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Physical activity trajectories and subsequent fall risk: ARIC Study[☆]

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ABSTRACT

To examine the impact of moderate to vigorous intensity physical activity (MVPA) trajectories during midlife and older adulthood with subsequent fall risk in later life. Cross-temporal analyses were conducted in 15,792 participants (27% black, 55% women) aged 45 to 64 years enrolled in the Atherosclerosis Risk in Communities (ARIC) Study. MVPA was collected at Exams 1 (1987–89), 3 (1993–95) and 5 (2011–13) using the ARIC/Baecke questionnaire. Latent class growth analysis was used to identify the MVPA trajectory groups. Reported falls outcomes were collected in 2013–14, 2015–16, and 2016–17. Generalized Linear Models were used to estimate associations of baseline predictors with trajectory class membership, as well as associations of trajectory classes with any falling (adjusted incident relative risks, aIRR) and with number of falls (adjusted relative rates, aRR). Four primary trajectory classes emerged, reflecting longitudinal patterns of maintained high (48%), maintained low (22%), increasing (14%) and decreasing (15%) MVPA. After adjustment for covariates, the *decreasing* MVPA trajectory group had a 14% higher risk of reporting any falling compared to the *maintained high* MVPA group [aIRR = 1.14 (1.01, 1.28)]. When compared to the *maintained high* MVPA group, the *maintained low* and *decreasing* group had a 28% [aRR = 1.28 (1.14, 1.44)] and 27% [aRR = 1.27 (1.17, 1.38)] higher rate in the reported number of falls, respectively. Findings support public health campaigns targeting habitual MVPA or exercise for fall prevention and suggest that interventions should be initiated in midlife; a time when individuals may be more able and willing to change behavior.

1. Introduction

Substantial evidence has accumulated regarding the numerous health benefits of habitual moderate to vigorous intensity physical activity (MVPA) during leisure-time or exercise, including reducing risk of fall related outcomes in older adulthood (U.S. Department of Health and Human Services, 2018; U.S. Department of Health and Human Services, 2008). Yet, other studies have demonstrated a u-shaped relation between physical activity and fall risk, whereby more active individuals may be at an increased risk due simply to greater exposure time or opportunity to fall when active (Campbell et al., 1989; Chan et al., 2007; Graafmans et al., 2003; Heesch et al., 2008). Regardless, the *2018 Physical Activity Guidelines Advisory Committee* concluded that exercise programs targeting fall prevention were effective among community dwelling older adults in reducing the risk of fall related injuries by 32–40% and bone fractures by 40–66% (U.S. Department of Health and Human Services, 2018; El-Khoury et al., 2013; Gillespie et al., 2012; Zhao et al., 2017). As a result of these supportive findings, several organizations (e.g., American Geriatric Society (Anon, 2011; Anon, 2001)) and public health resources (e.g., Centers for Disease Control and Prevention (CDC) *Compendium of Effective Fall Interventions: What Works For Community Dwelling Older Adults* (U.S. Department of

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Health and Human Services, Centers for Disease Control and Prevention, 2015) and the National Institute on Aging's *Go4Life* public health campaign (U.S. Department of Health and Human Services, National Institute on Aging, 2017)) promote physical activity as a key fall prevention strategy. Yet, several questions regarding the complex association between physical activity and falls remain largely unexplored, including the influence of changes in midlife MVPA on subsequent risk of falls using a life-course framework.

Functional decline and the subsequent risk for disability begin in midlife (U.S. Department of Health and Human Services, 2008). Similar to approaches used to reduce lifetime risk of cardiovascular disease and cancer (Eckel et al., 2013; Anon, 2014), strategies to promote MVPA during midlife could complement exercise programming that primarily targets an older adult population to reduce risk of falls. While the existing evidence base generally supports the beneficial effect of MVPA on risk of falls (U.S. Department of Health and Human Services, 2018; El-Khoury et al., 2013; Gillespie et al., 2012; Zhao et al., 2017), these studies have primarily utilized an older adult population (Campbell and Robertson, 2007), with findings that may be influenced by reverse causality. Therefore, the importance of being physically active in midlife and the cumulative exposure of MVPA from midlife to older adulthood with subsequent risk of falls in later life is largely unknown. Further, midlife may correspond to a time during the life-course when individuals may be more willing and physically able to initiate a regular MVPA routine given changes in life circumstances (e.g., retirement) (Evenson et al., 2002) and the higher burden of disease and disability that is often more characteristic of older adulthood.

