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Accelerometer-derived "weekend warrior" physical activity, sedentary behavior, and risk of dementia

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Abstract

Background Research has shown that sedentary behavior (SB) may increase dementia risk, but it remains unclear whether concentrated moderate to vigorous physical activity (MVPA) can compensate such negative effects. This study aimed to explore the association between different MVPA patterns combined with SB time and the risk of dementia.

Methods This prospective study used data from the UK Biobank cohort, which provided accelerometer-based physical activity data for a full week from February 2013 to December 2015. Participants were categorized into "weekend warriors (WW)" group, engaged in more than 50% MVPA (≥ 150 min/week) on 1 to 2 days; inactive group (total MVPA < 150 min/week); and regular group, who met the recommended MVPA (≥ 150 min/week) but not WW. The participants were further divided into six groups based on SB duration (≥ 8.52 h/day or < 8.52 h/day). A multivariable Cox model was used to assess the relationship between these patterns and the risk of dementia, adjusted by age, gender, ethnicity, Townsend deprivation index, education level, employment status, alcohol consumption, smoking, BMI, and baseline comorbidities (including cardiovascular disease, hypertension, and diabetes).

Results We included 91,948 participants without dementia at baseline. During a median follow-up of 7.93 years, 736 participants developed all-cause dementia. When the MVPA threshold was set at 150 min per week, 16,149 participants (17.5%) were classified as WW with long SB, 19,055 (20.7%) as regular with long SB, and 21,909 (23.8%) as inactive with long SB. Compared to inactive and long SB time, the WW group showed a reduction in dementia risk (WW with long SB time: HR = 0.69, 95% CI: 0.54–0.87, $P = 0.002$; WW with short SB time: HR = 0.74, 95% CI: 0.56–0.97, $P = 0.029$). And regular group with shorter SB time was associated with a lower dementia risk (HR = 0.75, 95% CI: 0.59–0.96, $P = 0.021$), but not in the group with longer SB time.

Conclusions The WW pattern may help mitigate the dementia risk associated with prolonged SB, suggesting that the quality and intensity of physical activity are also important factors.

Keywords Sedentary behavior, Physical activity, Dementia, UK Biobank, Weekend warrior

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Background

The growing number of dementia and the lack of effective treatments underscore the urgency of better understanding modifiable risk factors [1]. Addressing these risk factors could potentially prevent or delay up to 45% of dementia cases [2]. Lack of physical activity is a common modifiable risk factor among middle-aged individuals [2]. In recent years, sedentary time has steadily increased, with the average daily sitting time for adults rising from 5.5 to 6.4 h [3]. Notably, even though older adults have more leisure time, such as after retirement, they still spend over 9 h a day engaged in sedentary activities [3]. A recent meta-analysis indicates that the more time spent in sedentary behavior (SB), the higher the incidence of dementia [4]. The average daily SB shows a non-linear association with the incidence of dementia [5].

Current research suggests that even among participants with high levels of SB, those who engage in higher levels of physical activity (PA) have a lower risk of developing dementia (0.73 [0.62, 0.86]) [6], indicating that combining PA with reduced SB could help lower the risk of dementia. Additionally, regardless of age, higher levels of moderate to vigorous physical activity (MVPA) have been shown to benefit specific aspects of brain health, such as cognitive abilities and brain structure and function [7]. Given that during a typical 24-hour activity cycle, more than half of a person's waking hours are usually spent in SB, with the remaining time divided between light physical activity and MVPA [8]. And research showed that engaging in MVPA can mitigate the mortality risk associated with prolonged sedentary behavior [9]. This suggests that if reducing SB is challenging, increasing MVPA might be a beneficial alternative.

However, considering that SB and PA are interdependent, when SB occupies too much time, the remaining hours may be insufficient for regular MVPA. The "weekend warrior" (WW) pattern, where MVPA is concentrated on 1 to 2 days per week, may offer a new approach that fits modern lifestyles. Current research suggests that the WW pattern can reduce risks of cardiovascular outcomes, mortality, and dementia, similar to more evenly distributed activity [10–13]. However, these studies have not yet explored whether the WW pattern can offset or significantly diminish the dementia risk associated with prolonged SB. Such information could be valuable for public health recommendations and providing guidelines.

