical functioning (report (Ylitalo et al., 2013) and performance based (Sternfeld et al., 2019)) have been observed across the five race/ethnic groups. We extend this work by addressing the following objectives: 1) determine the cross-sectional association of accelerometer measured time spent sedentary and in low and high LPA, and MVPA with physical performance outcomes [stair climb (ascent), 40 foot walk test, and Short Physical Performance Battery (SPPB) (Guralnik et al., 1994), including the hypothetical effect of replacing 10 min of sedentary time with an equal duration of low-, high-LPA, or MVPA (Buman et al., 2010; Mekary et al., 2009), and 2) to test whether there are differences in these associations by race/ethnicity.

2. Material and methods

2.1. Study design overview and participants

Details on the sampling and recruitment strategy used in SWAN to obtain a representative sample are published elsewhere (Sowers et al., 2000). Briefly, 3,302 women aged 42–52 years were recruited in 1996–97 from seven U.S. metropolitan areas: Oakland and Los Angeles (CA), Chicago (IL), Boston (MA), Detroit and surrounding areas (MI), Newark (NJ), and Pittsburgh (PA). Eligibility criteria also included having a menstrual period within 3 months, an intact uterus and at least one ovary, and no exogenous hormone use. Each site recruited non-Hispanic White women and a site-specific designated number of participants who reported identifying with a single racial/ethnic minority group, including Black (Chicago, Boston, Detroit, and Pittsburgh), Chinese (Oakland), Japanese (Los Angeles) and Hispanic (Newark) women. Following baseline, participants have been seen approximately annually through follow-up Visit 15 (2015–17). At Visit 15, an accelerometer protocol was included for the first time. All participants provided written informed consent, and all study protocols were approved by the Institutional Review Board at each participating institution.

2.2. Data collection

2.2.1. Accelerometry

Study participants were given an ActiGraph wGT3X-BT accelerometer (ActiGraph LLC; Pensacola, FL) and asked to wear this device on the waist during all waking hours, except during water-based activities, for seven consecutive days following the visit. The ActiGraph was initialized to begin data collection at 12:00am on the day of the in-person visit and raw data were sampled (40 Hertz). Participants were asked to record the times when the monitor was put on and taken off each day in a paper-based diary. After 7 days, the monitor and diary were returned using a pre-stamped and addressed envelope. Triaxial data were downloaded and reintegrated to a 60 s epoch using ActiLife6 software and the 'PhysicalActivity' R package, adapted for this study, was used to derive summary estimates (Keadle et al., 2014). For all valid days (≥ 10 h·d⁻¹), average time spent per day (min·d⁻¹) in sedentary [< 76 vector magnitude counts per minute (VMct·min⁻¹); < 1.5 METs, e.g., watching television], low LPA [76 to < 903 VMct·min⁻¹; 1.6–2.2 METs, e.g., washing dishes], high LPA (903 to < 2075 VMct·min⁻¹; 2.3–2.9 METs, e.g., walking 1.5 miles per hour], and MVPA (≥ 2075 VMct·min⁻¹; ≥ 3.0 METs, e.g., walking 3 mph) were estimated using Evenson VM threshold values given they were developed and calibrated in older women (Evenson et al., 2015). The VM thresholds were multiplied by four to account for the longer epoch, with slight adjustments to obtain mutually exclusive threshold ranges (Stewart et al., 2020). Valid wear was defined as ≥ 4 days with ≥ 10 h, by convention (Troiano et al., 2008; Matthews et al., 2012). Summary accelerometer estimates represent minutes per day, averaged over the number of valid days.

2.2.2. Physical performance outcomes

Timed Stair Climb Participants were instructed to climb up and down the set of four standard stairs three times without stopping using a similar pace that she would normally use. At the top of the stairs, participants landed both feet on the top stair before returning back down. Participants were allowed to use the handrails for support; however, participants using assistive devices were ineligible for safety reasons. For each cycle, both the ascent and descent times (seconds) were recorded as well as the overall cumulative time. The average ascent time across the three cycles was used for analyses. Boston participants did not participate in the this protocol.

40 Foot Walk The course was set-up on a level floor with two tape markers denoting the start and end point, located 40 feet apart. Participants were instructed to complete the walk in a comfortable, but steady brisk pace and timing was stopped when both feet crossed the end line. Participants were able to use an assistive device for the walk and this information was recorded. The average time (seconds) across two repetitions was used for analyses. The Los Angeles and Newark SWAN sites did not participate in this protocol.

