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Research article

Association between Weekend Warrior Physical Activity Pattern and Osteoarthritis: A Prospective Cohort Study in the UK Biobank

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Abstract
Although regular physical activity is recommended for osteoarthritis (OA) prevention, many adults fail to exercise consistently due to time constraints. We evaluated the association between the "weekend warrior" (WW) pattern, defined as accumulating the recommended amount of physical activity within one or two days per week, and incident OA. This prospective cohort study used data from the UK Biobank accelerometer substudy. A total of 83, 386 participants with valid 7-day wrist-worn accelerometer data were included. Participants were classified as inactive (< 150 min/week of moderate-to-vigorous physical activity [MVPA]), weekend warriors (≥ 150 min/week with ≥ 50% of MVPA accumulated within 1 - 2 days), or regularly active (≥ 150 min/week with ≥ 50% distributed across > 2 days). Sensitivity analyses were additionally conducted using progressively stricter MVPA concentration thresholds ranging from ≥ 55% to ≥ 95%. Incident OA was identified through linked health records. Cox proportional hazards models were applied to estimate hazard ratios (HRs) and 95% confidence intervals (CIs). Over a median follow-up of 7.9 years, 8, 130 incident OA cases were identified. Compared with inactive participants, both regularly active and weekend warrior patterns were associated with lower OA risk in fully adjusted models (HR = 0.889, 95% CI: 0.835 - 0.946, HR = 0.894, 95% CI: 0.850 - 0.941, respectively), and these inverse associations remained stable when using stricter MVPA concentration thresholds ranging from ≥ 55% to ≥ 90%. In contrast, compared with regularly active participants, weekend warrior participants did not show a statistically significant difference in OA risk (HR, 1.031; 95% CI, 0.968 - 1.099), even after further adjustment for total MVPA volume. Accumulating guideline-recommended MVPA within one to two days per week was associated with a lower risk of incident OA, comparable to regularly distributed physical activity. The weekend warrior pattern may represent a practical option for OA prevention among time-constrained adults.

Key words: Physical activity, weekend warrior, MVPA, osteoarthritis, accelerometer, UK Biobank.

Introduction

Osteoarthritis affects over 595 million individuals globally and represents one of the principal causes of musculoskeletal pain and physical disability. Driven by population aging and the increasing prevalence of obesity, the burden of knee osteoarthritis is expanding rapidly and is projected to increase by 75% by 2050 (GBD Osteoarthritis Collaborators., 2023). Osteoarthritis has become a major global health challenge, adversely affecting quality of life, health care system sustainability, and participation in the workforce (Lynch et al., 2022). Although key risk factors for osteoarthritis, such as obesity and joint injury, are well established and modifiable, effective strategies addressing these factors remain limited in both primary and secondary prevention contexts (Tang et al., 2025). There is an urgent need for practical preventive approaches that can enhance long-term adherence at the population level.

Appropriate physical activity is widely regarded as a foundational component of first-line strategies for both the prevention and management of osteoarthritis (Huffman et al., 2024). In individuals participating in exercise-based interventions, maintenance of muscle mass is associated with improved joint function and reduced compressive loading across the knee joint (Jurado-Castro et al., 2022). Current U.S. physical activity guidelines recommend a minimum of 150 minutes of moderate-intensity activity or at least 75 minutes of vigorous-intensity activity per week, collectively referred to as moderate-to-vigorous physical activity (MVPA), to confer broad health benefits (Piercy et al., 2018). The current U.S. Physical Activity Guidelines for adults emphasize the total amount of physical activity accumulated per week and do not mandate a specific within-week distribution pattern, although they preferentially recommend that activity be spread throughout the week. However, increasingly fast-paced lifestyles and extended working hours pose substantial barriers to sustained participation in exercise interventions, with many individuals unable to achieve World Health Organization-recommended levels of leisure-time physical activity through regular daily exercise. As a result, a growing proportion of adults engage in the "weekend warrior" (WW) pattern, whereby the recommended weekly volume of physical activity is accumulated during one or two days, typically on weekends (O'Donovan et al., 2018). Emerging evidence indicates that, in selected health domains, the WW pattern may produce outcomes comparable to those associated with regularly distributed physical activity (Cao et al., 2025; Khurshid et al., 2023). In addition, multiple recent studies have reported comparable benefits of the WW activity pattern and regularly distributed physical activity on bone mineral density (Li and Wang, 2025; Wang et al., 2025; Xu et al., 2025). Collectively, these findings suggest that the WW pattern may serve as a feasible and effective approach to maintaining bone health among working-age populations. However, work and caregiving demands may make daily exercise difficult, leading some adults to

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concentrate their physical activity within a small number of days. This concentrated pattern has raised concerns that greater mechanical loading within individual exercise sessions may increase the risk of muscle or joint injury. Whether this activity pattern offers protective effects against osteoarthritis, and whether such effects are comparable to those achieved through a regularly active pattern, remains uncertain.

This study aimed to investigate the associations between osteoarthritis incidence and two guideline-concordant physical activity patterns: a concentrated weekend warrior pattern performed on one to two days per week and a more evenly distributed regularly active pattern. The findings are intended to support the development of more personalized, preference-sensitive physical activity recommendations and to enhance adherence to activity-based strategies for osteoarthritis prevention at the population level.

Methods

Study design and participants

This investigation was conducted using data from the UK Biobank, which obtained ethical approval from the North West Multicentre Research Ethics Committee (REC No. 11/NW/0382). All participants provided written informed consent and consented to linkage of their data with national electronic health-related records (Fry et al., 2017). This study received ethical approval and the project reference number is 1047335. The UK Biobank is a large prospective, population-based cohort comprising more than 500 000 participants recruited between 2006 and 2010 from 22 assessment centers throughout England, Scotland, and Wales. Participants completed detailed interviews and questionnaires that assessed sociodemographic factors, lifestyle behaviors, health status, and physical measurements (Bycroft et al., 2018).

Between May 2013 and December 2015, approximately 240, 000 UK Biobank participants were invited via email to take part in an accelerometer substudy, of whom 103, 520 provided valid accelerometer data. Participants were excluded for the following reasons: poorly calibrated accelerometer data (n = 130); insufficient wear time, defined as fewer than 3 days with data within any 1-hour period or no recorded data (n = 4, 581); implausibly high mean acceleration values (> 100 mg; n = 12); absence of daily MVPA data (n = 3, 502); accelerometer wear time of less than 1 complete week (n = 4, 001); missing covariate information (n = 1, 677); or a documented diagnosis of osteoarthritis at baseline (n = 6, 231). The final analytic cohort comprised 83, 386 participants. Participant selection is summarized in Figure 1.

Physical activity patterns

Participants enrolled in the accelerometer substudy were instructed to continuously wear a triaxial Axivity AX3 accelerometer on their dominant wrist for a 7-day period (Doherty et al., 2017). The accelerometer captured triaxial acceleration signals at a sampling rate of 100 Hz and within a dynamic range of ± 8 g. Raw acceleration signals were

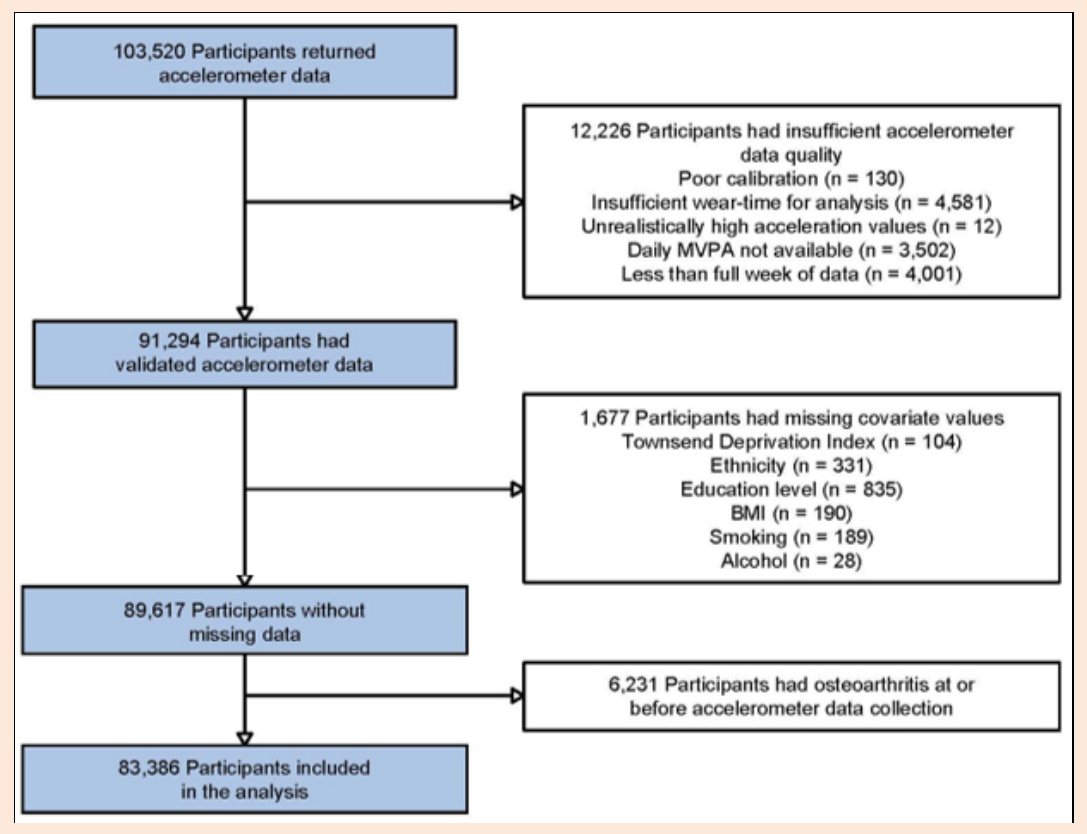

Figure 1. Flowchart of participant selection. Participants were excluded sequentially for accelerometer calibration failure, insufficient wear time, implausibly high mean acceleration, missing daily MVPA data, less than one complete week of accelerometer wear, missing covariates, or prevalent OA at baseline. The final analytic cohort included 83,386 participants without OA at baseline. Abbreviations: BMI, body mass index; MVPA, moderate-to-vigorous physical activity; OA, osteoarthritis.

summarized into 5-second epochs and expressed as mean vector magnitude values. Nonwear time was defined as intervals of at least 60 consecutive minutes with minimal movement, during which the standard deviation of acceleration across all three axes remained below 13.0 mg (Doherty et al., 2017). Identified nonwear intervals were imputed using the mean vector magnitude and activity intensity distributions from corresponding time periods on other valid days. Detailed descriptions of the accelerometer data collection and processing methods have been reported previously (Doherty et al., 2017). A previously published machine learning-based algorithm was applied to classify activity behaviors from wrist-worn accelerometer data, enabling accurate differentiation of MVPA from light-intensity activity, sedentary behavior, and sleep. The validity of this classification approach has been demonstrated in a population-based UK sample (Walmsley et al., 2021).

In this analysis, daily MVPA duration was quantified in minutes per day based on the proportion of time spent in MVPA per day (field ID 40045). Participants were categorized based on overall physical activity level and activity pattern in accordance with World Health Organization physical activity guidelines (Bull et al., 2020; Arnett et al., 2019; Khurshid et al., 2023). Participants were initially classified as inactive (weekly MVPA < 150 minutes) or physically active (weekly MVPA ≥ 150 minutes). The physically active group was further stratified according to the temporal distribution of MVPA across days, irrespective of whether activity occurred on weekends. Participants accumulating at least 50% of their weekly MVPA within 1 to 2 days were classified as weekend warriors, whereas those distributing at least 50% of MVPA across more than 2 days were classified as regularly active.

Osteoarthritis ascertainment

Osteoarthritis was identified using data from primary care records, hospital admissions, self-reports, death registries, or inpatient records and was defined according to International Classification of Diseases, Tenth Revision (ICD-10) codes M15 to M19 (Guo et al., 2024; Prieto-Alhambra et al., 2014).

