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Accelerometer-Derived "Weekend Warrior" Physical Activity and Incident Cardiovascular Disease

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IMPORTANCE Guidelines recommend 150 minutes or more of moderate to vigorous physical activity (MVPA) per week for overall health benefit, but the relative effects of concentrated vs more evenly distributed activity are unclear.

OBJECTIVE To examine associations between an accelerometer-derived "weekend warrior" pattern (ie, most MVPA achieved over 1-2 days) vs MVPA spread more evenly with risk of incident cardiovascular events.

DESIGN, SETTING, AND PARTICIPANTS Retrospective analysis of UK Biobank cohort study participants providing a full week of accelerometer-based physical activity data between June 8, 2013, and December 30, 2015.

EXPOSURES Three MVPA patterns were compared: active weekend warrior (active WW, ≥150 minutes with ≥50% of total MVPA achieved in 1-2 days), active regular (≥150 minutes and not meeting active WW status), and inactive (<150 minutes). The same patterns were assessed using the sample median threshold of 230.4 minutes or more of MVPA per week.

MAIN OUTCOMES AND MEASURES Associations between activity pattern and incident atrial fibrillation, myocardial infarction, heart failure, and stroke were assessed using Cox proportional hazards regression, adjusted for age, sex, racial and ethnic background, tobacco use, alcohol intake, Townsend Deprivation Index, employment status, self-reported health, and diet quality.

RESULTS A total of 89 573 individuals (mean [SD] age, 62 [7.8] years; 56% women) who underwent accelerometry were included. When stratified at the threshold of 150 minutes or more of MVPA per week, a total of 37 872 were in the active WW group (42.2%), 21 473 were in the active regular group (24.0%), and 30 228 were in the inactive group (33.7%). In multivariable-adjusted models, both activity patterns were associated with similarly lower risks of incident atrial fibrillation (active WW: hazard ratio [HR], 0.78 [95% CI, 0.74-0.83]; active regular: 0.81 [95% CI, 0.74-0.88; inactive: HR, 1.00 [95% CI, 0.94-1.07]), myocardial infarction (active WW: 0.73 [95% CI, 0.67-0.80]; active regular: 0.65 [95% CI, 0.57-0.74]; and inactive: 1.00 [95% CI, 0.91-1.10]), heart failure (active WW: 0.62 [95% CI, 0.56-0.68]; active regular: 0.64 [95% CI, 0.56-0.73]; and inactive: 1.00 [95% CI, 0.92-1.09]), and stroke (active WW: 0.79 [95% CI, 0.71-0.88]; active regular: 0.83 [95% CI, 0.72-0.97]; and inactive: 1.00 [95% CI, 0.90-1.11]). Findings were consistent at the median threshold of 230.4 minutes or more of MVPA per week, although associations with stroke were no longer significant (active WW: 0.89 [95% CI, 0.79-1.02]; active regular: 0.87 [95% CI, 0.74-1.02]; and inactive: 1.00 [95% CI, 0.90-1.11]).

CONCLUSIONS AND RELEVANCE Physical activity concentrated within 1 to 2 days was associated with similarly lower risk of cardiovascular outcomes to more evenly distributed activity.

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Supplemental content

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Physical activity is regarded as favorable for health and is consistently associated with lower risks of death and cardiovascular disease.[1] World Health Organization and American Heart Association guidelines recommend 150 minutes or more of moderate to vigorous physical activity (MVPA) per week, without specifying an optimal MVPA pattern.[1,2] The UK National Health Service recommends MVPA be spread "evenly over 4-5 days per week, or every day."[3] However, it remains unclear whether MVPA concentrated within 1 to 2 days per week ("weekend warrior" pattern[4]) confers similar benefits compared with more evenly distributed activity. Prior studies were limited by self-reported activity,[4] modest sample sizes,[5] and a limited set of outcomes (eg, mortality).[4,5]

Here, associations between physical activity patterns, defined using wrist-based accelerometers, and incident cardiovascular events were assessed among nearly 90 000 participants of the UK Biobank prospective cohort study.

Key Points

Question Does engagement in moderate to vigorous physical activity, with most activity concentrated within 1 to 2 days of the week (ie, a "weekend warrior" pattern), confer similar cardiovascular benefits to more evenly distributed physical activity?