To achieve these objectives, we utilized wrist-worn accelerometers to examine the relationship between different PA patterns and dementia risk among a large cohort of UK adults, stratified by high and low levels of sedentary time.

Methods

Study design and participants

Based on data from the UK Biobank study, a population-based cohort consisting of over 500,000 participants aged 40 to 69, recruited from England, Scotland and Wales between 2006 and 2010 [14]. Participants underwent a series of physical measurements, detailed assessments of health-related factors, and provided samples of blood, urine, and saliva (https://www.ukbiobank.ac.uk/), with ongoing follow-up for endpoint events, including dementia. The UK Biobank received ethical approval from the North West Multi-Centre Research Ethics Committee (REC reference: 11/NW/0382). The current analysis was conducted under UK Biobank application number 150,493. All participants provided written informed consent.

Figure 1 outlined the inclusion process of participants in our study. In brief, between 2013 and 2015, we contacted participants who had provided valid email addresses at baseline and invited them to wear a wrist-worn accelerometer (Axivity AX3) for 7 days. The device recorded triaxial acceleration data at a frequency of 100 Hz over the seven-day period, with a dynamic range of ±8 g [15]. Participants were instructed to wear the accelerometer continuously on their dominant wrist for 7 consecutive days, including during sleep, bathing, or swimming. After the 7-day period, participants returned the accelerometer to the research center using a prepaid envelope. The average vector magnitude was calculated by combining the sampled data into 5-second epochs. Non-wear time was defined as any continuous period of at least 60 min where all three axes showed a standard deviation of less than 13.0 mg. Non-wear segments were estimated using data from all wear time across different days and times of the day for each participant.

The exclusion criteria for participants included: [1] data quality issues; [2] insufficient valid wear time (less than 72 h of data during the 7-day data collection period or missing data for all 1-hour intervals within the 24-hour cycle); [3] inadequate calibration; [4] interruptions in the recording period (e.g., if participants attempted to connect the accelerometer device to a computer); [5] data recording errors. Additionally, participants diagnosed with all-cause dementia within two years before or after enrollment were excluded. A total of 91,948 participants were ultimately included in this study (Fig. 1).

Physical activity

We utilized a machine learning-based MVPA classification method that was previously developed and validated [16]. In brief, this algorithm was trained on data from 152 individuals wearing the Axivity AX3 device, whose free-living activities were manually classified using a wearable camera [16]. This training produced a machine learning