Covariates

Age was calculated using participants' date of birth and the date on which the accelerometer was worn. Sex (female or male), race (White or other), and the Townsend Deprivation Index were obtained from self-administered questionnaires. Additional covariates included educational attainment, smoking status, and frequency of alcohol consumption. Educational attainment was dichotomized as high or low. High educational attainment was defined as completion of a university degree or higher, whereas low educational attainment comprised participants without a university degree, including those with National Vocational Qualifications, Higher National Diplomas or Certificates, A-level or Advanced Subsidiary qualifications (or equivalent), or no formal educational qualifications. Smoking status was categorized as current, former, or never smoker. Alcohol consumption frequency was classified as daily or almost daily; 3 to 4 times per week; 1 to 2 times per week; 1 to 3 times per month; or rarely or never. Body mass index (BMI) was calculated as weight in kilograms divided by height in meters squared using measurements obtained at the initial assessment center visit. All covariates included in the analyses were derived from the assessment conducted closest in time to the accelerometer wear period. Detailed definitions of all covariates and their corresponding field identifiers are provided in Supplementary Table 1.

Table 1. Baseline characteristics of the study population according to physical activity pattern.

Characteristics	Active - weekend warrior	Active - regularly active	Inactive
n	36, 165	19, 823	27, 398
Age (years)	61.49 (7.76)	60.42 (7.91)	62.38 (7.86)
Male, n (%)	17, 626 (48.7)	9, 701 (48.9)	9, 102 (33.2)
Education, n (%)			
College or above	17, 140 (47.4)	10, 019 (50.5)	9, 707 (35.4)
Others	19, 025 (52.6)	9, 804 (49.5)	17, 691 (64.6)
Townsend deprivation index	-1.92 (2.70)	-1.31 (3.00)	-1.79 (2.78)
Ethnicity, n (%)			
White	35, 214 (97.4)	19, 124 (96.5)	26, 431 (96.5)
Non-White	951 (2.6)	699 (3.5)	967 (3.5)
Smoking status, n (%)			
Never	21, 492 (59.4)	11, 504 (58.0)	15, 146 (55.3)
Former	12, 616 (34.9)	7, 062 (35.6)	9, 807 (35.8)
Current	2, 057 (5.7)	1, 257 (6.3)	2, 445 (8.9)
Alcohol intake frequency, n (%)			
Daily or almost daily	8, 758 (24.2)	4, 881 (24.6)	5, 506 (20.1)
3 - 4 times/week	10, 217 (28.3)	5, 450 (27.5)	6, 104 (22.3)
1 - 2 times/week	9, 259 (25.6)	4, 806 (24.2)	6, 879 (25.1)
1 - 3 times/month	3, 553 (9.8)	1, 991 (10.0)	3, 543 (12.9)
Special occasions only	2, 768 (7.7)	1, 665 (8.4)	3, 407 (12.4)
Never	1, 610 (4.5)	1, 030 (5.2)	1, 959 (7.2)
BMI, kg/m^2	26.08 (3.93)	25.69 (3.97)	27.84 (5.11)
Total weekly MVPA, min	288.00 (216.00, 432.00)	432.00 (302.40, 604.80)	72.00 (43.20, 115.20)

Data are presented as mean (SD), median (IQR), or n (%), as appropriate. Active participants accumulated ≥150 min/week of MVPA. Weekend warriors accumulated ≥50% of weekly MVPA on their two most active days; regularly active participants accumulated <50% on their two most active days. Inactive participants accumulated <150 min/week of MVPA. Abbreviations: BMI, body mass index; IQR, interquartile range; MVPA, moderate-to-vigorous physical activity; SD, standard deviation.

Statistical analysis

Baseline participant characteristics were summarized according to physical activity patterns defined using guideline-based thresholds (≥ 150 minutes of MVPA per week). Continuous variables are reported as means with standard deviations (SDs), whereas categorical variables are presented as counts and percentages.

Cox proportional hazards regression models were applied to evaluate the associations between physical activity patterns and incident osteoarthritis, with effect estimates reported as hazard ratios (HRs) and 95% confidence intervals (CIs). The proportional hazards assumption was evaluated using Schoenfeld residuals, and no violations were observed. Cumulative incidence curves stratified by physical activity pattern were plotted to illustrate the median follow-up time of 7.9-year cumulative incidence of osteoarthritis; in a supplementary analysis, additional curves were generated with truncation at 5 years. Model 1 was adjusted for age at accelerometer assessment, sex, and ethnicity. Model 2 was further adjusted for educational attainment, Townsend Deprivation Index, and BMI. Model 3 was additionally adjusted for smoking status and alcohol intake frequency. In addition, Model 3 was further adjusted for total weekly MVPA volume to minimize the potential influence of overall MVPA volume on the association between different temporal concentration patterns of physical activity and osteoarthritis risk.

Subgroup analyses were performed using the fully adjusted model to examine potential effect modification by age (< 65 vs ≥ 65 years) and sex (female vs male) in the association between physical activity patterns and osteoarthritis. To further characterize the concentrated nature of the weekend warrior pattern, we conducted additional sensitivity analyses using progressively stricter thresholds for the proportion of weekly MVPA accumulated within 1 - 2 days, ranging from ≥ 55% to ≥ 95% in 5% increments. We also redefined weekend warriors using MVPA accumulated on any two consecutive days or specifically on 1 - 2 weekend days. In addition, to reduce potential reverse causation, lag analyses excluding osteoarthritis events occurring within the first 1 - 3 years of follow-up were performed to assess the robustness of the findings. All statistical analyses were conducted using R software, version 4.3.1 (Beagle Scouts). A 2-sided P value of less than 0.05 was considered statistically significant.

Results

Participant characteristics

A total of 83, 386 participants were included in this study, with a mean age of 61.53 years (SD, 7.86), and 43.7% were men. Baseline characteristics stratified by physical activity pattern are shown in Table 1. Participants were classified into 3 groups: inactive (32.9%; n = 27, 398), regularly active (23.8%; n = 19, 823), and weekend warrior, which comprised the largest proportion (43.4%; n = 36, 165). The total weekly MVPA was highest in the regularly active group (median, 432.00 minutes; interquartile range [IQR], 302.40 - 604.80 minutes), followed by the weekend warrior group (median, 288.00 minutes; IQR, 216.00 - 432.00 minutes), and lowest in the inactive group (median, 72.00 minutes; IQR, 43.20 - 115.20 minutes) (Figure 2a). Compared with weekend warrior participants, those in the inactive group were older, more likely to smoke, less likely to consume alcohol, had a lower prevalence of university or higher educational attainment, and had higher BMI levels. Figure 2b and 2c show the distributions of mean daily MVPA during the two most active days and the remaining five days among weekend warriors and regularly active participants, respectively. Density-peak height represents the relative concentration of participants at a given mean daily MVPA level. Dashed lines indicate the medians, and the double-headed arrow indicates the difference between the two medians. A larger median difference among weekend warriors indicates a greater concentration of weekly MVPA on the two most active days, whereas the smaller difference among regularly active participants reflects a more even distribution of activity across the week. In addition, density distributions for weekend warriors and regularly active participants classified using a 75% threshold for the concentration of weekly MVPA within one or two days are presented in Supplementary Figure 1, showing a greater difference in mean daily MVPA between the two most active days and the remaining five days. In addition, the day-by-day concentration analysis among active participants showed that the proportions requiring a minimum of 1, 2, 3, 4, 5, and 6 days to accumulate 75% of total weekly MVPA were 1.0%, 9.8%, 29.5%, 39.7%, 19.7%, and 0.3%, respectively. The proportions requiring 1, 2, 3, and 4 days to accumulate 50% of weekly MVPA were 10.7%, 53.9%, 34.3%, and 1.1%, respectively. These results are presented in Supplementary Figure 2 and Supplementary Table 2.

Associations between physical activity patterns and osteoarthritis

Over a median follow-up duration of 7.9 years (interquartile range, 7.3 - 8.4 years), osteoarthritis was newly identified in 8, 130 participants. Cumulative incidence curves estimates (Figure 3a and Supplementary Figure 3) demonstrated that individuals classified as inactive experienced the greatest cumulative incidence of osteoarthritis across the 7.9-years and 5-years follow-up period, while both the weekend warrior and regularly active groups showed lower risks. To delineate the dose-response relationship between physical activity patterns and incident osteoarthritis, spline regression analyses were performed. The spline models indicated that the lowest risk of osteoarthritis occurred at moderate-to-vigorous physical activity (MVPA) levels of approximately 150 to 250 minutes per week (Figure 3b).

In minimally adjusted analyses, engagement in either a regularly active or weekend warrior pattern was associated with a comparably lower risk of osteoarthritis relative to inactivity (HR = 0.724, 95% CI: 0.682 - 0.769; HR = 0.746, 95% CI: 0.710 - 0.783, respectively) (Figure 3c). With further adjustment for BMI, Townsend Deprivation Index, and educational level, the magnitude of the associations decreased modestly but retained statistical significance (HR = 0.885, 95% CI: 0.832 - 0.942) for the regularly active pattern and HR = 0.889, 95% CI: 0.845 - 0.935 for the weekend warrior pattern) (Figure 3c). After comprehensive adjustment for all covariates, both physical activity patterns remained similarly associated with a lower

osteoarthritis risk (HR = 0.889, 95% CI: 0.835 - 0.946 for the regularly active pattern and HR = 0.894, 95% CI: 0.850 - 0.941 for the weekend warrior pattern) (Figure 3c). Even after further adjustment for total weekly MVPA, both the regularly active and weekend warrior patterns remained associated with a lower risk of osteoarthritis. However, compared with regularly active participants, those following the weekend warrior pattern showed no statistically significant difference in osteoarthritis risk (HR, 1.031; 95% CI, 0.968 - 1.099) (Supplementary Table 6).

On the basis of this observation, participants in the weekend warrior and regularly active categories were further stratified according to a weekly MVPA threshold of 250 minutes. The analyses demonstrated that both weekend warriors and regularly active participants had a significantly lower risk of osteoarthritis than inactive participants when weekly MVPA exceeded 250 minutes, whereas only the weekend warrior pattern was associated with a lower osteoarthritis risk when weekly MVPA ranged from 150 to 250 minutes (Supplementary Table 3, top two days ≥ 50%). When weekend warriors were defined using thresholds of ≥ 55% to ≥ 65% of weekly MVPA accumulated on the two most active days, both the weekend warrior and regularly active patterns were associated with a lower osteoarthritis risk across weekly MVPA strata. At thresholds ranging from ≥ 70% to ≥ 95%, the regularly active pattern showed a more consistent association with a lower osteoarthritis risk.