With longitudinal physical activity data that characterizes leisure-time MVPA across the midlife to older adulthood transition and the availability of falls data collected in later life, the Atherosclerosis Risk in Communities (ARIC) Study is uniquely positioned to provide novel information regarding the role of life-course changes in MVPA on subsequent risk of falls, rather than physical activity changes that result from an intervention that is being tested within the context of a randomized controlled trial. Therefore, the purpose of this study is to examine the impact of MVPA trajectories during midlife and older adulthood with subsequent fall outcomes in later life, including *any falling* and *number of falls*.

2. Materials and methods

2.1. Design overview and participants

The ARIC Study design and objectives have been described in detail (The ARIC investigators, 1989). Briefly, ARIC included 15,792 adults aged 45 to 64 years at the Visit 1 examination (henceforth: Exam 1 or baseline; 1987–89). Male and female participants were recruited from defined populations in four field centers, including Forsyth County, NC, Jackson, MS (black participants, only), Minneapolis suburbs, MN, and Washington County, MD. Follow-up of the ARIC cohort is on-going and includes cohort exam visits and annual or semi-annual telephone calls. For this analysis, participants include those who completed Exam 1 (1987–89) and follow-up telephone surveys in 2013–14, 2015–16, and 2016–17 which included questions on falls. Information for MVPA trajectories was available from Exam 1 (1987–1989), Exam 3 (1993–95), and Exam 5 (2011–13). All ARIC participants provide informed consent and institutional review boards at each participating field center have approved the study.

2.2. Data collection

2.2.1. Participant characteristics and anthropometric measures

Standardized questionnaires were used at Exam 1 to assess participant characteristics including: age, socio-demographic factors (e.g., educational attainment), health behaviors (e.g., physical activity, sedentary behavior, smoking status, and television viewing), self-rated health, and prevalent chronic disease. In addition, height (stadiometer) and weight (balance-beam scale) were measured with the participant lightly clothed and without shoes (Cutter et al., 1991). Body mass index (BMI) was calculated as weight (kg) divided by height squared (m^2). Prevalent chronic disease included type 2 diabetes (fasting glucose ≥ 126 md/dL, non-fasting glucose ≥ 200, use of diabetes medication or self-report physician diagnosis), hypertension [mean of the second and third measurements (of three): systolic ≥ 140 mm Hg and/or diastolic ≥ 90 mm Hg or use of anti-hypertensive medications], and cardiovascular diseases (self-report physician diagnosis). Exam 1 measures were included in multivariable models as covariates given our study objective to predict subsequent risk of falls in later life; a strategy that reduces the biases associated with non-response and reverse causation that can be limitations of the prospective cohort study design.

2.2.2. Exposure: moderate to vigorous intensity physical activity

A modified version of the Baecke Questionnaire was used to assess past year physical activity in ARIC (Richardson et al., 1995; Baecke et al., 1982). The ARIC version of the Baecke consists of the following three components: sports and exercise, leisure, and work. For these analyses, items from the sports and exercise index were used to derive the trajectory classes, which provides quantitative information related to higher intensity, structured physical activity during discretionary periods of the day (i.e., leisure-time domain). This type of physical activity is also reflective of behavioral targets included in fall prevention exercise programs or interventions (U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, 2015). Briefly, participants were asked to report up to four sport or exercise activities performed most frequently. For each sport reported, additional information on the duration and frequency (hours per week and months per year) were recorded via response categories. While the sports and exercise component is traditionally reported as an index score, ranging from 1 (low active) to 5 (high active), for this analysis, data were re-scored by taking the product of the duration and frequency weighted by the metabolic equivalent of task (MET) (Ainsworth et al., 2011) that corresponds to each of the reported activity types. These activity specific estimates in MET·min·wk^{-1} were then summed across all reported activity types to derive the final MVPA summary score (also expressed as MET·min·wk^{-1}) (Ainsworth et al., 2011). MVPA trajectory classes from midlife to older adulthood were estimated using the sports and exercise summary scores from Exams 1, 3, and 5.