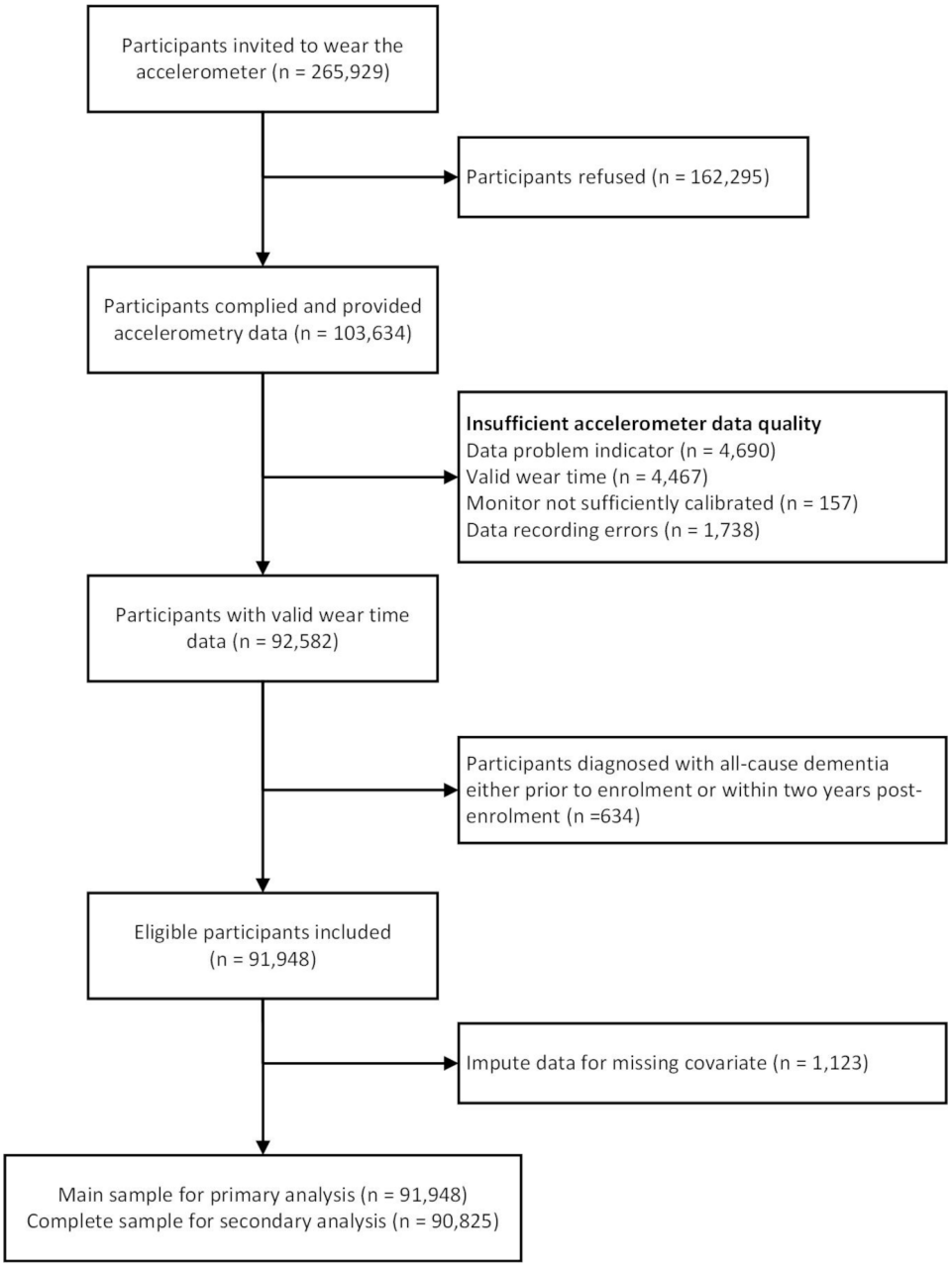

Fig. 1 Flow chart

model capable of classifying wrist-worn accelerometer data into activity behaviors (MVPA, light physical activity, sedentary behavior, and sleep) with an accuracy of 88% and a kappa of 0.80 [16]. MVPA was defined as any activity with a metabolic equivalent of ≥ 3. This new model was then applied to classify the activity behaviors of UK Biobank participants wearing accelerometers. Registered researchers with UK Biobank can access all computed variables (e.g., average daily MVPA: field 40045; average daily MVPA hours: field 40033). This study categorized participants into three groups based on the World Health Organization's recommended 150 min of MVPA per week and whether this activity was concentrated on 1 or 2 days. The groups were: the inactive group (MVPA < 150 min), the WW group (MVPA ≥ 150 min, and concentrating ≥ 50% of total MVPA in 1–2 days), and the regular group (MVPA ≥ 150 min, but not WW) [10].

Outcomes

Dementia was defined using the "algorithmically defined outcome" method (https://biobank.ndph.ox.ac.uk/showcase/refer.cgi?id=460), which identifies the earliest recorded date for a given health outcome. The algorithm utilizes data from several sources: UKB baseline

assessment data (self-reported during a verbal interview), linked hospital admission data (HES APC for England, SMR01 for Scotland, and PEDW for Wales), and death register data. Self-reported dementia diagnoses were excluded from our analysis. Dementia cases were identified using ICD-9 and ICD-10 codes. Follow-up for participants began at the time of their baseline assessment and continued until the first recorded dementia diagnosis, the end of follow-up at the assessment center, or death, whichever occurred first.