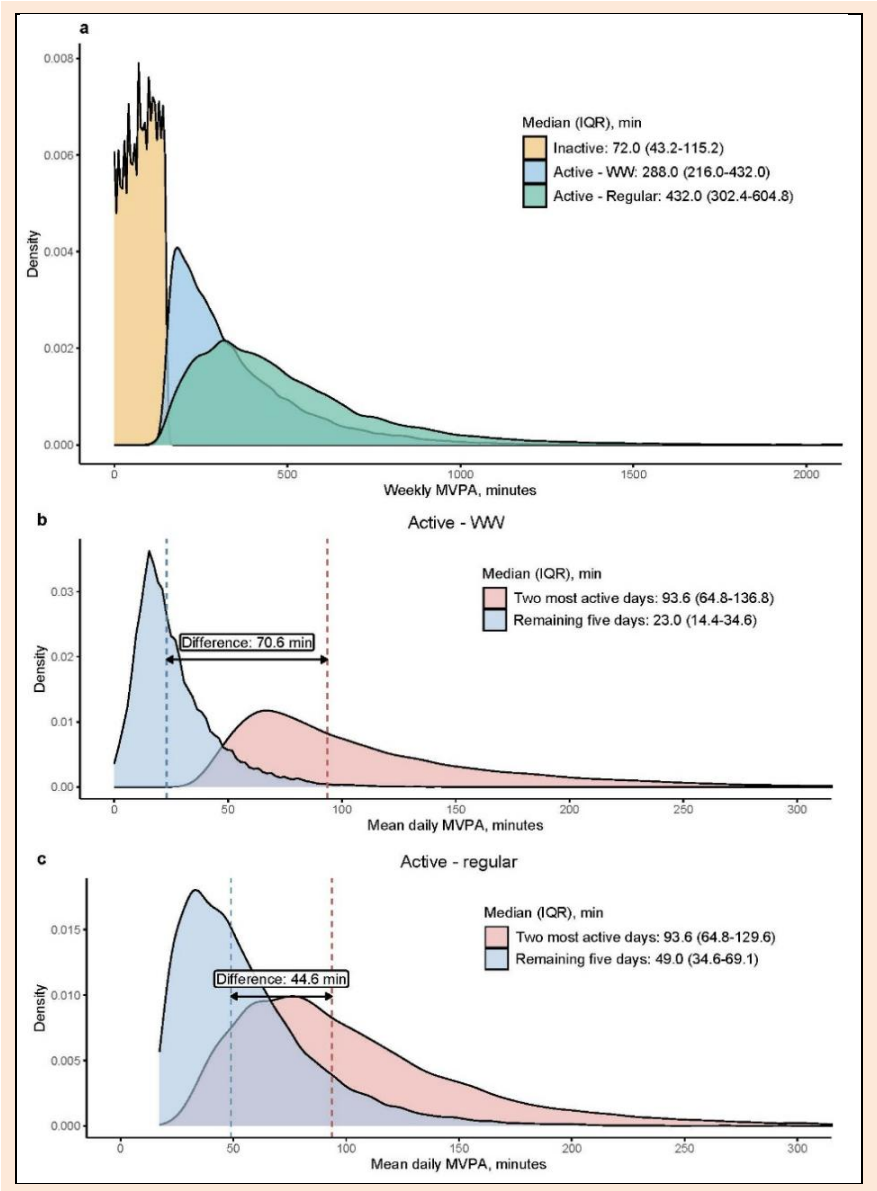

Figure 2. Distribution of accelerometer-measured MVPA according to physical activity pattern using the 50% top-two-day definition. a, Distribution of total weekly MVPA in inactive, WW, and regularly active participants. b and c, Distributions of mean daily MVPA during the two most active days and the remaining five days among WW and regularly active participants, respectively. Dashed vertical lines indicate medians; annotations report the median and IQR, and the double-headed horizontal arrow shows the difference between the two medians. Inactive participants accumulated <150 min/week of MVPA. Among participants accumulating >=150 min/week, WW participants accumulated >=50% of total weekly MVPA on the two most active days, whereas regularly active participants accumulated <50% on those days. Density is explicitly defined as the relative population distribution estimated using kernel density estimation. Abbreviations: IQR, interquartile range; MVPA, moderate-to-vigorous physical activity; WW, weekend warrior.

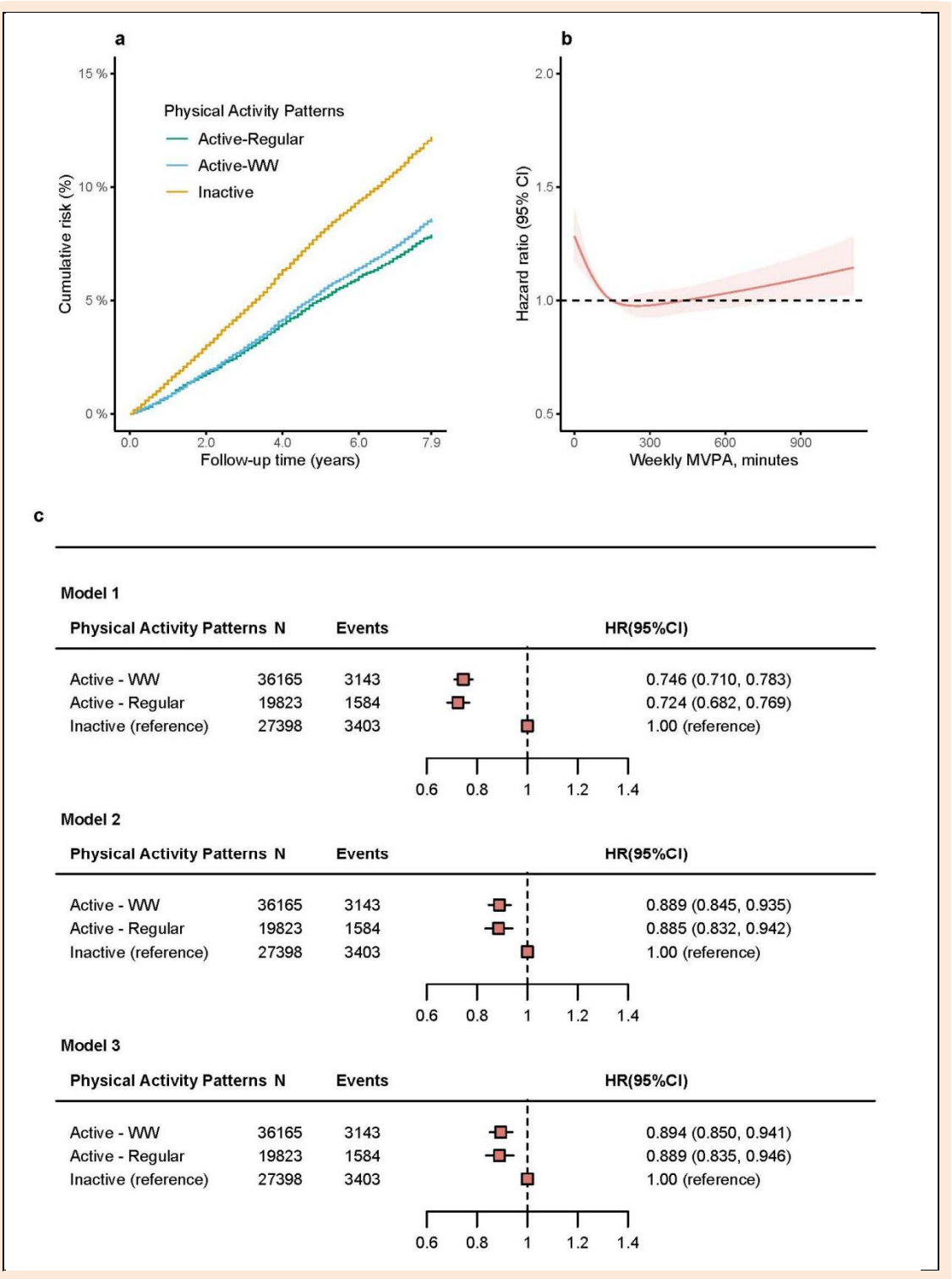

Figure 3. Associations of physical activity pattern and total weekly MVPA with incident osteoarthritis. a, Cumulative risk of incident overall OA through 7.9 years of follow-up by physical activity pattern. b, Association between continuous total weekly MVPA and incident overall OA estimated using a Cox proportional hazards model with a natural cubic spline; the shaded area indicates the 95% CI and 150 min/week is the HR reference value. The spline model adjusted for age at accelerometer assessment, sex, ethnicity, education, Townsend deprivation index, smoking status, alcohol intake frequency, and BMI. c, HRs for WW and regularly active participants versus inactive participants from Cox proportional hazards models. Model 1 adjusted for age at accelerometer assessment, sex, and ethnicity. Model 2 additionally adjusted for education, Townsend deprivation index, and BMI. Model 3 additionally adjusted for smoking status and alcohol intake frequency. Inactive participants accumulated <150 min/week of MVPA. Among participants accumulating >=150 min/week, WW participants accumulated >=50% of total weekly MVPA on the two most active days, whereas regularly active participants accumulated <50% on those days. The activity pattern reference group was inactive. Incident overall OA was defined as the first recorded ICD-10 M15-M19 diagnosis during follow-up among participants without OA at baseline. Abbreviations: BMI, body mass index; CI, confidence interval; HR, hazard ratio; ICD-10, International Classification of Diseases, 10th Revision; MVPA, moderate-to-vigorous physical activity; OA, osteoarthritis; WW, weekend warrior.

Subgroup analyses

In sex-stratified analyses, a significant association between the weekend warrior pattern and lower osteoarthritis risk was observed among females (HR = 0.847; 95% CI: 0.794 - 0.904), whereas no statistically significant association was detected among males (HR = 0.975; 95% CI: 0.896 - 1.060) (Figure 4a and Figure 4b). This sex-specific difference suggests that the lower risk of the weekend warrior pattern with osteoarthritis may be more pronounced in females. The results of the subgroup analyses according to age groups were generally consistent with those of the primary analysis. In the fully adjusted model, the weekend warrior pattern was significantly associated with a lower risk of osteoarthritis in both younger participants (HR = 0.881; 95% CI: 0.814 - 0.953) and older participants (HR = 0.867; 95% CI: 0.812 - 0.927) (Figure 4c and Figure 4d). These findings suggest that individuals across different age groups derive comparable benefits against risk of osteoarthritis when adhering to the weekend warrior physical activity pattern.