2.2.3. Outcome: falls

Information on falls was collected during three follow-up telephone calls (2013–14, 2015–16, and 2016–17) used for ongoing surveillance of the cohort. A fall was defined as unintentionally coming to rest on the ground, floor, or other level lower than one's starting point (Campbell et al., 1989; Lamb et al., 2005; Tinetti and Williams, 1998). Participants were asked whether they experienced a fall (yes/no) in the previous six months (2013–14) or twelve months (2015–16 and 2016–17) and, if so, reported the total number of falls (up to six or more). The falls questions were included for the first time in the semi-annual follow-up call and utilized a six month recall time frame. This was revised to a twelve month recall time frame in subsequent administrations to be consistent with the question structure used in the Behavioral Risk Factor Surveillance System to facilitate comparability with a nationally representative sample of U.S. adults. A binary "*any falling*" outcome was assigned the value of 1 to participants who report falling in any of the three falls survey cycles, otherwise it was assigned 0. The "*number of falls*" outcome was calculated by taking the sum of the number of falls across all three survey cycles. Dates of falls were not available so averaged person-time accounting methods were used to incorporate differential fall times. Participants reporting no falls throughout the study period provided the full 6 + 12 + 12 = 30 person-months of observation. Participants who fell were assigned person-months based on the midpoint of the closest recall timeframe. As an example, a participant reporting their first fall on the 2016 (third) survey was assigned 6 + 12 + (12/2) = 24 person-months of observation time. This approach averages out unknown differential fall times within the observation intervals.

2.3. Statistical analysis

Descriptive statistics included frequency distributions, measures of central tendency (mean) and measures of variability [standard deviation (SD)]. Baseline characteristic comparisons over MVPA trajectory classes used analysis of variance (ANOVA) F-tests and Chi-square tests for continuous and categorical variables respectively. MVPA estimates (MET·min·wk^{-1}) were skewed and log (base 2) transforms were used to derive the MVPA trajectory classes.

Latent class growth analysis was used to identify major trajectory classes of MVPA and model selection used Bayesian Information Criteria goodness of fit statistics and prior literature (Pettee Gabriel et al., 2017). Under a missing at random assumption, latent growth models are able to estimate MVPA trajectory classes for all participants regardless of whether data were missing, which generally decreases bias when compared to a complete-case analyses. After the MVPA trajectory classes were determined, participants were assigned to the trajectory class reflecting their highest posterior probability (Andruff et al., 2009). Multinomial logistic models were used to examine adjusted relative risk ratio (aRRR) associations of predictors with the assigned trajectory classes. Generalized Linear Models using log-links, Poisson distributions and log(months) offset terms to account for differential recall assessment times were used to estimate adjusted incident relative risk (aIRR) associations of MVPA trajectory class with *any falling*, and adjusted rate ratio (aRR) associations with the *number of falls*. All models were adjusted for baseline values of age, sex, race-site, education, income, self-rated health, BMI, smoking, television viewing, diabetes, hypertension and prevalent cardiovascular disease. Television viewing was included as a covariate given it has been shown to be an acceptable proxy measure for sedentary behavior and is related to a variety of non-communicable disease outcomes (Pettee et al., 2009). Further, under the 24-hour activity cycle framework (Rosenberger et al., 2018), physical activity and sedentary behaviors are inter-related behaviors that characterize waking time (i.e., time spent sedentary offsets active time). Sensitivity analyses to missing data were conducted by examining similar models using only the participant base who contributed physical activity data at all three exam visits. Additional sensitivity analyses to missing data were conducted using an inverse proportional weighting approach. All statistical analyses were conducted in STATA v. 15 (StataCorp, LLC., College Station, TX).

3. Results

Four major MVPA trajectory classes were identified in ARIC participants with patterns reflecting: (1) *maintained low* (22%), (2) *increasing* (14%), (3) *decreasing* (15%), and (4) *maintained high* (48%) MVPA (Fig. 1). Differences in baseline characteristics by MVPA trajectory group were all statistically significant (all comparisons $p < 0.001$; Table 1). In general, men, whites, and those with a college education were more likely to be assigned to the *maintained high* MVPA trajectory group. Table 2 provides additional context on associations of sociodemographic, health status, and behavioral characteristics with MVPA trajectory groups. For example, men were approximately 40% less likely to be characterized as *maintained low* MVPA versus *maintained high* MVPA group compared to women [aRRR = 0.60 (0.48, 0.73)]. Jackson participants were almost twice as likely to be in the *maintained low* MVPA group when compared with Washington County participants [aRRR = 1.79 (1.36, 2.37)]. Similarly, participants were over three times as likely to be in the *maintained low* MVPA group versus the *maintained high* group if they had less than high school education versus college and above [aRRR = 3.47 (2.54, 4.74)], or income less than