SPPB The SPPB is a set of standardized performance based measures, including the 4 m walk, repeated chair stands, and balance testing (Guralnik et al., 1994). For the 4 m walk test, participants were instructed to walk at their usual speed. Use of assistive devices were allowed and documented. The 4 m walk was completed twice and the faster of the two timed walks in seconds was used for analysis; gait speed is also reported, descriptively. For repeated chair stands, a standard height chair with a back was placed on a level floor (Guralnik et al., 1994). While sitting, participants were asked to sit and place their arms across her chest. Timing started when the participant stood without using their arms and ended when the participant was standing in a fully erect position. Time (seconds) taken to complete five consecutive repetitions was used in analysis. For the balance component, three different stands were completed in consecutive order (side-by-side, semi-tandem, and tandem). Each task was considered completed if the position was held for 10 s.

Each SPPB component was scored on a scale from 0 (unable to attempt due to safety concerns, inability, or pain) to 4. Scores of 1

(lowest quartile) to 4 were assigned based on quartiles of performance within the SWAN cohort (Müller et al., 2008). The intermediate scores were summed and participants were classified as having no (10–12), mild (7–9), moderate (4–6), or severe (0–3) limitations (Michael et al., 2011). For multivariable analysis, a dichotomous score (no versus any limitation) was used. All sites participated in the SPPB protocol.

2.2.3. Covariates

Race/ethnicity and was collected at baseline and all other covariates were collected at Visit 15 including, age and socio-demographic factors and other health behaviors. Body mass index (BMI) was calculated in kilograms per meters squared (kg/m^2) based on measured height (stadiometer) and body weight (calibrated scale) and categorized into race/ethnic-specific groups: under or normal weight ($<25 \text{ kg}/\text{m}^2$ for White, Black, and Hispanic women and $<24 \text{ kg}/\text{m}^2$ for Chinese or Japanese women), overweight (Yasunaga et al. (2017) (or Ware and Sherbourne (1992)) kg/m^2 to $<30 \text{ kg}/\text{m}^2$), or obese ($\geq 30 \text{ kg}/\text{m}^2$). Other measures include: menopausal status (natural post-menopause, post-menopausal by bilateral salpingo-oophorectomy, or unknown or hysterectomy), difficulty paying for basics (very hard/somewhat hard or not hard at all), presence of depressive symptoms (≥ 16 on Center for Epidemiological Studies Depression) (Radloff, 1977), self-rated health status (excellent/very good, good, or fair/poor), difficulty performing work or other activities (yes or no), bodily pain (from SF-36 (Ware and Sherbourne, 1992): none, very mild, mild, moderate, or severe/very severe), current smoker (yes or no), and reported co-morbidities [osteoarthritis, type 2 diabetes, and cardiovascular event (myocardial infarction, angina, stroke)]. Covariates, including SWAN clinical site, were selected based on the literature and biological plausibility for confounding the main association of interest.

2.3. Statistical analyses

Descriptive analysis included frequency distributions or measures of central tendency and measures of variability. For continuous variables, the assumption of normality was tested. Differences in participant characteristics were compared between the analytic sample and excluded participants using bivariate statistics. Analysis of variance was used to determine differences in participant characteristics and physical functioning outcomes by MVPA tertiles.

To inform the modeling strategy, multicollinearity between accelerometer estimates was assessed using a threshold of $r = 0.70$. Correlations ranged from $r = 0.01$ (low LPA and MVPA) to $r = -0.55$ (sedentary and high LPA) or $r = 0.55$ (high LPA and MVPA), which are indicative of weak to moderate associations (data not shown). Accordingly, three sets of multivariable linear (stair climb ascent and 40 foot walk) or logistic (SPPB) regression models were used to test the study objectives. Accelerometer estimates were scaled to 10 min as it represents a feasible behavioral target for older women and replicates an approach used in a similar study (Yasunaga et al., 2017). Single activity models were used to estimate the effect of each intensity specific estimate, separately, without taking the other intensity specific estimates into consideration, but with adjustment for wear time and other covariates. Partition models were used to estimate the unique effect of each intensity specific estimate after adjusting for the effect of the other intensity specific estimates and other covariates. Isotemporal substitution (Mekary and Ding, 2019), were used to estimate the effect of replacing 10 min of sedentary time for an equal amount of time in a different PA intensity category after adjustment for wear time and other covariates. Models were run for each physical performance outcome, proceeding first with an unadjusted model. Then, for adjusted models, a manual backward elimination approach was used to identify relevant covariates, based on associations with the physical performance outcomes at $p < 0.10$. Interactions by race/ethnicity were tested by including terms into the models representing the product of accelerometer-derived intensity specific estimates and race/ethnicity. Given that pain may influence

both the exposure and outcome variables, a sensitivity analysis was conducted that excluded participants reporting severe or very severe bodily pain (7.5%).