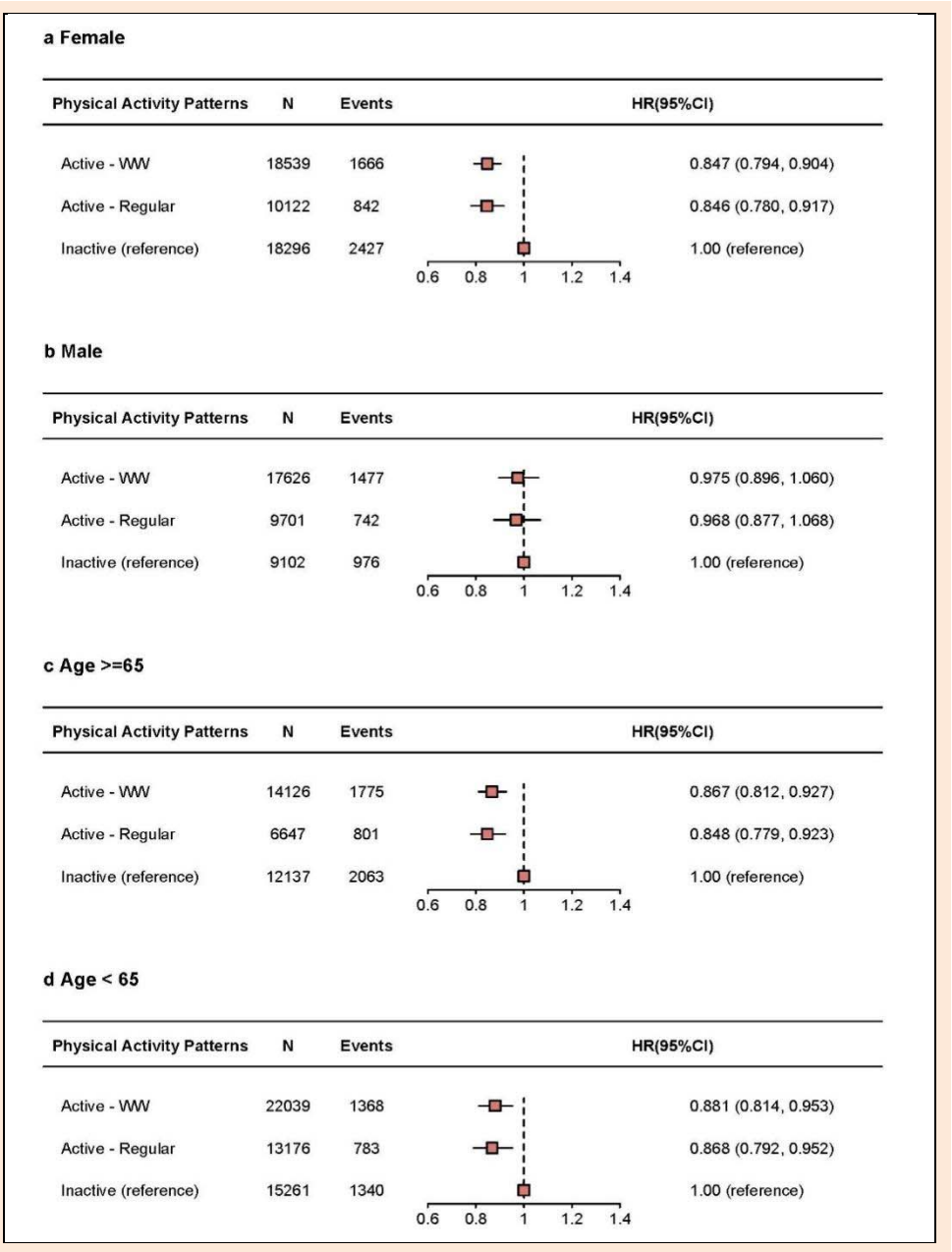

Figure 4. Sex- and age-stratified associations between physical activity pattern and incident osteoarthritis. HRs and 95% CIs were estimated using Cox proportional hazards models separately among females, males, participants aged >=65 years, and participants aged <65 years. Models adjusted for age at accelerometer assessment, sex, ethnicity, education, Townsend deprivation index, smoking status, alcohol intake frequency, and BMI, with the stratification variable omitted from the corresponding model. Inactive participants accumulated <150 min/week of MVPA. Among participants accumulating >=150 min/week, WW participants accumulated >=50% of total weekly MVPA on the two most active days, whereas regularly active participants accumulated <50% on those days. The reference group was inactive within each stratum. Incident overall OA was defined as the first recorded ICD-10 M15-M19 diagnosis during follow-up among participants without OA at baseline. Squares indicate HR estimates and horizontal lines indicate 95% CIs. Abbreviations: BMI, body mass index; CI, confidence interval; HR, hazard ratio; ICD-10, International Classification of Diseases, 10th Revision; MVPA, moderate-to-vigorous physical activity; OA, osteoarthritis; WW, weekend warrior.

Sensitivity analyses

The findings of the sensitivity analyses were consistent with those of the primary analysis. Robust inverse associations were also observed when alternative definitions of the weekend warrior pattern were applied. When the weekend warrior pattern was defined as accumulating at least 50% of total weekly MVPA within any 1 or 2 consecutive days, both the weekend warrior and regularly active patterns were associated with a lower risk of osteoarthritis compared with inactivity, with HRs of 0.886 (95% CI, 0.837 - 0.937) and 0.898 (95% CI, 0.851 - 0.947), respectively (Figure 5a). Similarly, when the weekend warrior pattern was defined as accumulating at least 50% of total weekly MVPA during 1 or 2 weekend days, the corresponding HRs were 0.845 (95% CI, 0.770 - 0.927) for the weekend warrior pattern and 0.899 (95% CI, 0.857 - 0.943) for the regularly active pattern (Figure 5b). Sensitivity analyses using alternative consecutive-day concentration thresholds generally yielded similar findings (Supplementary Table 4). In addition, excluding participants who developed osteoarthritis within the first 1, 2, or 3 years of follow-up did not materially alter the results. Using the primary ≥ 50% definition, the HRs for the weekend warrior pattern were 0.922 (95% CI, 0.874 - 0.973), 0.924 (95% CI, 0.872 - 0.979), and 0.930 (95% CI, 0.873 - 0.991) after the 1-, 2-, and 3-year exclusions, respectively. The corresponding HRs for the regularly active pattern were 0.908 (95% CI, 0.850 - 0.970), 0.907 (95% CI, 0.845 - 0.974), and 0.903 (95% CI, 0.836 - 0.976), respectively (Supplementary Table 5).

The weekend warrior pattern was alternatively defined using thresholds ranging from 55% to 95%, in 5-percentage-point increments, for the proportion of total weekly MVPA accumulated on the two most active days. In the fully adjusted models, at concentration thresholds ranging from 55% to 90%, both the weekend warrior and regularly active patterns were associated with a lower risk of osteoarthritis compared with inactivity. The HRs ranged from 0.747 to 0.910 for the weekend warrior pattern and from 0.889 to 0.902 for the regularly active pattern. When the concentration threshold was increased to 95%, the regularly active pattern remained significantly associated with a lower risk of osteoarthritis (HR, 0.893; 95% CI, 0.852 - 0.935), whereas the association for the weekend warrior pattern was no longer statistically significant (HR, 0.882; 95% CI, 0.670 - 1.160) (Figure 5c). Exploratory analysis excluding BMI from the covariate adjustment in the association between activity pattern and osteoarthritis were given in Supplementary Table 7.

Discussion

Using longitudinal cohort data with a median follow-up of 7.9 years, we evaluated the associations between distinct physical activity patterns and the risk of incident osteoarthritis. The results indicate that, compared with physically inactive individuals, both the weekend warrior pattern, characterized by accumulation of guideline-recommended physical activity within 1 to 2 days per week, and a more evenly distributed regularly active pattern were associated with a lower risk of osteoarthritis, with similar magnitudes of association. These findings suggest that the weekend warrior pattern may confer benefits against osteoarthritis and represent a feasible physical activity option for individuals who are unable to participate in regular daily exercise because of occupational or time constraints.

Physical inactivity is recognized as a major risk factor for the development of osteoarthritis. The health benefits of physical activity are well established and include prevention of obesity, attenuation of age-related functional decline, and preservation of joint health (Hootman et al., 2003). Among adults aged 50 to 79 years, vigorous physical activity has been associated with improved joint health (Racunica et al., 2007). Ding and colleagues (Ding et al., 2010) reported that women who engaged in regular walking were less likely to exhibit early joint abnormalities, including cartilage degeneration. Although evidence regarding the role of quadriceps strength in knee osteoarthritis remains mixed, older adults with greater muscle mass-potentially attributable to regular physical activity experience less cartilage loss, suggesting that exercise-related increases in muscle mass and strength may help protect joints from degenerative changes (Ding et al., 2010). Current guidelines from the World Health Organization (WHO) and the US Department of Health and Human Services (HHS) recommend at least 150 minutes per week of moderate-intensity aerobic activity, 75 minutes of vigorous-intensity activity, or an equivalent combination. These guidelines emphasize that achieving the minimum recommended activity threshold confers substantial health benefits. However, increasingly demanding work schedules often limit opportunities for daily exercise, rendering regular participation in physical activity unattainable for many individuals. Consequently, some adults adopt the “weekend warrior” pattern, in which the recommended volume of aerobic activity is completed within one or two sessions per week. The health benefits of the weekend warrior pattern were first reported in 2004 (Lee et al., 2004), when Lee and colleagues observed a 15% lower risk of all-cause mortality among weekend warriors compared with the general population. Subsequent investigations have demonstrated benefits of this activity pattern across multiple health domains, including mental and neurological health, as well as metabolic conditions such as diabetes (Hamer et al., 2017; Lei et al., 2025; Lin et al., 2024; Zhao et al., 2025). In addition, an increasing body of evidence supports potential benefits of the weekend warrior pattern for bone health. For example, an analysis of NHANES data by Yuao Tao and colleagues found that adults engaging in lower-frequency but sufficient total physical activity exhibited a reduced risk of low bone mineral density compared with inactive individuals, with effect estimates comparable to those observed among regularly active participants (Wang et al., 2025). Huanhuan Wang and colleagues further reported that both weekend warrior and regularly active patterns were positively associated with femoral neck bone mineral density, particularly among individuals younger than 50 years, men, and unmarried participants (Li and Wang, 2025). Even among adults aged 50 years or older, the weekend warrior pattern was associated with a significantly reduced risk of osteoporosis compared with physical inactivity (Xu et al., 2025). Collectively, these findings suggest that, for individuals unable to engage in daily

exercise, achieving the World Health Organization-recommended duration of physical activity at a lower frequency in a structured, goal-oriented manner may represent a viable alternative strategy for reducing osteoporosis risk.

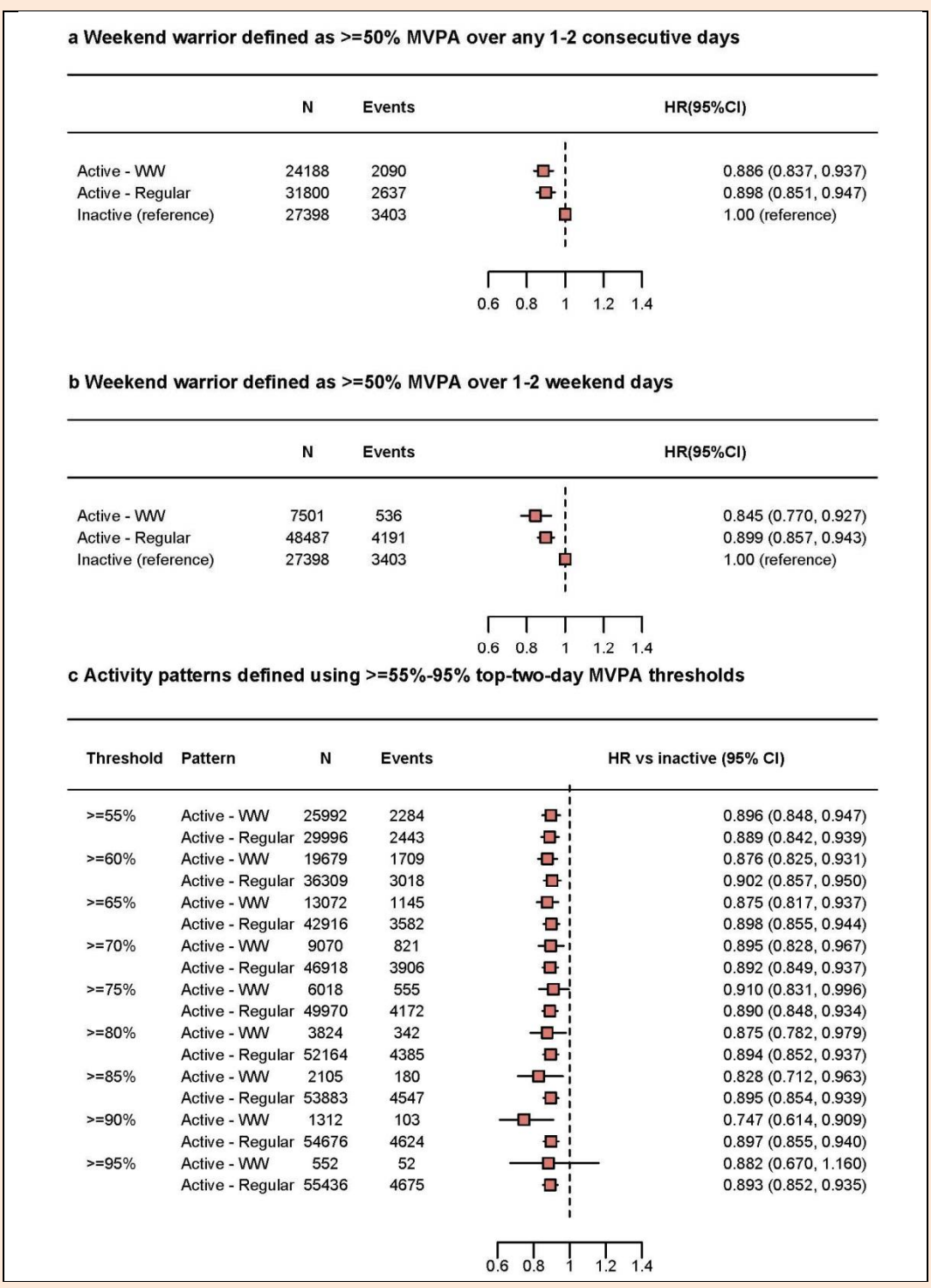

Figure 5. Associations between alternative weekend-warrior definitions and incident osteoarthritis. HRs and 95% CIs were estimated using Cox proportional hazards models adjusted for age at accelerometer assessment, sex, ethnicity, education, Townsend deprivation index, smoking status, alcohol intake frequency, and BMI. a, WW defined as accumulating >=50% of total weekly MVPA during any one or two consecutive days. b, WW defined as accumulating >=50% of total weekly MVPA during one or two weekend days. c, WW and regularly active patterns defined at top-two-day concentration thresholds from 55% to 95% in 5-percentage-point increments. At every definition, inactive participants accumulated <150 min/week of MVPA; among participants accumulating >=150 min/week, WW participants met the stated concentration threshold and regularly active participants did not. The reference group was inactive. Incident overall OA was defined as the first recorded ICD-10 M15-M19 diagnosis during follow-up among participants without OA at baseline. Squares indicate HR estimates and horizontal lines indicate 95% CIs. Abbreviations: BMI, body mass index; CI, confidence interval; HR, hazard ratio; ICD-10, International Classification of Diseases, 10th Revision; MVPA, moderate-to-vigorous physical activity; OA, osteoarthritis; WW, weekend warrior.