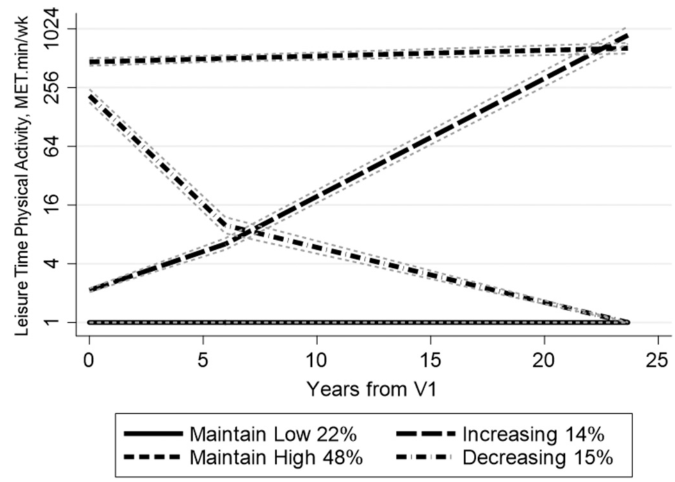

Fig. 1. Latent class moderate to vigorous intensity physical activity trajectory classes identified in ARIC, using reported data from the ARIC/Baecke, a self-administered reliable and valid self-report recall questionnaire (n = 15,792) (Richardson et al., 1995). A MET·min·wk^{-1} value of 450 is reflective of meeting aerobic physical activity guidelines (walking or lower threshold of moderate intensity physical activity = 3 METs ∗ 150 min·wk^{-1}).

\$25,000 versus income ≥\$50,000 [aRRR = 1.45 (1.06, 2.00)], or fair/poor self-rated health versus excellent health [aRRR = 1.82 (1.30, 2.55)], or obese versus underweight/normal [aRRR = 2.16 (1.66, 2.81)], or a smoker versus non-smoker [aRRR = 1.92 (1.52, 2.43)], or had prevalent versus no type 2 diabetes [aRRR = 1.61 (1.11, 2.33)].

Table 3 shows the adjusted associations of MVPA trajectory groups with fall outcomes, including *any falling* (yes versus no) and *number of falls*. For the *any falling* outcome, the *decreasing* MVPA trajectory group had a 14% higher risk of any falling compared to the *maintained high* physical activity group [aIRR = 1.14 (1.01, 1.28)]. For the *number of falls* outcome, when compared to the *maintained high* MVPA group (42 falls per 100 persons per year), the *maintained low* MVPA group had a 28% higher rate of falls [52 falls per 100 persons per year, aRR = 1.28 (1.14, 1.44)] and the *decreasing* group had a 27% increased rate of falls [57 falls per 100 persons per year, aRR = 1.27 (1.17, 1.38)]. Sensitivity analyses using both conditioning on the sample of ARIC participants with reported MVPA data at all three time-points (Supplemental Tables 1–3) and inverse-proportional weighting (Supplemental Table 4) showed similar associations as our main analyses and did not change overall interpretations.

4. Discussion

In the current study, four distinct patterns of MVPA change emerged during midlife in a well-characterized and diverse sample of black and white men and women. Further, the majority of participants (70%) were assigned to a trajectory group that reflected patterns of MVPA maintenance across midlife, with the highest proportion of participants (48%) assigned to the *maintained high* group. When compared to the *maintained high* MVPA group, participant characteristics reflecting membership in the *maintained low* group largely mirrored factors shown in other studies to be related to inadequate MVPA levels (Bauman et al., 2012; U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, 2013). Finally, study findings suggest that when compared to a trajectory pattern supporting maintenance of high MVPA from midlife to older adulthood: 1) decreasing MVPA across midlife increases risk of *any fall* and 2) decreasing and maintaining low MVPA across midlife were susceptible to an increased rate in the *number of falls* during later life. Thus, we are unable to confirm findings from previous studies that demonstrated a u-shaped relation of physical activity and falls (Campbell et al., 1989; Chan et al., 2007; Graafmans

Table 1
Characteristics of Atherosclerosis Risk in Communities (ARIC) Study participants at Visit 1 by moderate to vigorous intensity physical activity (MVPA) trajectory class (n = 15,792).