Covariates

Age was calculated based on the participant's birth date and the date they wore the accelerometer. Gender (female/male), ethnicity (White/Asian/Black/Other), and the Townsend deprivation index were determined through self-reported questionnaires. Other covariate data included education level (measured in years or equivalently converted from educational qualifications), employment status (paid employment/self-employed or retired/unemployed), smoking status (current/former/never), and alcohol consumption frequency. Body mass index (BMI) was calculated from height and weight measurements taken during the initial visit to the assessment center. Information on hypertension and the use of antihypertensive medications, diabetes and the use of antidiabetic medications, or cardiovascular disease was collected through self-reported questionnaires. All covariates included in the analysis were based on records closest to the period when the accelerometer was worn. Detailed information on the covariates and their field IDs is provided in Table S1.

Statistical analysis

Less than 1% of the covariate data, including demographic, lifestyle, and comorbidity information, were missing (eTable 2). We assumed that the data were missing completely at random and performed multiple imputations for the missing covariate data. Categorical variables are presented as numbers (percentages), and continuous variables are expressed as standard deviations (SD) or medians (25th-75th percentiles).

Before investigating the mitigating effect of MVPA on SB, we used penalized cubic splines fitted in a fully adjusted Cox model to assess the linear and non-linear associations between total MVPA time, sedentary time, and dementia risk. The fully adjusted model with only linear terms was compared to models with 3- and 5-knot cubic spline terms. The Akaike Information Criterion was used to determine whether linear or non-linear terms provided the best model fit. Specifically, adjustments were made for age, gender, ethnicity, Townsend deprivation index, education level, employment status, alcohol consumption, smoking, BMI, and baseline comorbidities (including cardiovascular disease, hypertension, and diabetes). The proportional hazards assumption was checked using Schoenfeld residuals, and no violations were detected. Calculating the hazard ratio (HR) for each value of the covariate, the location where the HR approaches 1 can be identified, which corresponds to the threshold.

Subsequently, a Cox model was employed to compare the dementia risk in the WW and regular groups against the inactive and highly sedentary participants. The model was adjusted for the same covariates as mentioned earlier. Since the optimal MVPA levels determined by accelerometer data are not yet well-established, we evaluated multiple thresholds. In our primary analysis, we assessed both the guideline-based threshold (≥ 150 min/week) and sample quartiles (≥ 115.2 min/week, ≥ 230.4 min/week, ≥ 403.2 min/week). We also performed several sensitivity analyses. First, the primary analysis was repeated in participants without any missing covariate data. Second, we defined the WW pattern as completing 50% or more of the weekly MVPA over the weekends and repeated the primary analysis using this definition. Third, Fine and Gray's subdistribution hazard model was calculated, accounting for all-cause mortality as a competing risk. All analyses were conducted using R software version 4.3.1 (Beagle Scouts). A two-tailed P-value of < 0.05 was considered statistically significant.

Results

Characteristics of participants

Of the 265,929 participants invited to wear the accelerometer, 38.97% complied ($n = 103{,}634$). Among these, 88.72% ($n = 91{,}948$) had complete exposure and outcome data and were included in the primary analysis. The overall 7-day wear time (in days) was 6.93 [6.73, 7.00]. The median age of the participants was 63 years (interquartile range [IQR]: 55.8–68.1 years), and 43.5% of the participants were male. During a median follow-up of 7.93 years (95% CI: 7.92–7.94 years), 736 dementia cases were recorded. Table 1 presented the baseline characteristics of participants stratified by MVPA and SB levels. Supplementary eTable 3 described the baseline characteristics of the overall analysis sample and the complete sample. In contrast, participants who were highly sedentary and inactive (comprising 23.8% of the total sample) were more likely to be current smokers, more obese, and had a higher prevalence of hypertension, diabetes, and cardiovascular disease compared to their less sedentary and more active counterparts.