However, direct evidence from large-scale longitudinal cohort studies evaluating whether the weekend warrior pattern confers protection against osteoarthritis, and whether such potential benefits are comparable to those associated with a regularly active pattern, has remained limited. Preclinical evidence indicates that moderate-intensity physical activity alters synovial expression of proinflammatory mediators (eg, IL-1β, IL-6, TNF-α, and MMP-13) and increases anti-inflammatory and chondroprotective markers (eg, IL-4, IL-10, and lubricin) in rat models of osteoarthritis, supporting a potential role in slowing early disease progression through improved synovial cellular function (Castrogiovanni et al., 2019). In this longitudinal analysis of UK Biobank participants (median follow-up, 7.9 years), both the weekend warrior and regularly active patterns were associated with a lower risk of incident osteoarthritis relative to inactivity. After multivariable adjustment, both activity patterns were associated with an approximately 10% lower osteoarthritis risk. The estimate for the weekend warrior pattern was lower among women. Consistent with these results, data from the Osteoarthritis Initiative showed that women reporting moderate physical activity had slower structural progression of knee osteoarthritis than those with low activity, whereas comparable differences were not observed in men. Together, these findings suggest that meeting guideline-recommended physical activity targets may be associated with similar lower osteoarthritis risk, independent of activity frequency. These observations may inform physical activity-based prevention strategies for osteoarthritis, particularly for individuals with limited time to engage in regular physical activity throughout the week.

From a public health standpoint, sustaining moderate physical activity may be a practical approach to knee osteoarthritis prevention (Abbasi, 2017), and encouraging a weekend warrior pattern could broaden engagement in exercise-based preventive efforts. The association between the weekend warrior pattern and lower osteoarthritis risk may reflect multiple mechanisms. Accumulating activity into fewer sessions may improve muscle strength, enhance periarticular support, and lessen mechanical loading across the joint. However, the weekend warrior pattern may also entail potential harms. When physical activity is compressed into a limited time window, session intensity may be higher, which could increase the likelihood of sports-related injury. A systematic review suggested that exposure to vigorous activity-such as elite sports participation or heavy occupational workloads-may be associated with earlier onset of osteoarthritis, particularly in men (Migliorini et al., 2022). In contrast, other studies observed no clear association between the duration of sports participation and knee osteoarthritis risk (Gates et al., 2022). Collectively, these data indicate a nonlinearity in the association between physical activity and osteoarthritis risk, with potential benefit limited to a specific exposure range. Higher-intensity or excessive activity has been linked to greater risk of radiographic knee and hip osteoarthritis (Lefèvre-Colau et al., 2016), possibly through injury-related pathways. A meta-analysis of 14 observational studies reported a dose-response association between activity intensity and knee osteoarthritis risk, with higher intensity associated with greater risk than moderate-intensity activity. Limited evidence further suggests that activity levels exceeding international recommendations may be associated with increased osteoarthritis risk. However, much of the mechanistic and epidemiological evidence discussed above was derived from studies of knee or hip osteoarthritis. Because the outcome in the present study combined osteoarthritis diagnoses across anatomical sites, these mechanisms should be interpreted only as potential biological context and may not apply uniformly to knee, hip, hand, generalized, and other forms of osteoarthritis. Our findings therefore cannot determine whether the associations between physical activity patterns and osteoarthritis differ according to anatomical site. Accordingly, we evaluated the nonlinear association between weekly activity duration and osteoarthritis risk and observed a U-shaped pattern. The lowest estimated risk occurred at approximately 150 to 250 minutes per week. We then stratified both activity patterns according to whether weekly duration was below or above this threshold. When weekend warriors were defined using thresholds of ≥ 55% to ≥ 65% of weekly MVPA accumulated on the two most active days, both the weekend warrior and regularly active patterns were associated with a lower risk of osteoarthritis, regardless of whether total weekly MVPA was 150 - 250 minutes or > 250 minutes. Taken together, approximately 150 to 250 minutes per week may represent a lower risk across both activity patterns.

This study is strengthened by a large sample, a prospective design, and extensive adjustment for potential confounders. In addition, results were robust across multiple MVPA thresholds, and we formally assessed nonlinear associations between physical activity and incident osteoarthritis. Several limitations should be acknowledged. First, physical activity in the UK Biobank was assessed using a wrist-worn accelerometer over a single week. Changes in behavior during follow-up or an unrepresentative monitoring week may therefore have resulted in exposure misclassification. Accordingly, our study evaluated accelerometer-derived physical activity patterns at baseline rather than assuming that participants maintained a fixed behavioral pattern throughout the follow-up period. Future studies incorporating longer and repeated accelerometer assessments during follow-up are warranted. Second, MVPA classification was derived from heterogeneous activity types (eg, walking, jogging, and stationary cycling). Although this approach has been previously validated, variation in activity type may still have contributed to misclassification. Third, MVPA was quantified using wrist-worn accelerometers; however, the optimal intensity thresholds remain uncertain, despite consistent findings across alternative cut points. Fourth, because the cohort was predominantly White and based in the United Kingdom, generalizability to other populations may be limited. Fifth, comprehensive data on undiagnosed joint pain, previous injuries, and cumulative occupational mechanical loading were unavailable; therefore, residual confounding may remain. Sixth, our findings should therefore not be interpreted as specific to any individual joint site. Future studies using complete site-specific diagnostic histories are warranted. Finally, given the observational design, residual confound-

ing by unmeasured factors cannot be fully excluded, even after adjustment for measured covariates.

Conclusion

In this cohort, both weekend warrior and regularly active physical activity patterns were associated with a similarly lower risk of incident osteoarthritis. Accumulating guideline-recommended activity within 1 - 2 weekly sessions may therefore be a practical option for time-constrained individuals in osteoarthritis prevention.

Acknowledgements

This investigation was conducted using data from the UK Biobank, which obtained ethical approval from the North West Multicentre Research Ethics Committee (REC No. 11/NW/0382). This project reference number is 1047335. We are grateful to all participants who donated their time to this project and the UK Biobank team for collecting, processing, and disseminating data used in this study.
The data described in this article are publicly accessible from the UK Biobank via their standard data access procedure (https://www.ukbiobank.ac.uk/). The datasets generated during the current study are not publicly available but are available from the corresponding author upon reasonable request. Each author certifies that there are no funding or commercial associations (consultancies, stock ownership, equity interest, patent/licensing arrangements, etc.) that might pose a conflict of interest in connection with the submitted article related to the author or any immediate family members. This research did not receive funding. All experimental procedures were conducted in compliance with the relevant legal and ethical standards of the country where the study was carried out. The authors declare that no Generative AI or AI-assisted technologies were used in the writing of this manuscript.

References

Abbasi, J. (2017) Can exercise prevent knee osteoarthritis? *JAMA* **318**, 2169-2171. https://doi.org/10.1001/jama.2017.16144

Arnett, D.K., Blumenthal, R.S., Albert, M.A., Buroker, A.B., Goldberger, Z.D., Hahn, E.J., Himmelfarb, C.D., Khera, A., Lloyd-Jones, D., McEvoy, J.W., Michos, E.D., Miedema, M.D., Muñoz, D., Smith, S.C., Jr., Virani, S.S., Williams, K.A., Sr., Yeboah, J. and Ziaeian, B. (2019) 2019 ACC/AHA guideline on the primary prevention of cardiovascular disease: A report of the American College of Cardiology/American Heart Association Task Force on Clinical Practice Guidelines. *Circulation* **140**, e596-e646. https://doi.org/10.1161/cir.0000000000000678

Bycroft, C., Freeman, C., Petkova, D., Band, G., Elliott, L.T., Sharp, K., Motyer, A., Vukcevic, D., Delaneau, O., O'Connell, J., Cortes, A., Welsh, S., Young, A., Effingham, M., McVean, G., Leslie, S., Allen, N., Donnelly, P. and Marchini, J. (2018) The UK Biobank resource with deep phenotyping and genomic data. *Nature* **562**, 203-209. https://doi.org/10.1038/s41586-018-0579-z

Bull, F.C., Al-Ansari, S.S., Biddle, S., Borodulin, K., Buman, M.P., Cardon, G., Carty, C., Chaput, J.P., Chastin, S., Chou, R., Dempsey, P.C., DiPietro, L., Ekelund, U., Firth, J., Friedenreich, C.M., Garcia, L., Gichu, M., Jago, R., Katzmarzyk, P.T., Lambert, E., Leitzmann, M., Milton, K., Ortega, F.B., Ranasinghe, C., Stamatakis, E., Tiedemann, A., Troiano, R.P., van der Ploeg, H.P., Wari, V. and Willumsen, J.F. (2020) World Health Organization 2020 guidelines on physical activity and sedentary behaviour. British Journal of Sports Medicine 54, 1451-1462. https://doi.org/10.1136/bjsports-2020-102955

Cao, Z., Min, J. and Xu, C. (2025) Accelerometer-derived "weekend warrior" physical activity pattern and incident type 2 diabetes. *Cardiovascular Diabetology* **24**, 130. https://doi.org/10.1186/s12933-025-02676-x

Castrogiovanni, P., Di Rosa, M., Ravalli, S., Castorina, A., Guglielmino, C., Imbesi, R., Vecchio, M., Drago, F., Szychlinska, M.A. and Musumeci, G. (2019) Moderate physical activity as a prevention method for knee osteoarthritis and the role of synoviocytes as biological key. *International Journal of Molecular Sciences* **20**. https://doi.org/10.3390/ijms20030511

Ding, C., Jones, G., Wluka, A.E. and Cicuttini, F. (2010) What can we learn about osteoarthritis by studying a healthy person against a person with early onset of disease? *Current Opinion in Rheumatology* **22**, 520-527. https://doi.org/10.1097/bor.0b013e32833b90e9

Doherty, A., Jackson, D., Hammerla, N., Plötz, T., Olivier, P., Granat, M.H., White, T., van Hees, V.T., Trenell, M.I., Owen, C.G., Preece, S.J., Gillions, R., Sheard, S., Peakman, T., Brage, S. and Wareham, N.J. (2017) Large scale population assessment of physical activity using wrist worn accelerometers: The UK Biobank Study. *PLoS ONE* **12**, e0169649. https://doi.org/10.1371/journal.pone.0169649

Fry, A., Littlejohns, T.J., Sudlow, C., Doherty, N., Adamska, L., Sprosen, T., Collins, R. and Allen, N.E. (2017) Comparison of sociodemographic and health-related characteristics of UK Biobank participants with those of the general population. *American Journal of Epidemiology* **186**, 1026-1034. https://doi.org/10.1093/aje/kwx246

Gates, L.S., Perry, T.A., Golightly, Y.M., Nelson, A.E., Callahan, L.F., Felson, D., Nevitt, M., Jones, G., Cooper, C., Batt, M.E., Sanchez-Santos, M.T. and Arden, N.K. (2022) Recreational physical activity and risk of incident knee osteoarthritis: An international meta-analysis of individual participant-level data. *Arthritis & Rheumatology* **74**, 612-622. https://doi.org/10.1002/art.42001

Guo, R., Ou, Y.N., Ma, L.Y., Tang, L., Yang, L., Feng, J.F., Cheng, W., Tan, L. and Yu, J.T. (2024) Osteoarthritis, osteoarthritis treatment and risk of incident dementia: a prospective cohort study based on UK Biobank. Age and Ageing 53, afae167. https://doi.org/10.1093/ageing/afae167

GBD 2021 Osteoarthritis Collaborators (2023) Global, regional, and national burden of osteoarthritis, 1990-2020 and projections to 2050: A systematic analysis for the Global Burden of Disease Study 2021. *The Lancet Rheumatology* **5**, e508-e522.