Variable		Overall	Maintain low MVPA	Increasing MVPA	Decreasing MVPA	Maintain high MVPA	p-Value[a]
		n = 15,792	n = 3496 (22%)	n = 2243 (14%)	n = 2399 (15%)	n = 7654 (48%)	
Age	Mean (SD)	54.16 (5.76)	54.43 (5.71)	53.45 (5.66)	54.11 (5.66)	54.27 (5.83)	< 0.001
Sex	Female	8710 (55%)	2061 (59%)	1302 (58%)	1463 (61%)	3884 (51%)	< 0.001
	Male	7082 (45%)	1435 (41%)	941 (42%)	936 (39%)	3770 (49%)	
Race	Black	4266 (27%)	1587 (45%)	729 (33%)	550 (23%)	1400 (18%)	< 0.001
	White	11,478 (73%)	1904 (55%)	1505 (67%)	1846 (77%)	6223 (82%)	
Field center	Forsyth County, NC	4035 (26%)	720 (21%)	536 (24%)	556 (23%)	2223 (29%)	< 0.001
	Jackson, MS	3728 (24%)	1459 (42%)	664 (30%)	475 (20%)	1130 (15%)	
	Minneapolis suburbs, MN	4009 (25%)	479 (14%)	489 (22%)	511 (21%)	2530 (33%)	
	Washington County, MD	4020 (25%)	838 (24%)	554 (25%)	857 (36%)	1771 (23%)	
Education	< High school	3767 (24%)	1440 (41%)	534 (24%)	556 (23%)	1237 (16%)	< 0.001
	High school	6412 (41%)	1339 (38%)	975 (44%)	1086 (45%)	3012 (39%)	
	College and above	5586 (35%)	712 (20%)	728 (33%)	754 (31%)	3392 (44%)	
Income	< $25,000	5683 (38%)	1868 (58%)	835 (40%)	882 (39%)	2098 (29%)	< 0.001
	$25,000–$49,999	5524 (37%)	983 (30%)	829 (39%)	918 (40%)	2794 (39%)	
	≥ $50,000	3658 (25%)	397 (12%)	439 (21%)	468 (21%)	2354 (32%)	
Self-rated health	Excellent	5246 (33%)	668 (19%)	689 (31%)	787 (33%)	3102 (41%)	< 0.001
	Good	7368 (47%)	1584 (45%)	1122 (50%)	1166 (49%)	3496 (46%)	
	Fair/poor	3170 (20%)	1241 (36%)	432 (19%)	445 (19%)	1052 (14%)	
Body mass index (BMI) category	Underweight/normal	5213 (33%)	956 (27%)	655 (29%)	699 (29%)	2903 (38%)	< 0.001
	Overweight	6206 (39%)	1208 (35%)	927 (41%)	951 (40%)	3120 (41%)	
	Obese	4348 (28%)	1323 (38%)	661 (29%)	745 (31%)	1619 (21%)	
Current smoker	No	11,644 (74%)	2173 (62%)	1682 (75%)	1829 (76%)	5960 (78%)	< 0.001
	Yes	4132 (26%)	1318 (38%)	559 (25%)	567 (24%)	1688 (22%)	
Television viewing	Never	140 (2%)	10 (2%)	21 (2%)	41 (3%)	68 (2%)	< 0.001
	Seldom/sometimes	2889 (48%)	235 (36%)	544 (47%)	541 (43%)	1569 (53%)	
	Often/very often	3003 (50%)	399 (62%)	594 (51%)	679 (54%)	1331 (45%)	
Race-site	Washington white	3975 (25%)	835 (24%)	539 (24%)	849 (36%)	1752 (23%)	< 0.001
	Minnesota white	3972 (25%)	474 (14%)	485 (22%)	508 (21%)	2505 (33%)	
	Forsyth white	3531 (23%)	595 (17%)	481 (22%)	489 (20%)	1966 (26%)	
	Forsyth black	483 (3%)	123 (4%)	52 (2%)	67 (3%)	241 (3%)	
	Jackson black	3728 (24%)	1459 (42%)	664 (30%)	475 (20%)	1130 (15%)	
Prevalent type 2 diabetes	No	13,774 (88%)	2803 (82%)	1987 (89%)	2137 (90%)	6847 (90%)	< 0.001
	Yes	1870 (12%)	632 (18%)	234 (11%)	247 (10%)	757 (10%)	
Prevalent hypertension	No	10,208 (65%)	1848 (53%)	1479 (66%)	1524 (64%)	5357 (70%)	< 0.001
	Yes	5504 (35%)	1627 (47%)	750 (34%)	864 (36%)	2263 (30%)	
Prevalent cardiovascular disease[b]	No	14,682 (95%)	3220 (94%)	2136 (98%)	2233 (95%)	7093 (94%)	< 0.001
	Yes	766 (5%)	191 (6%)	52 (2%)	106 (5%)	417 (6%)	