The partition and isotemporal substitution models were highlighted in the text given general consensus among experts that intensity specific estimates should not be considered independently when additional information is available. To aid interpretation, associations obtained from the isotemporal substitution models were expressed in the text as percent improvement. For each specified group, the change in mean outcome value resulting from the substitution of 10 min of sedentary time for equal time in a given intensity category (numerator) was divided by the original mean of the specified group (denominator) multiplied by 100. All statistical analyses were conducted in SAS v.9.3 (SAS Institute Inc., Cary, North Carolina).

3. Results

The analytic sample included participants who attended Visit 15 in-person ($n = 2,089$) and were approached to participate in the accelerometer protocol ($n = 2,029$) to meet a recruitment goal for of $n = 1,500$ for this protocol. Of those, 1,333 women agreed to participate and 1,269 participants had valid wear (88.9% and 84.6%, respectively, of the recruitment goal). The analytic sample included 1,256 participants who also completed at least one physical performance assessment. Excluded women were older and more likely to be Black, separated, widowed, or divorced, participants of the Boston site, obese, current smokers, and report higher depressive symptoms, fair/poor health status, severe/very severe bodily pain, and ≥ 2 comorbidities (all $p < 0.05$; Supplemental Table 1).

Characteristics of the analytic sample [mean age 64.9 (2.7) years; 45.9% White] are included on Supplemental Table 1. Compliance to the accelerometer protocol was excellent [mean wear time 914.9 (111.9) minutes per day] and consistent across all race/ethnic groups [range mean wear time 949.7 (79.5) to 881.4 (126.6) minutes per day in Japanese and Hispanic participants, respectively]. As shown in Table 1, statistically significant differences were noted across MVPA tertiles for all participant characteristics except for menopausal status and reported arthritis or osteoarthritis at Visit 15. Participants in the high MVPA tertile were more likely to be White, currently married or living as married, enrolled at the UCLA site, excellent or very good health status, and no bodily pain, have a lower BMI, and less likely to have difficulty paying for basics, depressive symptoms, difficulty performing work activities, any comorbidities or be current smokers (all $p < 0.05$). In addition, participants in the high MVPA tertile had the fastest stair climb ascent and 40 foot walk times and highest proportion of no limitations based on the SPPB (all $p < 0.0001$).

Based on the partition model, a 10 min increment in MVPA was associated with a $\beta = -0.023$ [95% confidence interval (CI): $-0.04, -0.005$; $p = 0.01$] second faster average ascent time after adjustment for other intensity categories and covariates. There was a statistically significant interaction by race/ethnicity ($p < 0.001$) such that a similar association between MVPA and faster ascent time was found in White, Chinese, and Japanese participants, but not in Black or Hispanic women. While not statistically significant in the entire analytic sample or other race/ethnic groups, after adjustment, a 10 min increment in high LPA was related to a $\beta = -0.076$ [95% CI: $-0.13, 0.02$; $p = 0.01$; p for interaction $= <0.001$] second faster average ascent time in Black participants (Table 2). In the entire sample, isotemporal substitution models estimated that replacing 10 min of sedentary time with equal time in MVPA would result in a 0.79% improvement in ascent time. By race/ethnic groups, replacing 10 min of sedentary time for MVPA would result in a 0.74%, 1.6%, and 1.1% improvement in ascent time in White, Chinese, and Japanese women, respectively. In Black women, isotemporal substitution models estimated that replacing 10 min of sedentary time with equal time in high LPA would result in a 2.4% improvement in ascent time. Single activity models are shown in

Table 1
Participant characteristics by tertiles of moderate to vigorous intensity physical activity (MVPA).