Findings In an analysis of 89 573 individuals providing a week of accelerometer-based physical activity data, a weekend warrior pattern of physical activity was associated with similarly lower risks of incident atrial fibrillation, myocardial infarction, heart failure, and stroke compared with more evenly distributed physical activity.

Meaning Increased activity, even when concentrated within 1 to 2 days each week, may be effective for improving cardiovascular risk profiles.

Methods

The UK Biobank is a prospective cohort of 502 629 participants enrolled between 2006 and 2010.[6] Briefly, 9.2 million individuals aged 40 to 69 years living within 25 miles of 22 assessment centers in the UK were invited, and 5.4% participated in the baseline assessment (**Table**). Information on race and ethnicity were included given prior associations with physical activity and cardiovascular events and was determined by self-report based on fixed categories.

Within the accelerometer substudy, 103 695 participants submitted data from an Axivity AX3 wrist-based triaxial accelerometer worn for 1 week.[7] The sensor captured continuous acceleration at 100 Hz with dynamic range ±8*g*. As described previously, acceleration signals were calibrated to gravity.[7] Sample data were combined into 5-second epochs, each representing mean vector magnitude. Nonwear time was identified as consecutive stationary episodes of 60 minutes or more in which all 3 axes had an SD less than 13.0 mg.[7] Epochs representing non-wear time were imputed based on the mean of similar time-of-day vector magnitude and intensity distribution data points on different days. We excluded individuals whose wear time was insufficient to support imputation (no wear data in each 1-hour period of the 24-hour cycle), whose signals were insufficient for calibration or MVPA estimation, and whose mean acceleration values were nonphysiologic (eFigure 1 in Supplement 1).[8]

MVPA was then classified using a published machine-learning-based method developed to classify a broad range of activities (eg, walking, jogging, stationary cycling, elliptical, and others) and validated in a UK-based sample.[8] Because optimal MVPA levels using wrist-based accelerometers are unclear,[9] we assessed multiple thresholds. For our primary analyses, we assessed the guideline-based threshold (≥150 minutes/week[1-3]) and the sample median (≥230.4 minutes) based on UK national health surveys reporting approximately half of individuals are physically active.[10] We tested additional thresholds in secondary analyses. Individuals were classified as active weekend warrior (active WW, at or above the MVPA threshold and ≥50% of total MVPA over 1-2 days[4]), active regular (at or above MVPA threshold but not active WW), and inactive (below MVPA threshold).

We assessed associations between activity pattern and incident atrial fibrillation (AF), myocardial infarction (MI), heart failure (HF), and stroke using Cox proportional hazards models adjusted for age, sex, racial and ethnic background, tobacco use, Townsend Deprivation Index, alcohol intake, educational attainment, employment status, self-reported health, and diet quality. We used a complete case analysis (eFigure 1 in Supplement 1). To compare activity patterns without thresholding, we fit analogous models comparing active WW vs regular patterns with MVPA decile as a stratification variable. Exposure and outcome definitions are described in eTables 1 and 2 in Supplement 1. We plotted the Kaplan-Meier cumulative incidence of each outcome stratified by activity pattern and calculated E-values. We performed multiple secondary analyses (eMethods in Supplement 1).

Participants provided written informed consent. The UK Biobank was approved by the UK Biobank Research Ethics Committee (reference No. 11/NW/0382). UK Biobank data were used under application 17488. Analyses were performed using R version 4.0.[11] Hazard ratios and 95% CIs are presented using floating absolute risks.[12]

Results

Our analyses included 89 573 individuals who underwent activity measurement between June 8, 2013, and December 30, 2015 (Table; eTables 3 and 4 and eFigure 1 in Supplement 1). The median follow-up time was 6.3 years (quartile 1: 5.7, quartile 3: 6.8). Stratified at the guideline-based threshold of 150 minutes or more of MVPA per week, a total of 37 872 participants were in the active WW group (42.2%), 21 473 were in the active regular group (24.0%), and 30 228

Table. Sample Characteristics of Participants in an Accelerometer-Derived Physical Activity Study