Independent association between total MVPA, SB and dementia

After adjusting for age, gender, ethnicity, Townsend deprivation index, education level, employment status,

Table 1 Baseline characteristics of the study participants

Average sedentary time	Inactive pattern		Regular pattern		WW pattern	
	≥ 8.85 h/day (*n* = 21,909)	< 8.85 h/day (*n* = 9,155)	≥ 8.85 h/day (*n* = 19,055)	< 8.85 h/day (*n* = 15,311)	≥ 8.85 h/day (*n* = 16,149)	< 8.85 h/day (*n* = 10,369)
Participants' characteristics						
Age, median (IQR), y	64.2 [56.8;69.2]	64.0 [57.0;68.6]	61.6 [54.4;67.3]	62.5 [55.7;67.4]	62.6 [55.3;67.8]	63.1 [56.3;67.8]
Sex, *n* (%)						
Female	13,664 (62.4)	7150 (78.1)	8320 (43.7)	9220 (60.2)	7159 (44.3)	6440 (62.1)
Male	8245 (37.6)	2005 (21.9)	10,735 (56.3)	6091 (39.8)	8990 (55.7)	3929 (37.9)
Townsend deprivation index, median (IQR)	-2.4 [-3.8; -0.2]	-2.6 [-3.9; -0.6]	-2.1 [-3.6; 0.5]	-2.4 [-3.8; -0.1]	-2.6 [-3.9; -0.5]	-2.7 [-4.0; -0.7]
Ethnic type, *n* (%)						
White	21,148 (96.5)	8813 (96.3)	18,409 (96.6)	14,849 (97)	15,767 (97.6)	10,082 (97.2)
Black	232 (1.1)	97 (1.1)	166 (0.9)	103 (0.7)	106 (0.7)	79 (0.8)
Asian	301 (1.4)	135 (1.5)	219 (1.6)	159 (1)	142 (0.9)	103 (1)
Other ethnic group	228 (1.0)	110 (1.2)	261 (1.4)	200 (1.3)	134 (0.8)	105 (1)
Educational attainment, median (IQR)	18.0 [16.0;20.0]	17.0 [16.0;20.0]	20.0 [17.0;20.0]	20.0 [16.0;20.0]	20.0 [17.0;20.0]	18.0 [16.0;20.0]
Employment status, *n* (%)						
Paid employment or self-employed	846 (3.9)	295 (3.2)	698 (3.7)	483 (3.2)	682 (4.2)	384 (3.7)
Retired or unemployed	21,063 (96.1)	8860 (96.8)	18,357 (96.3)	14,828 (96.8)	15,467 (95.8)	9985 (96.3)
Smoking status, *n* (%)						
Never	11,800 (53.9)	5275 (57.6)	11,053 (58.0)	8959 (58.5)	9467 (58.6)	6120 (59)
Previous	8162 (37.3)	3173 (34.7)	6808 (35.7)	5527 (36.1)	5778 (35.8)	3696 (35.6)
Current	1947 (8.9)	707 (7.7)	1194 (6.3)	825 (5.4)	904 (5.6)	553 (5.3)
Alcohol status, *n* (%)						
Low frequency	4372 (20.0)	1941 (21.2)	2349 (12.3)	2234 (14.6)	1757 (10.9)	1482 (14.3)
moderate frequency	8370 (38.2)	3483 (38.0)	6473 (34.0)	5390 (35.2)	5806 (36)	3748 (36.1)
high frequency	9167 (41.8)	3731 (40.8)	10,233 (53.7)	7687 (50.2)	8586 (53.2)	5139 (49.6)
BMI, mg/m^2, median (IQR)	27.7 [24.8;31.3]	26.2 [23.6;29.4]	25.8 [23.5;28.5]	24.8 [22.7, 27.3]	26.2 [23.9, 28.9]	25.2 [23.0, 27.6]
Hypertension, *n* (%)	7071 (32.3)	2467 (26.9)	4371 (22.9)	2998 (19.6)	3797 (23.5)	2114 (20.4)
Diabetes, *n* (%)	1404 (6.4)	319 (3.5)	579 (3)	304 (2)	461 (2.9)	205 (2)
Cardiovascular disease, *n* (%)	1337 (6.1)	411 (4.5)	697 (3.7)	413 (2.7)	603 (3.7)	307 (3)