Hamer, M., Biddle, S.J.H. and Stamatakis, E. (2017) Weekend warrior physical activity pattern and common mental disorder: A population wide study of 108,011 British adults. *International Journal of Behavioral Nutrition and Physical Activity* **14**, 96. https://doi.org/10.1186/s12966-017-0549-0

Hootman, J.M., Macera, C.A., Ham, S.A., Helmick, C.G. and Sniezek, J.E. (2003) Physical activity levels among the general US adult population and in adults with and without arthritis. *Arthritis & Rheumatism* **49**, 129-135. https://doi.org/10.1002/art.10911

Huffman, K.F., Ambrose, K.R., Nelson, A.E., Allen, K.D., Golightly, Y.M. and Callahan, L.F. (2024) The critical role of physical activity and weight management in knee and hip osteoarthritis: A narrative review. *The Journal of Rheumatology* **51**, 224-233. https://doi.org/10.3899/jrheum.2023-0819

Jurado-Castro, J.M., Muñoz-López, M., Ledesma, A.S. and Ranchal-Sanchez, A. (2022) Effectiveness of exercise in patients with overweight or obesity suffering from knee osteoarthritis: A systematic review and meta-analysis. *International Journal of Environmental Research and Public Health* **19**. https://doi.org/10.3390/ijerph191710510

Khurshid, S., Al-Alusi, M.A., Churchill, T.W., Guseh, J.S. and Ellinor, P.T. (2023) Accelerometer-derived "weekend warrior" physical activity and incident cardiovascular disease. *JAMA* **330**, 247-252. https://doi.org/10.1001/jama.2023.10875

Lee, I.M., Sesso, H.D., Oguma, Y. and Paffenbarger, R.S., Jr. (2004) The "weekend warrior" and risk of mortality. *American Journal of Epidemiology* **160**, 636-641. https://doi.org/10.1093/aje/kwh274

Lefèvre-Colau, M.M., Nguyen, C., Haddad, R., Delamarche, P., Paris, G., Palazzo, C., Poiraudeau, S., Rannou, F. and Roren, A. (2016) Is physical activity, practiced as recommended for health benefit, a risk factor for osteoarthritis? *Annals of Physical and Rehabilitation Medicine* **59**, 196-206. https://doi.org/10.1016/j.rehab.2016.02.007

Lei, L., Li, J., Wang, W., Zhang, L., Meng, X., Xia, C., Li, Y., Zhao, Y., Yuan, X., Wang, X. and Wang, F. (2025) Accelerometer-derived "weekend warrior" and regularly active physical activity and incident diabetes. *Obesity* **33**, 1154-1164. https://doi.org/10.1002/oby.24278

Li, H. and Wang, H. (2025) Association between weekend warrior physical activity pattern and bone mineral density among adults: National Health and Nutrition Examination Survey. *Osteoporosis International* **36**, 1221-1229. https://doi.org/10.1007/s00198-025-07535-9

Lin, F., Lin, Y., Chen, L., Huang, T., Lin, T., He, J., Lu, X., Chen, X., Wang, Y., Ye, Q. and Cai, G. (2024) Association of physical activity pattern and risk of Parkinson's disease. *npj Digital Medicine* **7**, 137. https://doi.org/10.1038/s41746-024-01135-3

Lynch, M., Bucknall, M., Jagger, C. and Wilkie, R. (2022) Healthy working life expectancy at age 50 for people with and without osteoarthritis in local and national English populations. *Scientific Reports* **12**, 2408. https://doi.org/10.1038/s41598-022-06490-3

Migliorini, F., Torsiello, E., La Padula, G., Oliva, F. and Maffulli, N. (2022) The association between sex and osteoarthritis in the physically active population: A systematic review. *Sports Medicine and Arthroscopy Review* **30**, 87-91. https://doi.org/10.1097/jsa.0000000000000346

O'Donovan, G., Sarmiento, O.L. and Hamer, M. (2018) The rise of the "weekend warrior". *Journal of Orthopaedic & Sports Physical Therapy* **48**, 604-606. https://doi.org/10.2519/jospt.2018.0611

Piercy, K.L., Troiano, R.P., Ballard, R.M., Carlson, S.A., Fulton, J.E., Galuska, D.A., George, S.M. and Olson, R.D. (2018) The Physical Activity Guidelines for Americans. *JAMA* **320**, 2020-2028. https://doi.org/10.1001/jama.2018.14854

Prieto-Alhambra, D., Judge, A., Javaid, M.K., Cooper, C., Diez-Perez, A. and Arden, N.K. (2014) Incidence and risk factors for clinically diagnosed knee, hip and hand osteoarthritis: Influences of age, gender and osteoarthritis affecting other joints. *Annals of the Rheumatic Diseases* **73**, 1659-1664. https://doi.org/10.1136/annrheumdis-2013-203355

Racunica, T.L., Teichtahl, A.J., Wang, Y., Wluka, A.E., English, D.R., Giles, G.G., O'Sullivan, R. and Cicuttini, F.M. (2007) Effect of physical activity on articular knee joint structures in community-based adults. *Arthritis & Rheumatism* **57**, 1261-1268. https://doi.org/10.1002/art.22990

Tang, S., Zhang, C., Oo, W.M., Fu, K., Risberg, M.A., Bierma-Zeinstra, S.M., Neogi, T., Atukorala, I., Malfait, A.M., Ding, C. and Hunter, D.J. (2025) Osteoarthritis. *Nature Reviews Disease Primers* **11**, 10. https://doi.org/10.1038/s41572-025-00594-6

Walmsley, R., Chan, S., Smith-Byrne, K., Ramakrishnan, R., Woodward, M., Rahimi, K., Dwyer, T., Bennett, D. and Doherty, A. (2021) Reallocation of time between device-measured movement behaviours and risk of incident cardiovascular disease. *British Journal of Sports Medicine* **56**, 1008-1017. https://doi.org/10.1136/bjsports-2021-104050

Wang, Y., Long, L., Liu, L., Fan, P., Zheng, X., Li, X., Wang, Y.T., Xu, B.S. and Tao, Y.A. (2025) Association of the various physical activity patterns with low bone mineral density in Americans aged 20-60. *Archives of Osteoporosis* **20**, 23. https://doi.org/10.1007/s11657-024-01479-z

Xu, J., Dai, C., Sun, X., Chen, F., Cheng, M., Li, L. and Li, X. (2025) Association between weekend warrior physical activity patterns, physical activity intensity, and osteoporosis in adults over 50 years old: A cross-sectional study based on the NHANES 2017-2020. *BMC Public Health* **25**, 3370. https://doi.org/10.1186/s12889-025-24209-7

Zhao, R., Ding, J., Ji, Y., Cheng, Z. and Wang, Y. (2025) Associations of "weekend warrior" and other physical activity patterns with the risk of metabolic syndrome and its components: From NHANES 2007-2018. *Journal of Sports Sciences* **43**, 1606-1615. https://doi.org/10.1080/02640414.2025.2515757

Key points

- Both weekend warrior and regularly active patterns were associated with lower incident osteoarthritis risk compared with inactivity.
- Lower risks were similar between concentrated and regularly distributed physical activity patterns.
- These findings support flexible physical activity recommendations for adults with limited time for daily exercise.

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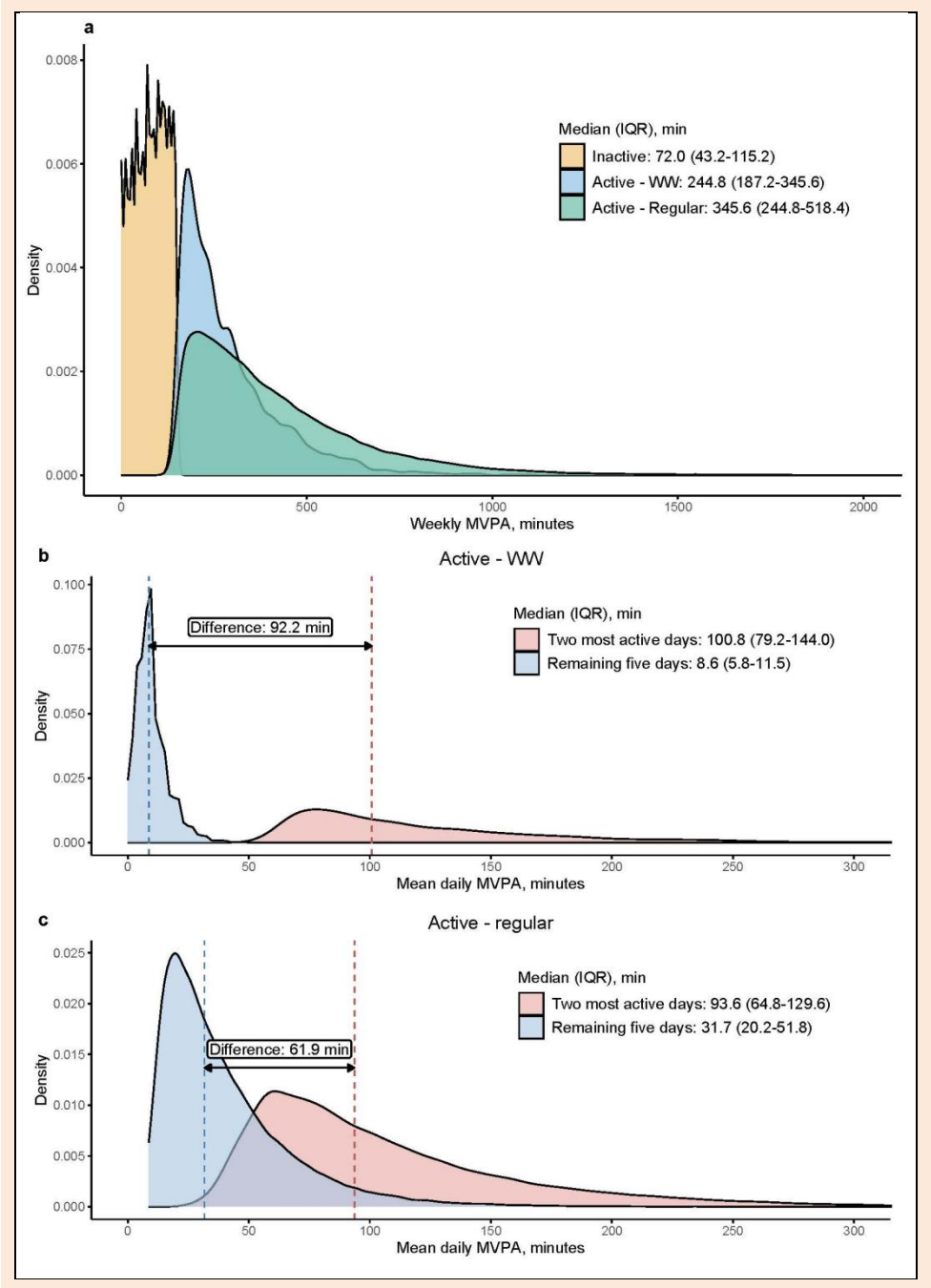
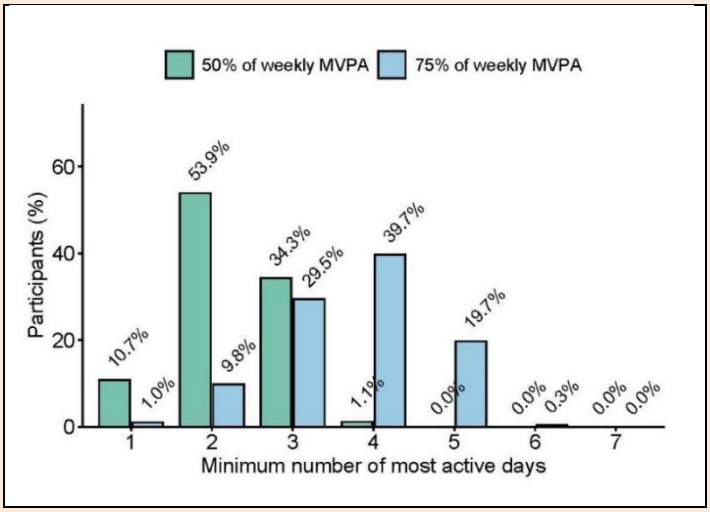
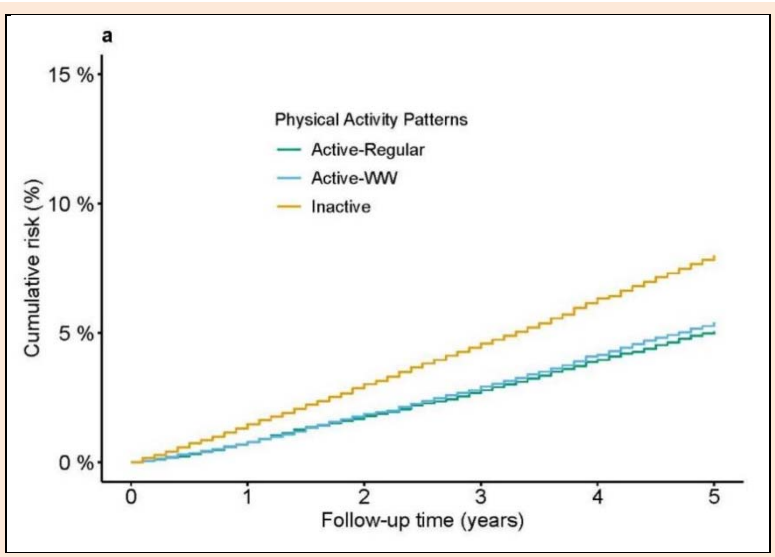
Supplementary Materials