Baseline characteristic	No. (%)		
	Active WW (n = 37 872)[a]	Active regular (n = 21 473)[a]	Inactive (n = 30 228)[a]
Age, mean (SD), y	62.2 (7.7)	61.2 (7.9)	63.3 (7.9)
Sex			
Female	19 325 (51.0)	10 964 (51.1)	20 180 (66.8)
Male	18 547 (49.0)	10 509 (48.9)	10 048 (33.2)
Race and ethnicity[b]			
Asian	353 (0.9)	261 (1.2)	411 (1.4)
Black	247 (0.7)	177 (0.8)	305 (1.0)
Multiracial or multiethnic	181 (0.5)	135 (0.6)	171 (0.6)
White	36 909 (97.5)	20 750 (96.6)	29 210 (96.6)
Other	182 (0.5)	150 (0.7)	131 (0.4)
Tobacco use			
Never	22 388 (59.1)	12 408 (57.8)	16 613 (55.0)
Former	13 416 (35.4)	7754 (36.1)	11 031 (36.5)
Current	2068 (5.5)	1311 (6.1)	2584 (8.5)
Alcohol intake, median (IQR), g/wk[c]	96 (32-192)	96 (32-192)	64 (8-152)
Townsend Deprivation Index, mean (SD)[d]	−1.9 (3.8)	−1.3 (3.0)	−1.8 (2.8)
Educational attainment, mean (SD), y	15.6 (4.6)	15.9 (4.6)	14.4 (4.7)
Employed	23 330 (61.5)	14 232 (66.3)	16 765 (55.5)
Self-reported health			
Excellent	9429 (24.9)	5573 (26.0)	4334 (14.3)
Good	23 105 (61.0)	12 840 (59.8)	17 791 (58.9)
Fair	4790 (12.6)	2724 (12.7)	6652 (22.0)
Poor	548 (1.4)	336 (1.6)	1451 (4.8)
Diet quality			
Good	6790 (17.9)	4337 (20.2)	4761 (15.8)
Intermediate	19 087 (50.4)	10 750 (50.1)	15 057 (49.8)
Poor	11 995 (31.7)	6386 (29.7)	10 410 (34.4)
Antihypertensive medication use[e]	5777 (15.3)	2904 (13.5)	6903 (22.8)
Body mass index[e,f]	26.1 (4.0)	25.6 (3.9)	27.6 (5.0)
Body mass index >30[f]	5603 (14.8)	2881 (13.4)	8862 (29.4)
Blood pressure			
Systolic, mean (SD), mm Hg[e]	137 (18)	135 (18)	137 (18)
>140 mm Hg	14 636 (38.7)	7788 (36.3)	12 533 (41.5)
Diastolic, mean (SD) mm Hg[e]	81 (10)	81 (10)	82 (10)
>90 mm Hg	6969 (18.4)	3818 (17.8)	6032 (20.0)
Diabetes	854 (2.3)	467 (2.2)	1659 (5.5)

Abbreviations: MVPA, moderate to vigorous physical activity; WW, weekend warrior.

[a] Inactive defined as MVPA below the guideline-based threshold of 150 minutes of MVPA per week.[1-3]

[b] Represents self-reported racial and ethnic background. Race classification of "Other" defined as self-report of a race other than Asian, Black, multiracial or multiethnic, or White.

[c] Can be converted to standard US drinks per week by dividing by 14 g.

[d] The Townsend Deprivation Index is a measure of material deprivation standardized by geographic area. Numerically greater values indicate more deprivation. The sample range is −6.2 to 10.1, with values around −2 and −1 indicating somewhat less deprivation compared with mean based on geographic location.

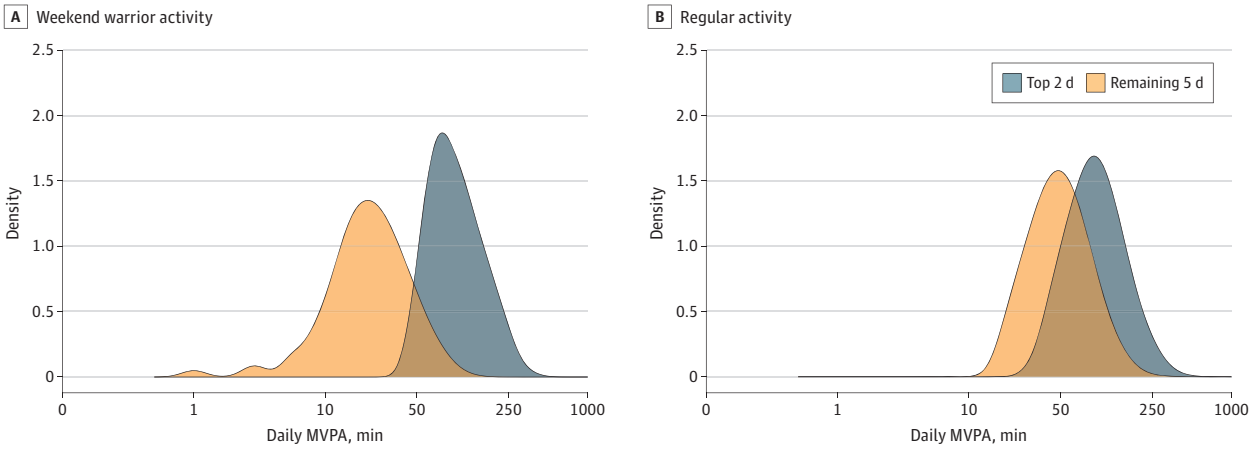
[e] Indicates covariates that may lie on the causal pathway between physical activity and cardiovascular events and are included only in a secondary additionally adjusted model (see eTable 9 in Supplement 1).