[a] p values representing differences in Visit 1 characteristics by moderate to vigorous intensity physical activity trajectory groups were obtained via analysis of variance (ANOVA) or Chi-square tests.
[b] CVD = cardiovascular disease.

et al., 2003; Heesch et al., 2008). Yet, study findings complement results of prior randomized controlled trials, but provide novel information on the influence of life-course changes in MVPA on subsequent fall risk within a naturalistic setting.

Falls are the leading cause of injury and death from injury in older adults (Bergen et al., 2016). Based on 2014 CDC Behavioral Risk Factor Surveillance System data, 28.7% of U.S. older adults reported an estimated 29.0 million falls in the past 12 months (Bergen et al., 2016). Using multiple data sources, Burns et al. reported that the direct costs for fatal and non-fatal falls in the U.S. were $616.5 million and $31.3 billion, respectively (Burns et al., 2016). With the aging Baby Boomer generation, it is expected that the U.S. older adult population will increase by 55% in 2030, which means that more individuals will be susceptible to falls than ever before. This *Silver Tsunami* is projected to result in an estimated 48.8 million falls and 11.9 million injurious falls (Bergen et al., 2016). Therefore, it is of critical importance to continue to identify effective fall prevention strategies to minimize the impact of the *Silver Tsunami*.

Indeed, there is a strong body of literature that has identified a variety of intervention targets to reduce the risk of falls among older adults. For example, the CDC published the third edition of the *CDC Compendium of Effective Fall Interventions: What Works For Community Dwelling Older Adults* (U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, 2015) in 2015, which details specific interventions that have been shown to be effective for fall prevention, including those focused specifically on habitual physical activity. Yet, these evidence-based intervention strategies exclusively target older adults. Findings from the current study suggest that physical activity during midlife may also reduce the risk falls in older adulthood and supports the implementation of fall prevention strategies during midlife to optimize successful aging and reduce risk of falls (Rowe and Kahn, 1997). Regarding the outcome of *any fall*, participants demonstrating a pattern of *decreasing* MVPA overtime had a statistically significantly higher risk of falls in later life. This suggests that exercise participation closest in time to the outcome confers benefit in relation to *any fall*, which is a notion supported by the underlying biological plausibility including maintenance of optimal physical functioning (Nelson et al., 2007; Laurin et al., 2001; Haskell et al., 2007) and overall resilience (i.e., the ability to “bounce back” or recover from a fall) (MacLeod et al., 2016).

With no differences observed in any fall between the *maintained low* and *maintained high* MVPA groups, study findings also support the premise that fall risk can also decrease as a result of physical activity restriction due to mobility limitations and/or a fear of falling (Jefferis et al., 2014; Jefferis et al., 2015). However, regarding the *number of falls* outcome, the *maintained low* MVPA group had a 28% higher rate in the number of falls (an additional 10 reported falls per 100 person years) when compared to the *maintained high* MVPA group; an observed rate

Table 2
Adjusted multinomial logistic regression models examining the adjusted relative risk ratios (aRRR)[b] of sociodemographic, health status, and behavioral characteristics with moderate to vigorous intensity physical activity (MVPA) trajectories, compared to the maintained high PA trajectory group.[a]