Supplementary Figure 1. Distribution of accelerometer-measured MVPA according to physical activity pattern using the 75% top-two-day definition. a, Distribution of total weekly MVPA in inactive, WW, and regularly active participants. b and c, Distributions of mean daily MVPA during the two most active days and the remaining five days among WW and regularly active participants, respectively. Dashed vertical lines indicate medians; annotations report the median and IQR, and the double-headed horizontal arrow shows the difference between the two medians. Inactive participants accumulated <150 min/week of MVPA. Among participants accumulating >=150 min/week, WW participants accumulated >=75% of total weekly MVPA on the two most active days, whereas regularly active participants accumulated <75% on those days. Density is explicitly defined as the relative population distribution estimated using kernel density estimation. Abbreviations: IQR, interquartile range; MVPA, moderate-to-vigorous physical activity; WW, weekend warrior.



Supplementary Figure 2. Minimum number of most active days required to accumulate 50% or 75% of total weekly MVPA. Among participants accumulating >=150 min/week of MVPA, bars show the percentage requiring one through seven of their most active days to accumulate at least 50% or 75% of total weekly MVPA. Percentages are displayed above all bars, including zero values. Abbreviation: MVPA, moderate-to-vigorous physical activity.



Supplementary Figure 3. Five-year cumulative risk of incident osteoarthritis by physical activity pattern. Cumulative risk curves were truncated at 5 years. Inactive participants accumulated <150 min/week of MVPA. Among participants accumulating >=150 min/week, WW participants accumulated >=50% of total weekly MVPA on the two most active days, whereas regularly active participants accumulated <50% on those days. Incident overall OA was defined as the first recorded ICD-10 M15-M19 diagnosis during follow-up among participants without OA at baseline. Abbreviations: ICD-10, International Classification of Diseases, 10th Revision; MVPA, moderate-to-vigorous physical activity; OA, osteoarthritis; WW, weekend warrior.

Supplementary Table 1. Definitions of covariates.

Covariate	Definition	UK Biobank Field ID(s)
Age	Age at accelerometer assessment (years), continuous.	21003, 53, 90010
Sex	Female or male.	31
Ethnicity	White or non-White.	21000
Education	College/university degree or above versus other qualifications.	6138
Townsend deprivation index	Area-level socioeconomic deprivation score; higher values indicate greater deprivation.	189
Smoking status	Never, former, or current smoker.	20116
Alcohol intake frequency	Daily/almost daily, 3 - 4 times/week, 1 - 2 times/week, 1 - 3 times/month, special occasions only, or never.	1558
Body mass index	Weight divided by height squared (kg/m^2), continuous.	21001

Supplementary Table 2. Threshold-gradient associations after additional adjustment for total weekly MVPA.

Top-two-day threshold	Weekend warrior, HR (95% CI); P	Regularly active, HR (95% CI); P
≥ 50%	0.864 (0.813, 0.918); < 0.001	0.843 (0.777, 0.913); < 0.001
≥ 55%	0.867 (0.814, 0.924); < 0.001	0.848 (0.789, 0.910); < 0.001
≥ 60%	0.854 (0.799, 0.913); < 0.001	0.868 (0.811, 0.929); < 0.001
≥ 65%	0.853 (0.793, 0.919); < 0.001	0.865 (0.810, 0.923); < 0.001
≥ 70%	0.872 (0.803, 0.946); < 0.001	0.856 (0.804, 0.912); < 0.001
≥ 75%	0.887 (0.807, 0.974); 0.012	0.855 (0.803, 0.909); < 0.001
≥ 80%	0.856 (0.764, 0.960); 0.008	0.861 (0.810, 0.916); < 0.001
≥ 85%	0.811 (0.696, 0.944); 0.007	0.864 (0.813, 0.918); < 0.001
≥ 90%	0.734 (0.602, 0.894); 0.002	0.867 (0.816, 0.921); < 0.001
≥ 95%	0.864 (0.656, 1.137); 0.297	0.860 (0.810, 0.914); < 0.001

HRs were estimated using Cox proportional hazards models. The exposure was the physical activity pattern defined separately at each top-two-day threshold: inactive (<150 min/week of MVPA), WW (>=150 min/week of MVPA and at least the stated percentage of total weekly MVPA accumulated on the two most active days), or regularly active (>=150 min/week of MVPA but below the stated percentage). Inactive participants were the reference group. The outcome was incident overall OA, defined as the first recorded ICD-10 M15-M19 diagnosis during follow-up among participants without OA at baseline. Models adjusted for age at accelerometer assessment, sex, ethnicity, education, Townsend deprivation index, smoking status, alcohol intake frequency, and BMI, and additionally adjusted for continuous total weekly MVPA (min/week). N=83,386; OA events=8,130. Abbreviations: BMI, body mass index; CI, confidence interval; HR, hazard ratio; ICD-10, International Classification of Diseases, 10th Revision; MVPA, moderate-to-vigorous physical activity; OA, osteoarthritis; WW, weekend warrior.

Supplementary Table 3. Threshold-gradient associations stratified by weekly MVPA volume.

Threshold	MVPA volume (min/week) and pattern	HR (95% CI)	P value
Top two days ≥ 50%	150 - 250, regularly active	0.934 (0.828, 1.053)	0.264
	150 - 250, weekend warrior	0.874 (0.819, 0.933)	< 0.001
	> 250, regularly active	0.880 (0.823, 0.941)	< 0.001
	> 250, weekend warrior	0.909 (0.857, 0.965)	0.002
Top two days ≥ 55%	150 - 250, regularly active	0.908 (0.831, 0.992)	0.033
	150 - 250, weekend warrior	0.871 (0.810, 0.936)	< 0.001
	> 250, regularly active	0.884 (0.832, 0.938)	< 0.001
	> 250, weekend warrior	0.916 (0.857, 0.979)	0.010
Top two days ≥ 60%	150 - 250, regularly active	0.919 (0.849, 0.994)	0.036
	150 - 250, weekend warrior	0.854 (0.790, 0.923)	< 0.001
	> 250, regularly active	0.897 (0.847, 0.949)	< 0.001
	> 250, weekend warrior	0.897 (0.832, 0.968)	0.005
Top two days ≥ 65%	150 - 250, regularly active	0.894 (0.833, 0.960)	0.002
	150 - 250, weekend warrior	0.868 (0.793, 0.950)	0.002
	> 250, regularly active	0.900 (0.853, 0.951)	< 0.001
	> 250, weekend warrior	0.883 (0.807, 0.966)	0.007
Top two days ≥ 70%	150 - 250, regularly active	0.887 (0.828, 0.949)	< 0.001
	150 - 250, weekend warrior	0.879 (0.794, 0.973)	0.013
	> 250, regularly active	0.895 (0.848, 0.944)	< 0.001
	> 250, weekend warrior	0.913 (0.822, 1.014)	0.089
Top two days ≥ 75%	150 - 250, regularly active	0.882 (0.826, 0.941)	< 0.001
	150 - 250, weekend warrior	0.896 (0.796, 1.010)	0.072
	> 250, regularly active	0.894 (0.848, 0.943)	< 0.001
	> 250, weekend warrior	0.927 (0.815, 1.053)	0.243
Top two days ≥ 80%	150 - 250, regularly active	0.889 (0.834, 0.947)	< 0.001
	150 - 250, weekend warrior	0.855 (0.740, 0.988)	0.033
	> 250, regularly active	0.897 (0.851, 0.945)	< 0.001
	> 250, weekend warrior	0.905 (0.766, 1.069)	0.240
Top two days ≥ 85%	150 - 250, regularly active	0.894 (0.840, 0.952)	< 0.001
	150 - 250, weekend warrior	0.755 (0.614, 0.927)	0.007
	> 250, regularly active	0.896 (0.851, 0.944)	< 0.001
	> 250, weekend warrior	0.925 (0.747, 1.146)	0.476
Top two days ≥ 90%	150 - 250, regularly active	0.896 (0.842, 0.953)	< 0.001
	150 - 250, weekend warrior	0.673 (0.522, 0.867)	0.002
	> 250, regularly active	0.897 (0.852, 0.945)	< 0.001
	> 250, weekend warrior	0.889 (0.656, 1.206)	0.451
Top two days ≥ 95%	150 - 250, regularly active	0.887 (0.834, 0.943)	< 0.001
	150 - 250, weekend warrior	0.769 (0.527, 1.123)	0.174
	> 250, regularly active	0.896 (0.851, 0.944)	< 0.001
	> 250, weekend warrior	1.049 (0.707, 1.555)	0.813

HRs were estimated using Cox proportional hazards models stratified by weekly MVPA volume. The exposure was the physical activity pattern defined separately at each top-two-day threshold: inactive (<150 min/week of MVPA), WW (>=150 min/week and at least the stated percentage of total weekly MVPA on the two most active days), or regularly active (>=150 min/week and below the stated percentage). Active WW and regularly active participants were further classified as 150-250 or >250 min/week of MVPA; inactive participants were the reference group for every comparison. The outcome was incident overall OA, defined as the first recorded ICD-10 M15-M19 diagnosis during follow-up among participants without OA at baseline. Models adjusted for age at accelerometer assessment, sex, ethnicity, education, Townsend deprivation index, smoking status, alcohol intake frequency, and BMI. Abbreviations: BMI, body mass index; CI, confidence interval; HR, hazard ratio; ICD-10, International Classification of Diseases, 10th Revision; MVPA, moderate-to-vigorous physical activity; OA, osteoarthritis; WW, weekend warrior.