Characteristics	Low MVPA (0–36.6 min·d ⁻¹)	Moderate MVPA (36.7–64.0 min·d ⁻¹)	High MVPA (64.1–234.5 min·d ⁻¹)	p-value
Age at Current Visit, years				
Mean(SD)	65.33 (2.73)	64.80 (2.57)	64.69 (2.68)	0.001
Race/Ethnicity				
Black	147 (35.08%)	118 (28.16%)	63 (15.07%)	<0.0001
White	167 (39.86%)	183 (43.68%)	227 (54.31%)	
Chinese	45 (10.74%)	40 (9.55%)	62 (14.83%)	
Hispanic	34 (8.11%)	22 (5.25%)	15 (3.59%)	
Japanese	26 (6.21%)	56 (13.37%)	51 (12.20%)	
Marital status				
Single/never married	46 (11.00%)	46 (10.98%)	51 (12.20%)	0.003
Currently married/living as married	224 (53.59%)	259 (61.81%)	270 (64.59%)	
Separated/widowed/divorced	148 (35.41%)	114 (27.21%)	97 (23.21%)	
Employment status				
Employed	189 (45.32%)	234 (55.98%)	229 (54.78%)	0.003
Site				
Michigan	84 (20.05%)	65 (15.51%)	42 (10.05%)	<0.0001
Boston	46 (10.98%)	59 (14.08%)	58 (13.88%)	
Chicago	70 (16.71%)	66 (15.75%)	41 (9.81%)	
UC Davis	60 (14.32%)	59 (14.08%)	90 (21.53%)	
UCLA	42 (10.02%)	74 (17.66%)	94 (22.49%)	
New Jersey	47 (11.22%)	26 (6.21%)	27 (6.46%)	
Pittsburgh	70 (16.71%)	70 (16.71%)	66 (15.79%)	
Body Mass Index				
Mean(SD)	31.22 (7.26)	28.95 (6.63)	26.67 (6.14)	<0.0001
Obesity status				
Underweight/Normal	90 (21.58%)	122 (29.12%)	190 (45.45%)	<0.0001
Overweight	108 (25.90%)	145 (34.61%)	124 (29.67%)	
Obese	219 (52.52%)	152 (36.28%)	104 (24.88%)	
Menopausal status				
Post by BSO	28 (6.70%)	27 (6.46%)	18 (4.32%)	0.62
Natural post	380 (90.91%)	381 (91.15%)	389 (93.29%)	
Unknown or hysterectomy	10 (2.39%)	10 (2.39%)	10 (2.40%)	
Difficulty paying for basics				
Very hard/somewhat hard	115 (28.40%)	87 (21.12%)	61 (14.81%)	<0.0001
Not hard at all	290 (71.60%)	325 (78.88%)	351 (85.19%)	
Depression status at V15				
Depressed	59 (14.08%)	42 (10.02%)	35 (8.37%)	0.02
Overall health status				
		215 (51.81%)	261 (62.44%)	<0.0001

Table 1 (continued)

Characteristics	Low MVPA (0–36.6 min·d ⁻¹)	Moderate MVPA (36.7–64.0 min·d ⁻¹)	High MVPA (64.1–234.5 min·d ⁻¹)	p-value
Excellent/very good	152 (36.89%)			
Good	164 (39.81%)	147 (35.42%)	123 (29.43%)	
Fair/poor	96 (23.30%)	53 (12.77%)	34 (8.13%)	
Difficulty Performing Work/Activities				
Yes	142 (34.30%)	112 (26.86%)	81 (19.42%)	<0.0001
Bodily pain				
None	52 (12.56%)	60 (14.35%)	78 (18.71%)	<0.0001
Very mild	122 (29.47%)	151 (36.12%)	156 (37.41%)	
Mild	86 (20.77%)	103 (24.64%)	107 (25.66%)	
Moderate	100 (24.15%)	80 (19.14%)	60 (14.39%)	
Severe/very severe	54 (13.04%)	24 (5.74%)	16 (3.84%)	
Current Smoker				
Yes	36 (8.70%)	19 (4.55%)	14 (3.35%)	0.002
Told had Arthritis or Osteoarthritis at V15				
Yes	158 (38.26%)	146 (35.01%)	134 (32.13%)	0.18
Ever had Arthritis or Osteoarthritis				
Yes	292 (69.69%)	253 (60.38%)	222 (53.11%)	<0.0001
Ever had Diabetes				
Yes	123 (29.36%)	63 (15.04%)	28 (6.70%)	<0.0001
Ever had CVD Event				
Myocardial infarction, angina or stroke				
Yes	38 (9.07%)	17 (4.06%)	7 (1.67%)	<0.0001
Categorical Comorbidity Score¹				
0 comorbidities	23 (5.49%)	43 (10.26%)	51 (12.20%)	<0.0001
1 comorbidity	46 (10.98%)	67 (15.99%)	91 (21.77%)	
≥2 comorbidities	350 (83.53%)	309 (73.75%)	276 (66.03%)	
Physical Performance				
Average ascent time on the stair climb test, seconds²				
Mean (SD)	3.63 (1.19)	3.20 (0.91)	3.01 (0.67)	<0.0001
Average timed 40 foot walk test³				
Seconds, Mean (SD)	9.90 (2.78)	9.09 (1.80)	8.43 (1.57)	<0.0001
Meters per second, (Mean (SD))	1.34 (0.30)	1.42 (0.26)	1.53 (0.27)	<0.0001
SPPB (SWAN scoring), n (%)				
No Limitations	93 (22.85%)	179 (43.03%)	226 (54.33%)	<0.0001
Mild Limitations	191 (46.93%)	177 (42.55%)	166 (39.90%)	
Moderate Limitations	111 (27.27%)	57 (13.70%)	23 (5.53%)	
Severe Limitations	12 (2.95%)	3 (0.72%)	1 (0.24%)	

¹ Comorbidities included in the categorical comorbidity score: myocardial infarction/angina, diabetes, osteoarthritis, high blood pressure, high cholesterol, thyroid problems, osteoporosis, stroke.