Variable		Multivariable models (aRRR)[b]			
		Maintain low MVPA	Increasing MVPA	Decreasing MVPA	Maintain high MVPA
		n = 3496 (22%)	n = 2243 (14%)	n = 2399 (15%)	n = 7654 (48%)
Age	Mean (SD)	0.98 (0.96, 1.00)	0.99 (0.97, 1.00)	1.04 (1.02, 1.05)	-ref-
Sex	Female	-ref-	-ref-	-ref-	-ref-
	Male	0.60 (0.48, 0.73)	0.80 (0.68, 0.94)	0.59 (0.50, 0.69)	-ref-
Race-site	Washington white	-ref-	-ref-	-ref-	-ref-
	Minnesota white	0.42 (0.31, 0.56)	0.91 (0.74, 1.13)	0.39 (0.32, 0.47)	-ref-
	Forsyth white	0.46 (0.33, 0.64)	1.32 (1.05, 1.66)	0.40 (0.32, 0.50)	-ref-
	Forsyth black	0.57 (0.26, 1.23)	1.18 (0.67, 2.07)	0.32 (0.17, 0.62)	-ref-
	Jackson black	1.79 (1.36, 2.37)	2.05 (1.60, 2.62)	0.63 (0.50, 0.80)	-ref-
Education	College and above	-ref-	-ref-	-ref-	-ref-
	High school	1.97 (1.56, 2.50)	1.38 (1.17, 1.63)	1.35 (1.14, 1.59)	-ref-
	< High school	3.47 (2.54, 4.74)	1.84 (1.41, 2.40)	1.65 (1.28, 2.13)	-ref-
Income	≥ $50,000	-ref-	-ref-	-ref-	-ref-
	$25,000–$49,999	1.26 (0.97, 1.64)	1.50 (1.25, 1.80)	1.30 (1.09, 1.56)	-ref-
	< $25,000	1.46 (1.06, 2.00)	1.71 (1.35, 2.18)	1.60 (1.27, 2.01)	-ref-
Self-rated health	Excellent	-ref-	-ref-	-ref-	-ref-
	Good	1.40 (1.12, 1.75)	1.51 (1.28, 1.78)	1.29 (1.10, 1.51)	-ref-
	Fair/poor	1.82 (1.30, 2.55)	1.65 (1.23, 2.21)	1.67 (1.26, 2.21)	-ref-
BMI category	Underweight/normal	-ref-	-ref-	-ref-	-ref-
	Overweight	1.09 (0.86, 1.39)	1.14 (0.95, 1.36)	1.32 (1.11, 1.57)	-ref-
	Obese	2.16 (1.66, 2.81)	1.67 (1.35, 2.07)	2.34 (1.90, 2.87)	-ref-
Current smoker	No	-ref-	-ref-	-ref-	-ref-
	Yes	1.92 (1.52, 2.43)	1.36 (1.12, 1.65)	1.48 (1.21, 1.80)	-ref-
Television viewing	Never	-ref-	-ref-	-ref-	-ref-
	Seldom/sometimes	1.22 (0.53, 2.77)	1.01 (0.59, 1.72)	0.58 (0.37, 0.90)	-ref-
	Often/very often	1.91 (0.84, 4.34)	1.11 (0.65, 1.89)	0.76 (0.49, 1.18)	-ref-
Prevalent type 2 diabetes	No	-ref-	-ref-	-ref-	-ref-
	Yes	1.61 (1.11, 2.33)	0.72 (0.49, 1.05)	1.20 (0.87, 1.65)	-ref-
Prevalent hypertension	No	-ref-	-ref-	-ref-	-ref-
	Yes	1.18 (0.94, 1.49)	1.10 (0.91, 1.33)	1.16 (0.97, 1.39)	-ref-
Prevalent cardiovascular disease	No	-ref-	-ref-	-ref-	-ref-
	Yes	1.25 (0.63, 2.46)	0.69 (0.37, 1.31)	1.18 (0.70, 1.96)	-ref-

[a] Moderate to vigorous intensity physical activity trajectory group assignment based on Visit 1 population (n = 15,792).
[b] Adjusted for all other variables.

that was similar among the *decreasing* MVPA group. Yet, findings suggested no differences in either fall outcome in the *increasing* group compared to *maintained high* MVPA group, which supports the notion that it is never too late in life to become physically active or begin an exercise program. This important finding further supports the inclusion of midlife adults in health promotion efforts targeting physical activity initiation and maintenance for fall prevention.