Supplementary Table 4. **Threshold-gradient sensitivity analysis using any two consecutive days.**

Consecutive-two-day threshold	Weekend warrior, HR (95% CI); P	Regularly active, HR (95% CI); P
≥ 55%	0.868 (0.812, 0.927); < 0.001	0.902 (0.858, 0.949); < 0.001
≥ 60%	0.878 (0.815, 0.946); < 0.001	0.896 (0.853, 0.941); < 0.001
≥ 65%	0.840 (0.766, 0.921); < 0.001	0.900 (0.858, 0.944); < 0.001
≥ 70%	0.863 (0.775, 0.961); 0.007	0.895 (0.854, 0.939); < 0.001
≥ 75%	0.860 (0.755, 0.980); 0.024	0.894 (0.853, 0.938); < 0.001
≥ 80%	0.850 (0.723, 1.000); 0.050	0.894 (0.853, 0.937); < 0.001
≥ 85%	0.762 (0.606, 0.958); 0.020	0.895 (0.854, 0.938); < 0.001
≥ 90%	0.702 (0.521, 0.945); 0.020	0.895 (0.854, 0.938); < 0.001
≥ 95%	0.669 (0.421, 1.063); 0.089	0.894 (0.853, 0.937); < 0.001

HRs were estimated using Cox proportional hazards models. At each threshold, the exposure was classified as inactive (<150 min/week of MVPA), consecutive-day WW (>=150 min/week and at least the stated percentage of total weekly MVPA accumulated during any two consecutive days), or regularly active (>=150 min/week and below the stated percentage). Inactive participants were the reference group. The outcome was incident overall OA, defined as the first recorded ICD-10 M15-M19 diagnosis during follow-up among participants without OA at baseline. Models adjusted for age at accelerometer assessment, sex, ethnicity, education, Townsend deprivation index, smoking status, alcohol intake frequency, and BMI. Abbreviations: BMI, body mass index; CI, confidence interval; HR, hazard ratio; ICD-10, International Classification of Diseases, 10th Revision; MVPA, moderate-to-vigorous physical activity; OA, osteoarthritis; WW, weekend warrior.

Supplementary Table 5. **Threshold-gradient lag analyses excluding early osteoarthritis events**

Threshold	Lag period	Weekend warrior, HR (95% CI); P	Regularly active, HR (95% CI); P
≥ 50%	1-year lag	0.922 (0.874, 0.973); 0.003	0.908 (0.850, 0.970); 0.004
	2-year lag	0.924 (0.872, 0.979); 0.007	0.907 (0.845, 0.974); 0.007
	3-year lag	0.930 (0.873, 0.991); 0.024	0.903 (0.836, 0.976); 0.010
≥ 55%	1-year lag	0.924 (0.872, 0.979); 0.008	0.912 (0.861, 0.966); 0.002
	2-year lag	0.913 (0.857, 0.972); 0.005	0.924 (0.868, 0.983); 0.012
	3-year lag	0.918 (0.857, 0.983); 0.015	0.924 (0.863, 0.989); 0.022
≥ 60%	1-year lag	0.910 (0.854, 0.969); 0.003	0.922 (0.873, 0.974); 0.004
	2-year lag	0.898 (0.839, 0.962); 0.002	0.931 (0.878, 0.987); 0.017
	3-year lag	0.908 (0.843, 0.978); 0.011	0.929 (0.871, 0.991); 0.025
≥ 65%	1-year lag	0.910 (0.846, 0.978); 0.010	0.920 (0.873, 0.970); 0.002
	2-year lag	0.901 (0.834, 0.975); 0.009	0.924 (0.874, 0.978); 0.007
	3-year lag	0.907 (0.833, 0.987); 0.024	0.926 (0.870, 0.985); 0.015
≥ 70%	1-year lag	0.935 (0.862, 1.014); 0.106	0.914 (0.868, 0.962); < 0.001
	2-year lag	0.920 (0.842, 1.004); 0.063	0.918 (0.869, 0.971); 0.003
	3-year lag	0.928 (0.843, 1.022); 0.129	0.919 (0.865, 0.977); 0.007
≥ 75%	1-year lag	0.949 (0.863, 1.044); 0.286	0.913 (0.868, 0.961); < 0.001
	2-year lag	0.923 (0.832, 1.024); 0.130	0.918 (0.869, 0.970); 0.002
	3-year lag	0.943 (0.843, 1.055); 0.305	0.918 (0.865, 0.975); 0.005
≥ 80%	1-year lag	0.901 (0.801, 1.014); 0.083	0.919 (0.874, 0.967); 0.001
	2-year lag	0.876 (0.770, 0.997); 0.044	0.922 (0.874, 0.974); 0.003
	3-year lag	0.879 (0.764, 1.012); 0.073	0.925 (0.871, 0.981); 0.009
≥ 85%	1-year lag	0.878 (0.751, 1.026); 0.101	0.920 (0.875, 0.967); < 0.001
	2-year lag	0.875 (0.739, 1.035); 0.119	0.921 (0.872, 0.972); 0.003
	3-year lag	0.912 (0.761, 1.093); 0.319	0.921 (0.869, 0.977); 0.006
≥ 90%	1-year lag	0.782 (0.637, 0.959); 0.018	0.922 (0.877, 0.969); 0.001
	2-year lag	0.794 (0.637, 0.988); 0.039	0.922 (0.874, 0.973); 0.003
	3-year lag	0.844 (0.669, 1.064); 0.151	0.923 (0.871, 0.979); 0.008
≥ 95%	1-year lag	0.906 (0.679, 1.210); 0.504	0.918 (0.873, 0.965); < 0.001
	2-year lag	0.852 (0.618, 1.174); 0.327	0.919 (0.871, 0.970); 0.002
	3-year lag	0.907 (0.646, 1.274); 0.575	0.921 (0.869, 0.977); 0.006

HRs were estimated using Cox proportional hazards models after excluding participants with follow-up of no more than the stated 1-, 2-, 3-year lag interval, thereby excluding OA events occurring within that interval. The exposure was the physical activity pattern defined separately at each top-two-day threshold: inactive (<150 min/week of MVPA), WW (>=150 min/week and at least the stated percentage of total weekly MVPA on the two most active days), or regularly active (>=150 min/week and below the stated percentage). Inactive participants were the reference group. The outcome was incident overall OA, defined as the first recorded ICD-10 M15-M19 diagnosis during follow-up among participants without OA at baseline. Models adjusted for age at accelerometer assessment, sex, ethnicity, education, Townsend deprivation index, smoking status, alcohol intake frequency, and BMI. Abbreviations: BMI, body mass index; CI, confidence interval; HR, hazard ratio; ICD-10, International Classification of Diseases, 10th Revision; MVPA, moderate-to-vigorous physical activity; OA, osteoarthritis; WW, weekend warrior.

Supplementary Table 6. Threshold-gradient direct comparison of weekend warriors with regularly active participants

Top-two-day threshold	Covariate-adjusted HR (95% CI); P	Additionally adjusted for weekly MVPA, HR (95% CI); P
≥ 50%	1.004 (0.945, 1.067); 0.901	1.031 (0.968, 1.099); 0.344
≥ 55%	1.006 (0.950, 1.065); 0.844	1.028 (0.969, 1.091); 0.362
≥ 60%	0.968 (0.912, 1.028); 0.291	0.988 (0.929, 1.051); 0.699
≥ 65%	0.971 (0.908, 1.038); 0.382	0.989 (0.923, 1.059); 0.752
≥ 70%	0.998 (0.925, 1.077); 0.965	1.019 (0.943, 1.101); 0.633
≥ 75%	1.016 (0.930, 1.111); 0.719	1.038 (0.949, 1.136); 0.413
≥ 80%	0.975 (0.873, 1.088); 0.649	0.996 (0.891, 1.114); 0.948
≥ 85%	0.920 (0.792, 1.068); 0.271	0.939 (0.808, 1.091); 0.409
≥ 90%	0.827 (0.680, 1.006); 0.057	0.846 (0.695, 1.030); 0.095
≥ 95%	0.978 (0.744, 1.286); 0.873	1.001 (0.761, 1.316); 0.997

HRs were estimated using Cox proportional hazards models restricted to active participants accumulating >=150 min/week of MVPA. At each top-two-day threshold, the exposure contrasted WW participants (at least the stated percentage of total weekly MVPA accumulated on the two most active days) with regularly active participants (below the stated percentage); regularly active participants were the reference group. The outcome was incident overall OA, defined as the first recorded ICD-10 M15-M19 diagnosis during follow-up among participants without OA at baseline. The covariate-adjusted model included age at accelerometer assessment, sex, ethnicity, education, Townsend deprivation index, smoking status, alcohol intake frequency, and BMI; the second model additionally included continuous total weekly MVPA (min/week). Abbreviations: BMI, body mass index; CI, confidence interval; HR, hazard ratio; ICD-10, International Classification of Diseases, 10th Revision; MVPA, moderate-to-vigorous physical activity; OA, osteoarthritis; WW, weekend warrior.

Supplementary Table 7. Threshold-gradient sensitivity analysis excluding BMI.

Top-two-day threshold	Weekend warrior, HR (95% CI); P	Regularly active, HR (95% CI); P
≥ 50%	0.779 (0.741, 0.818); < 0.001	0.751 (0.707, 0.798); < 0.001
≥ 55%	0.782 (0.741, 0.826); < 0.001	0.757 (0.718, 0.799); < 0.001
≥ 60%	0.770 (0.725, 0.816); < 0.001	0.769 (0.731, 0.809); < 0.001
≥ 65%	0.770 (0.720, 0.824); < 0.001	0.769 (0.733, 0.807); < 0.001
≥ 70%	0.794 (0.735, 0.857); < 0.001	0.764 (0.729, 0.801); < 0.001
≥ 75%	0.809 (0.739, 0.885); < 0.001	0.764 (0.729, 0.801); < 0.001
≥ 80%	0.781 (0.699, 0.874); < 0.001	0.768 (0.734, 0.805); < 0.001
≥ 85%	0.736 (0.633, 0.856); < 0.001	0.771 (0.736, 0.807); < 0.001
≥ 90%	0.674 (0.554, 0.821); < 0.001	0.772 (0.737, 0.808); < 0.001
≥ 95%	0.792 (0.602, 1.042); 0.096	0.769 (0.735, 0.805); < 0.001

HRs were estimated using Cox proportional hazards models as a sensitivity analysis excluding BMI from the covariate set. The exposure was the physical activity pattern defined separately at each top-two-day threshold: inactive (<150 min/week of MVPA), WW (>=150 min/week and at least the stated percentage of total weekly MVPA on the two most active days), or regularly active (>=150 min/week and below the stated percentage). Inactive participants were the reference group. The outcome was incident overall OA, defined as the first recorded ICD-10 M15-M19 diagnosis during follow-up among participants without OA at baseline. Models adjusted for age at accelerometer assessment, sex, ethnicity, education, Townsend deprivation index, smoking status, and alcohol intake frequency. Abbreviations: BMI, body mass index; CI, confidence interval; HR, hazard ratio; ICD-10, International Classification of Diseases, 10th Revision; MVPA, moderate-to-vigorous physical activity; OA, osteoarthritis; WW, weekend warrior.