² Stair climb test was not conducted at the Boston SWAN site (included Black and White women).

³ 40 foot walk test was not conducted at the Los Angeles (only SWAN site including Japanese women) or Newark (only SWAN site including Hispanic women) SWAN sites.

Supplemental Table 2. Results of the sensitivity analysis were mostly consistent. However, results of the partition models examining the associations of MVPA with average ascent time were attenuated and became statistically null in White and Japanese women (**Supplemental Tables 5-6**).

After adjustment for covariates and other intensity specific estimates, partition models showed that a 10 min increment in MVPA was associated with $\beta = -0.086$ (95% CI: $-0.133, -0.038$) faster 40 foot walk time ($p < 0.001$) (**Table 3**). Isotemporal substitution models estimated that replacing 10 min of sedentary time with an equal amount of MVPA would result in a 0.98% improvement in walk time. Interactions by race/ethnicity were not statistically significant. See **Supplemental Table 3** for single activity models. Excluding women reporting severe or very severe bodily pain yielded consistent results (**Supplemental Tables 7-8**).

As shown in **Table 4**, a 10 min increment in MVPA was associated with a 9% lower odds of mild, moderate, or severe limitations [OR = 0.91 (95% CI: 0.87, 0.96; $p = 0.004$) after full adjustment. The isotemporal substitution models suggested that a replacement of 10 min of sedentary time for MVPA would relate to 11% lower odds of mild, moderate, or severe limitations based on the SPPB. While the interaction between MVPA and race/ethnicity was not statistically significant in either the partition or isotemporal substitution models, the association of MVPA with SPPB was statistically significant in White and Japanese women. Single activity models are presented in **Supplemental Table 4**. In the partition models, when excluding women reporting severe or very severe bodily pain, a 10-minute increment in low and high LPA was associated with a higher odds of any limitations in Hispanic and Japanese women, respectively. Further, in the isotemporal substitution models, a 10-minute replacement of sedentary time for low LPA was associated with a higher odds of limitation (**Supplemental Tables 9-10**).

4. Discussion

This study addressed several research gaps outlined by the 2018 PAG Committee ([U.S. Department of Health and Human Services, 2018](#)) and included four key findings. First, there were statistically significant differences in both the exposures and physical performance outcomes by race/ethnic groups. Second, across all outcomes, MVPA was consistently related to better performance after adjustment for other intensity specific estimates and relevant covariates. Third, consistent with these findings, a 10-minute replacement of time spent sedentary for MVPA was statistically significantly associated with improvements on the stair climb and 40 foot walk and lower odds of limitations. Finally, important race/ethnic differences in the observed associations were noted for the stair climb ascent. Results of the sensitivity analysis excluding participants reporting severe or very severe bodily pain yielded mostly consistent findings; however, a few associations stratified by race/ethnicity either attenuated and became statistically null or statistically significant.

The ability to climb stairs is an important functional attribute that necessitates coordination among multiple anatomical systems ([Gagliano-Jucá et al., 2020](#)). Given the complexities of this task, poorer performance on stair climb tests is thought of as a bellwether of functional decline and mobility disability ([Gagliano-Jucá et al., 2020](#); [Vergheze et al., 2008](#)). Given the cross-sectional data, we can only conclude that higher accumulated MVPA and faster stair climb ascent

times are correlated. However, findings are consistent with a prior SWAN analysis ([Lange-Maia et al., 2019](#)) which found reported PA to be related to better stair climb performance at every time point; however, it did not impact the age-related rate of decline. Future longitudinal studies are needed to formally test these associations, including any influence on rate of decline, using accelerometry.