Study strengths include use of the well-characterized ARIC cohort, including representation of black and white men and women. This provided the unique opportunity to examine the role of MVPA during the midlife to older adult transition as a possible fall prevention strategy in older adulthood, which has not been explored widely in the literature due to the limited number of studies with sufficient follow-up to characterize important adult life-course transitions. Despite these strengths, there are limitations to consider including the use of reported physical activity data, which may be prone to recall bias (Troiano et al., 2012). Further, physical activity data from three time-points were used to construct the trajectories. Additional time-points may have resulted in greater refinement of the various trajectory classes. For example, in the Study of Women's Health Across the Nation (SWAN) cohort, five physical activity trajectories (also utilizing reported participation in sports and exercise or MVPA) emerged including three patterns of maintenance [*low* (26.2%), *middle* (23.9%), and *high* (14.1%)] and *increasing* (13.4%) and *decreasing* (22.4%) physical activity based on data

Table 3
Multivariable models[a] examining the adjusted incidence relative risk (aIRR) and rate ratio (aRR) of moderate to vigorous intensity physical activity (MVPA) trajectory group with any falling and number of falls outcomes, respectively.[b]

PA trajectory group	Any falling		Number of falls	
	Obs %/yr[c]	aIRR (95% CI)	Obs #/100 p/yr[d]	aRR (95% CI)
Maintain high MVPA	20.00%	-ref-	42	-ref-
Maintain low MVPA	21.73%	1.06 (0.89, 1.26)	52	1.28 (1.14, 1.44)
Increasing MVPA	18.81%	0.98 (0.86, 1.12)	37	0.94 (0.86, 1.04)
Decreasing MVPA	24.65%	1.14 (1.01, 1.28)	57	1.27 (1.17, 1.38)

[a] Models adjusted for age, sex, race-site, education, income, self-rated health, body mass index (BMI) category, current smoking status, reported TV viewing, type 2 diabetes mellitus, hypertension, and prevalent coronary heart disease (CHD).
[b] Moderate to vigorous intensity physical activity trajectory group assignment based on Visit 1 population (n = 15,792).
[c] Observed %/year (Obs %/yr) was calculated by dividing the total number of fallers by the total observed person years.
[d] Observed #/100 persons/year (Obs #/100 p/yr) was calculated by dividing the total number of falls by the total observed person years, respectively.

collected over ≥3 of 7 available time points (Pettee Gabriel et al., 2017). Also, the date of reported falls was not collected, which makes it challenging to report the average follow-up period with any precision. Therefore, the observed measures of association should be interpreted with caution given that averaged person-time accounting methods were used to incorporate differential fall times. However, physical activity data collection did precede the falls measures. Further, as previously mentioned, the recall time frame for falls ascertainment changed from six to twelve months after the first administration, which was done to optimize comparability with the Behavioral Risk Factor Surveillance System falls questions. Importantly, a six and twelve month recall time frame are relatively long periods and may have led to inaccuracies in the reporting of falls, and these biases may vary by recall time frame. Yet, a fall event, particularly if an injury was sustained, is likely more salient and easily recalled and reported than more habitual behaviors or events. Finally, several factors that have been shown to be associated with fall risk (Rubenstein, 2006), including depression, cognitive and physical functioning were not assessed in ARIC at Exam 1 and; therefore, not included in these analyses. However, given that these factors are also associated with low or declining MVPA levels (U.S. Department of Health and Human Services, 2018), their influence was likely characterized by MVPA trajectory exposure group assignment.

5. Conclusions

The principal findings from the current study suggest that promoting habitual MVPA during midlife, in addition to older adulthood, may be an effective intervention strategy to reduce subsequent risk of falls in older adulthood. Without additional fall prevention strategies, a *Silver Tsunami* is projected which will cause significant health and financial burden to the U.S. health care system. Future studies should examine the effectiveness of activity types across the intensity spectrum that are both effective in reducing late life falls and acceptable to a variety of populations across the lifespan, including the potential health benefits of light intensity physical activity.

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Conflict of interest

The authors have no conflicts of interest.

Disclosures

None.

Author contributions

Study concept and design (KPG, MEG, LAP), acquisition of subjects and/or data (KPG, LAP, BGW), analysis (MEG, WW) and interpretation of data (KPG, SHC, BGW, PP, AKN, LAP), and preparation of manuscript (KPG, MEG, WW, SHC, BGW, PP, AKN, LAP).

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ypmed.2019.02.007.

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