[f] Calculated as weight in kilograms divided by height in meters squared.

were in the inactive group (33.7%). Individuals in the activeWW group had substantially more MVPA on their 2 most active days vs the remaining 5 days, while those in the active regular group had more consistent MVPA (**Figure 1**; eFigure 2 in Supplement 1).

In multivariable-adjusted models, both activity patterns were associated with similarly lower risks of incident AF, MI, and HF at both the guideline-based (≥150 minutes) and median (≥230.4 minutes) thresholds (**Figure 2**). Stroke associations were also similar, although significant only at the guideline-based threshold (Figure 2). Event rates were comparable between the active WW and active regular groups (eFigures 3 and 4 in Supplement 1). In multivariable models stratified by MVPA decile, there were no differences in risk with the WW pattern (AF: hazard ratio [HR], 0.98 [95% CI, 0.89-1.09]; MI: HR, 1.12 [95% CI, 0.95-1.30]; HF: HR, 0.92 [95% CI, 0.79-1.08]; stroke: HR, 0.92 [95% CI, 0.77-1.11]). Findings were generally consistent across other activity thresholds (Figure 2; eTable 5 in Supplement 1), alternative WW definitions (eTables 6 and 7 and eFigure 5 in Supplement 1), a 2-year blanking period (eTable 8 in Supplement 1), additional covariate adjustment (eTable 9 in Supplement 1), individuals with incomplete accelerometer data included as inactive (eTable 10 in Supplement 1), and excluding imputed

Figure 1. Distribution of Moderate to Vigorous Physical Activity (MVPA) on Top 2 Days vs Remaining 5 Days Among Active Individuals Using Guideline-Based Activity Threshold of 150 Minutes or More of MVPA Per Week



Depicted is the distribution of daily MVPA on the 2 most active days of the week (blue), vs the remaining 5 days (yellow), among individuals with activity above the guideline-based threshold (ie, ≥150 minutes MVPA over the week,[1-3] n = 59 345). A, Individuals meeting criteria for weekend warrior activity (ie, ≥50% of total MVPA achieved in 1-2 days) are shown. B, Active individuals not meeting criteria for weekend warrior activity (regular) are shown. A total of 431 individuals in the weekend warrior group (1.1%) with a value of zero for the remaining 5 days were attributed 1 minute of MVPA to accommodate logarithmic x-axis scale.

wear time (eTable 11 in Supplement 1). Both activity patterns were associated with similarly lower risks of incident musculoskeletal conditions (eTable 12 and eFigure 6 in Supplement 1).

Discussion

These study results have implications for efforts leveraging physical activity to reduce cardiovascular morbidity. First, when quantified using accelerometry, a weekend warrior pattern appears common. Across multiple activity thresholds, more than half of active individuals accrued most of their MVPA in 1 to 2 days. Second, varying activity patterns were observed, in only 5 years' time, to have similar associations with lower risk of AF, MI, HF, and stroke. These observations thereby extend prior work reporting improved cardiovascular outcomes with increasing moderate and vigorous activity,[8,13,14] as well as reports suggesting that concentrated physical activity is associated with similar reductions in mortality to more regular activity.[4,5] Specifically, these findings suggest that engagement in physical activity, regardless of pattern, may optimize risk across a broad spectrum of cardiovascular diseases. Third, efforts to increase physical activity for cardiovascular health may be effective even when such efforts are concentrated into 1 to 2 days per week. Because weekend warrior patterns may be more feasible for certain schedules, targeted interventions delivered over shorter timeframes may be more accessible. Despite concern that weekend warrior activity may be associated with musculoskeletal injury,[15] similarly lower risk of musculoskeletal conditions with both activity patterns was observed. Future research is warranted to better define potential negative effects of concentrated activity.