Timed walk tests over moderate distances, like 40 feet, provide important information on cardiorespiratory endurance. Participants are instructed to “walk at a comfortable, yet brisk pace”, which is equivalent to 3.0 to 3.5 METs ([Ainsworth et al., 2011](#)); depending upon individual effort. This distance and requested level of exertion provides valuable information on a participant’s ability to perform everyday activities such as walking from a parked car to a store front. It also aligns with the threshold value applied to the accelerometer data to estimate MVPA; this threshold was determined in a laboratory-based study where accelerometer data were calibrated against three walking activities ([Evenson et al., 2015](#)). Therefore, the association of higher MVPA with improved performance on the 40 foot walk test, regardless of race/ethnicity, lends support to overall compliance to the prompt to walk at a brisk pace and fidelity of the SWAN 40 foot walk test.

The SPPB is used to evaluate lower extremity function ([Guralnik et al., 1994](#)). Similar to the other physical performance outcomes, findings suggested a beneficial association of MVPA, and not other intensity categories, with a lower odds of mild, moderate or severe limitations. While the results from the multivariable models were shown stratified by race/ethnicity, interactions by race/ethnicity were statistically significant for all other intensity categories except MVPA. Therefore, the findings showing benefit among White and Japanese women should be interpreted with caution. That said, while an older ActiGraph model and different data processing methods were used, these findings compliment a prior study in Project Older People and Active Living (OPAL) ([Davis et al., 2014](#)), which found that accumulated MVPA, and not sedentary time, had the strongest independent association with the SPPB. This was also shown in mid- and late-life men and women enrolled in the Framingham Offspring Study ([Spartano et al., 2019](#)). Unfortunately, these studies only utilized sedentary and MVPA estimates and did not examine associations with LPA.

Regarding the stair climb ascent, isotemporal substitution models suggest that replacement of 10 min of sedentary time with an equal amount of high LPA was associated with a 2.4% improvement in Black women; whereas, in White, Chinese, and Japanese women benefit was only shown with MVPA. This finding has important public health and clinical implications for Black women given they also had the highest sedentary time and the lowest MVPA and supports initially targeting increases in LPA, rather than MVPA, which may resonate more strongly and be more achievable among less active women. While Hispanic women also had low levels of MVPA and the slowest average ascent time, the lack of association was likely due to limited statistical power ($n = 71$). Previous studies have shown racial/ethnic disparities related to physical functioning with Blacks and Hispanics experiencing more dependency in later life than Whites and Asians ([Freedman et al., 2008](#)). A recent SWAN formal mediation analysis ([Sternfeld et al., 2019](#)) found that physical performance differences between Whites and Asian participants were direct effects of race/ethnicity; whereas, in Black and Hispanic women, 75% or more of the disparity was through mediators including socio-economic factors, BMI, pain, and PA. Therefore, PA may have a weaker benefit for physical functioning in Black and Hispanic women given there are other factors that relate to the observed disparities.

Study strengths include the use of the multivariable modeling strategy, including partition models which considers each intensity category adjusted for the others and isotemporal substitution models which estimates the effect of substituting sedentary time with each incrementally higher intensity activity category. This modeling approach addressed important research gaps outlined by the 2018 PAG Committee ([U.S. Department of Health and Human Services., 2018](#)). An

Table 2

Partition and isotemporal substitution models for the association between accelerometer derived physical activity (scaled by 10 min) and average ascent time on stair climb (seconds)¹ in the total cohort and after stratification by race/ethnicity (n = 1048).