Limitations

This study had some limitations. First, activity was measured over 1 week, and individuals may have modified their behavior during observation. Second, a validated MVPA classification method developed using a broad range of activities (eg, walking, jogging, stationary cycling, elliptical, and others) was used,[8] but MVPA classification accuracy may vary by activity type. Third, optimal MVPA thresholds using wrist-based accelerometers remain unclear.[9] However, findings were consistent across multiple thresholds, including the 25th percentile or 115.2 minutes or more (ie, below guideline recommendations[1-3]). Fourth, analysis of a single UK-based sample comprising predominantly White individuals may limit generalizability. Fifth, most covariates were ascertained several years prior to accelerometry and are subject to misclassification. Sixth, the weekend warrior pattern is less well-defined using accelerometers, but findings were consistent across multiple definitions.

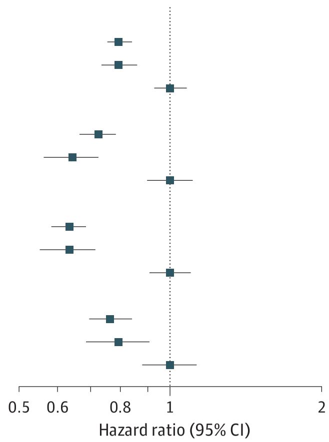
Conclusions

Within nearly 90 000 individuals providing wrist-based activity quantification, physical activity concentrated within 1 to 2 days was associated with similarly lower risk of cardiovascular outcomes to more regular activity. Future prospective studies are warranted to assess whether interventions to increase physical activity, even when concentrated within a day or 2 each week, improve cardiovascular outcomes.

Figure 2. Associations Between Physical Activity Pattern and Incident Cardiovascular Disease

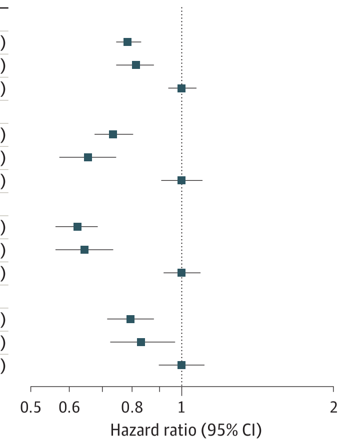
A WW defined as ≥115.2 min of MVPA/wk (25th percentile) with ≥50% over 1-2 d

Outcome	No. of events	No. of participants	Hazard ratio (95% CI)
Atrial fibrillation			
Active WW	1264	44 507	0.79 (0.75-0.84)
Active regular	569	21 698	0.79 (0.73-0.86)
Inactive	809	20 829	1.00 (0.93-1.08)
Myocardial infarction			
Active WW	582	44 804	0.72 (0.66-0.78)
Active regular	241	21 807	0.64 (0.56-0.72)
Inactive	406	20 873	1.00 (0.90-1.11)
Heart failure			
Active WW	536	45 469	0.63 (0.58-0.68)
Active regular	241	22 083	0.63 (0.55-0.71)
Inactive	498	21 319	1.00 (0.91-1.10)
Stroke			
Active WW	387	45 152	0.76 (0.69-0.84)
Active regular	180	21 997	0.79 (0.68-0.91)
Inactive	273	21 159	1.00 (0.88-1.13)



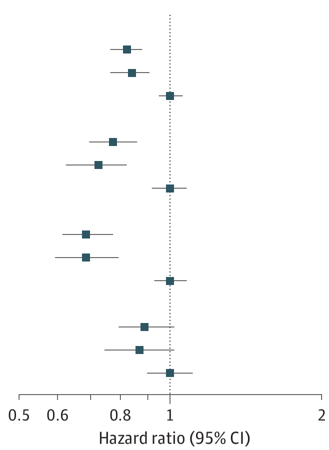
B WW defined as ≥150 min of MVPA/wk (guideline based) with ≥50% over 1-2 d