		Adjusted ² Model (Total)		Adjusted Model ^{2,3}									
				White		Black		Chinese		Hispanic		Japanese	
		<i>Estimate (95% CI)</i>	<i>p-value</i>	<i>Estimate (95% CI)</i>	<i>p-value</i>	<i>Estimate(95% CI)</i>	<i>p-value</i>	<i>Estimate (95% CI)</i>	<i>p-value</i>	<i>Estimate (95% CI)</i>	<i>p-value</i>	<i>Estimate (95% CI)</i>	<i>p-value</i>
Partition Models													
	Sedentary	0.003 (−0.002,0.01)	0.19	0.002 (−0.01,0.01)	0.64	0.005 (−0.01,0.02)	0.29	0.007 (−0.01,0.02)	0.29	0.006 (−0.02,0.03)	0.57	−0.002 (−0.01,0.01)	0.81
	Low-light	0.002 (−0.01,0.01)	0.96	−0.004 (−0.02,0.01)	0.55	0.019 (−0.004,0.04)	0.10	0.017 (−0.01,0.04)	0.16	−0.043 (−0.09,0.01)	0.10	−0.006 (−0.02,0.01)	0.49
	High-light	−0.009 (−0.03,0.01)	0.25	−0.006 (−0.03,0.01)	0.57	−0.076 (−0.13,−0.02)	0.01	0.002 (−0.04,0.04)	0.92	0.039 (−0.05,0.12)	0.36	0.015 (−0.02,0.05)	0.34
	MVPA	−0.023 (−0.04,−0.005)	0.01	−0.022 (−0.04,−0.0001)	0.043	0.022 (−0.05,0.09)	0.52	−0.049 (−0.09,−0.01)	0.03	−0.064 (−0.20,0.07)	0.35	−0.035 (−0.07,−0.001)	0.04
Isotemporal Substitution Models													
		Adjusted Model (Total) ²		Adjusted Model ^{2,3}									
		<i>Estimate (95% CI)</i>	<i>p-value</i>	White		Black		Chinese		Hispanic		Japanese	
		<i>Estimate (95% CI)</i>	<i>p-value</i>	<i>Estimate (95% CI)</i>	<i>p-value</i>	<i>Estimate (95% CI)</i>	<i>p-value</i>	<i>Estimate (95% CI)</i>	<i>p-value</i>	<i>Estimate (95% CI)</i>	<i>p-value</i>	<i>Estimate (95% CI)</i>	<i>p-value</i>
Replacing Sedentary	Low-light	0.0001 (−0.10,0.01)	0.81	−0.005 (−0.02,0.01)	0.39	0.014 (−0.01,0.04)	0.27	0.011 (−0.01,0.03)	0.37	−0.049 (−0.10,0.001)	0.06	−0.005 (−0.02,0.01)	0.57
	High-light	−0.015 (−0.03,0.01)	0.05	−0.007 (−0.03,0.01)	0.45	−0.082 (−0.13,−0.03)	0.002	0.0004 (−0.04,0.03)	0.81	0.032 (−0.05,0.11)	0.42	0.017 (−0.01,0.05)	0.24
	MVPA	−0.026 (−0.04,−0.01)	<0.001	−0.023 (−0.04,−0.003)	0.03	0.016 (−0.05,0.08)	0.63	−0.056 (−0.10,−0.01)	0.01	−0.070 (−0.21,0.07)	0.31	−0.034 (−0.07,−0.001)	0.05

¹ Stair climb test was not conducted at the Boston SWAN site (included Black and White women).

² Model adjusted for age, site, BMI, overall health, interaction of BMI*overall health, difficulty paying for basics, and ever had osteoarthritis (total cohort and stratified by race/ethnicity).

³ P-values for the interaction between activity type and race/ethnicity group were: sedentary*race/ethnicity = 0.32, low-light*race/ethnicity = 0.004, high-light*race/ethnicity = <0.0001, MVPA*race/ethnicity = 0.0003.

Table 3

Partition and isotemporal substitution models for the association between accelerometer derived physical activity (scaled by 10 min) and average time to complete 40 foot walk (seconds) (n = 934).¹

Adjusted Model ²		
Partition Models		
	<i>Estimate</i>	<i>p-value</i>
Sedentary	0.006 (−0.007, 0.018)	0.353
Low-light	−0.007 (−0.031,0.017)	0.548
High-light	0.019 (−0.025,0.062)	0.399
MVPA	−0.086 (−0.133, −0.038)	0.0004
Adjusted Model²		
Isotemporal Substitution Models		
	<i>Estimate</i>	<i>p-value</i>
<i>Replacing Sedentary</i>		
Low-light	−0.013 (−0.038,0.012)	0.296
High-light	0.013 (−0.028,0.054)	0.543
MVPA	−0.090 (−0.139, −0.044)	0.0002

¹ 40 foot walk test was not conducted at the Los Angeles (only SWAN site including Japanese women) or Newark (only SWAN site including Hispanic women) SWAN sites.

² Model adjusted for age, BMI, site, ethnicity, difficulty paying for basics, and overall health.

additional strength was conducting this study using the racially and ethnically diverse SWAN cohort, which provided the unique opportunity to conduct stratified analyses, when statistically appropriate. Limitations of the study include the cross-sectional design; however, the time-replacement scenarios tested with the isotemporal substitution models are useful for generating new hypotheses that can be tested in future longitudinal studies. Also, SWAN participants excluded from this analysis, primarily due to not be willing to participate in the accelerometer protocol, were older and were more likely to represent race/ethnic minorities, have obesity, be current smokers, and report other conditions associated with the exposures and outcomes (Jensen and Friedmann, 2002; Manini, 2011; Centers for Disease Control and Prevention, 2013). This may have provided inadequate statistical power to detect significant associations; particularly related to associations with sedentary and light intensity estimates that may be more relevant in these subgroups. While this SWAN SPPB scoring strategy reduces the potential for ceiling effects and has good internal study validity, the generalizability of these findings to other studies using traditional scoring methods (Guralnik et al., 1994) is difficult. Also, information on living environments was not ascertained. Finally, while measures of mobility disability are not