Outcome	No. of events	No. of participants	Hazard ratio (95% CI)
Atrial fibrillation			
Active WW	1009	36 887	0.78 (0.74-0.83)
Active regular	548	20 980	0.81 (0.74-0.88)
Inactive	1085	29 167	1.00 (0.94-1.07)
Myocardial infarction			
Active WW	470	37 124	0.73 (0.67-0.80)
Active regular	226	21 077	0.65 (0.57-0.74)
Inactive	533	29 283	1.00 (0.91-1.10)
Heart failure			
Active WW	411	37 657	0.62 (0.56-0.68)
Active regular	169	21 343	0.64 (0.56-0.73)
Inactive	640	29 871	1.00 (0.92-1.09)
Stroke			
Active WW	313	37 417	0.79 (0.71-0.88)
Active regular	224	21 260	0.83 (0.72-0.97)
Inactive	354	29 631	1.00 (0.90-1.11)



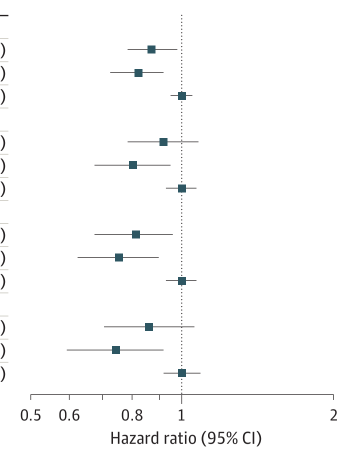
C WW defined as ≥230.4 min of MVPA/wk (median) with ≥50% over 1-2 d

Outcome	No. of events	No. of participants	Hazard ratio (95% CI)
Atrial fibrillation			
Active WW	702	25 795	0.82 (0.76-0.88)
Active regular	471	18 521	0.84 (0.76-0.91)
Inactive	1469	42 718	1.00 (0.95-1.06)
Myocardial infarction			
Active WW	321	25 964	0.77 (0.69-0.86)
Active regular	202	18 597	0.72 (0.62-0.82)
Inactive	706	42 923	1.00 (0.92-1.08)
Heart failure			
Active WW	282	26 313	0.68 (0.61-0.77)
Active regular	188	18 836	0.68 (0.59-0.79)
Inactive	805	42 722	1.00 (0.93-1.08)
Stroke			
Active WW	227	26 156	0.89 (0.79-1.02)
Active regular	146	18 768	0.87 (0.74-1.02)
Inactive	467	43 384	1.00 (0.91-1.11)



D WW defined as ≥403.2 min of MVPA/wk (75th percentile) with ≥50% over 1-2 d

Outcome	No. of events	No. of participants	Hazard ratio (95% CI)
Atrial fibrillation			
Active WW	306	10 820	0.87 (0.78-0.98)
Active regular	267	11 427	0.82 (0.72-0.92)
Inactive	2069	64 787	1.00 (0.95-1.05)
Myocardial infarction			
Active WW	149	10 927	0.92 (0.78-1.08)
Active regular	125	11 476	0.80 (0.67-0.95)
Inactive	955	65 081	1.00 (0.93-1.07)
Heart failure			
Active WW	124	11 048	0.81 (0.67-0.96)
Active regular	109	11 617	0.75 (0.62-0.90)
Inactive	1042	66 206	1.00 (0.93-1.07)
Stroke			
Active WW	92	10 987	0.86 (0.70-1.06)
Active regular	74	11 566	0.74 (0.59-0.92)
Inactive	674	65 755	1.00 (0.92-1.09)



Depicted are plots of multivariable-adjusted associations between activity pattern and incident atrial fibrillation, myocardial infarction, heart failure, and stroke. Three activity groups are compared: active weekend warrior (active WW), active regular, and inactive (reference). Each plot depicts a different activity threshold used to define the inactive group (see title above each plot). Bars depict 95% CIs.

ARTICLE INFORMATION

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Author Contributions: Dr Khurshid had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.
Concept and design: Khurshid.
Acquisition, analysis, or interpretation of data: All authors.
Drafting of the manuscript: Khurshid, Guseh, Ellinor.
Critical revision of the manuscript for important intellectual content: Al-Alusi, Churchill, Guseh, Ellinor.
Statistical analysis: Khurshid.
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Supervision: Guseh, Ellinor.

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Data Sharing Statement: See Supplement 2.

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