Table 4

Partition and isotemporal substitution models for the association between accelerometer derived physical activity (scaled by 10 min) and dichotomous SWAN SPPB score¹, in the total cohort and after stratification by race/ethnicity (n = 1239).²

Adjusted Model (Total) ²			Adjusted Model ^{2,3}				
			White	Black	Chinese	Hispanic	Japanese
Partition Models							
	<i>OR (95% CI)</i>	<i>p value</i>	<i>OR (95% CI)</i>	<i>OR (95% CI)</i>	<i>OR (95% CI)</i>	<i>OR (95% CI)</i>	<i>OR (95% CI)</i>
Sedentary	1.00 (0.98,1.01)	0.61	0.99 (0.97,1.02)	1.00 (0.98,1.03)	0.98 (0.95,1.02)	0.97 (0.90,1.04)	1.02 (0.95,1.09)
Low-light	1.01 (0.98,1.03)	0.21	0.97 (0.94,1.01)	1.05 (0.99,1.11)	1.03 (0.96,1.10)	1.29 (1.03,1.60)	0.97 (0.85,1.09)
High-light	0.99 (0.94,1.03)	0.33	0.99 (0.93,1.06)	0.95 (0.86,1.07)	0.99 (0.88,1.10)	0.78 (0.58,1.06)	1.21 (0.97,1.52)
MVPA	0.91 (0.87,0.96)	0.004	0.91 (0.85,0.98)	1.01 (0.89,1.15)	0.88 (0.77,1.00)	0.95 (0.63,1.43)	0.69 (0.52,0.90)
Isotemporal Substitution Models							
	<i>Adjusted Model (Total)²</i>		<i>Adjusted Model^{2,3}</i>				
			White	Black	Chinese	Hispanic	Japanese
	<i>OR (95% CI)</i>	<i>p value</i>					
<i>Replacing Sedentary</i>							
Low-light	1.04 (0.96,1.12)	0.38	0.98 (0.94,1.02)	1.04 (0.98,1.11)	1.05 (0.97,1.13)	1.33 (1.06,1.67)	0.95 (0.84,1.07)
High-light	0.98 (0.86,1.10)	0.65	1.00 (0.94,1.06)	0.95 (0.86,1.06)	1.01 (0.91,1.12)	0.81 (0.61,1.07)	1.19 (0.97,1.46)
MVPA	0.78 (0.67,0.90)	0.001	0.92 (0.86,0.98)	1.00 (0.88,1.14)	0.89 (0.79,1.02)	0.98 (0.66,1.46)	0.67 (0.51,0.88)

¹ Dichotomous SPPB score was defined as no versus any limitation.

² Model adjusted for age, employment, BMI, site, bodily pain and ever had diabetes (total cohort and stratified by race/ethnicity). Models for Chinese, Hispanic and Japanese women do not adjust for site. Model for Chinese does not adjust for bodily pain, and model for Hispanic does not adjust for bodily pain and employment due to quasi-complete separation of data points.

³ P-values for the interaction between activity type and race/ethnicity group were: sedentary*race/ethnicity = 0.05, low-light*race/ethnicity = 0.005, high-light*race/ethnicity = 0.09, MVPA*race/ethnicity = 0.43.

currently available in SWAN, the physical performance tests used at Visit 15 have been shown to predict mobility (Pahor et al., 2014; Vasunilashorn et al., 2009; Fielding et al., 2011).

5. Conclusion

Findings support the importance of higher intensity PA on physical performance outcomes. Future longitudinal studies, with objective measures, are needed to examine the complex associations between physical (in)activity and physical function/performance by race/ethnicity to provide more targeted recommendations to reduce risk of mobility disability in older women.

Author contributions

K. Pettee Gabriel conceptualized the study and wrote the paper. C. Karvonen-Gutierrez provided critical review of the analysis and manuscript. A. Colvin provided statistical expertise, performed the statistical analysis, and provided critical review of the manuscript. K. Ylitalo provided critical review of the analysis and manuscript. K. Whitaker provided critical review of the analysis and manuscript. B. Lange-Maia provided critical review of the analysis and manuscript. A. Lucas provided critical review of the analysis and manuscript. S. Dugan provided critical review of the analysis and manuscript. C. Derby provided critical review of the analysis and manuscript. J. Cauley provided critical review of the analysis and manuscript. B. Sternfeld conceptualized the study and provided critical review of the analysis and manuscript.

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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

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.pmedr.2021.101408>.

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