Abbreviations: MVPA, moderate to vigorous physical activity; BMI, body mass index; WW, Weekend Warrior

Data were median (IQR) or *n* (%)

Inactive pattern: individuals who engaged in less than 150 min of MVPA per week; WW pattern: individuals who completed 50% MVPA (150 min) within 1–2 days per week; Regular pattern: individuals who distributed 150 min of MVPA per week, but not WW

smoking status, alcohol consumption frequency, BMI, and comorbidities, the restricted cubic spline model revealed significant non-linear associations between total MVPA, sedentary behavior time, and dementia risk ($P_{non-linear} < 0.05$; Fig. 2). Figure 2A illustrated the association between total MVPA per week and dementia outcomes after adjustment. MVPA (as a continuous variable) was associated with a lower risk of dementia ($P_{overall} < 0.001$). This association was non-linear, with a steeper decline in risk observed between approximately 0–150 min/week, after which the risk plateaued ($P_{non-linear} = 0.014$). The non-linear model in Fig. 2B depicts the relationship between average daily sedentary behavior time and dementia events. When treating SB time as a continuous variable, each additional hour of SB per day was associated with a 13% increase in dementia risk (HR = 1.13, 95%CI: 1.08–1.18). The dementia risk remained relatively stable until approximately 8.52 h of SB per day, after which it began to rise sharply ($P_{non-linear} < 0.001$).

Joint association of different MVPA pattern and SB with dementia

Based on the model linking SB time to dementia risk, we identified an SB threshold of 8.52 h per day. We then stratified the inactive, regular, and WW groups according to SB time into those with ≥ 8.52 h/day and < 8.52 h/day of SB, resulting in a total of six exposure groups (Fig. 3, Supplementary eFigure 1). When the MVPA threshold was set at 150 min/week and WW was defined as completing

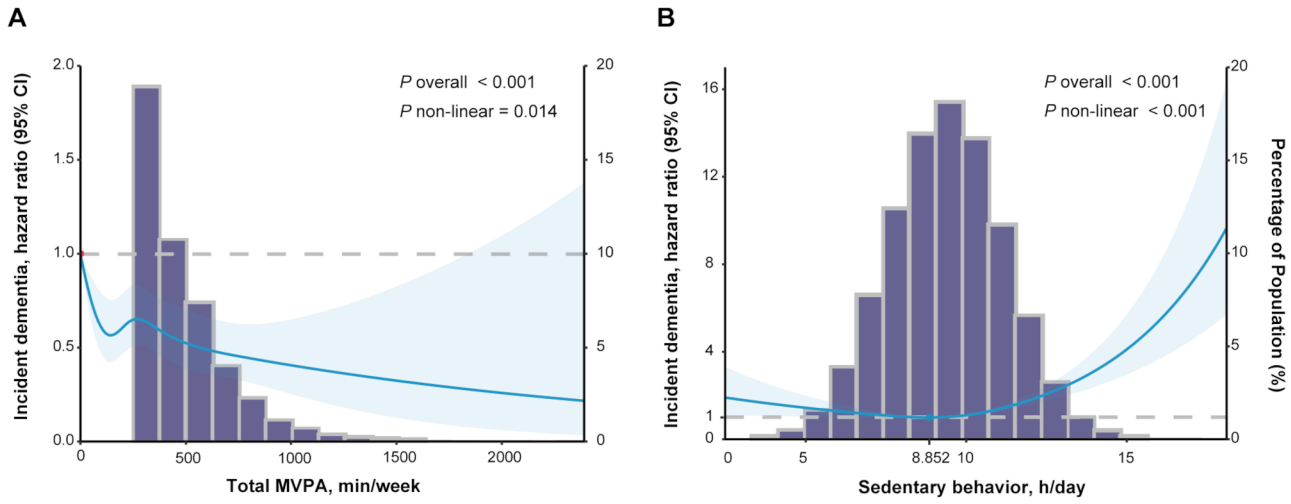

Fig. 2 Dose-response curve of weekly MVPA minutes and average daily sedentary time on all-cause dementia risk with confidence intervals
Abbreviations: MVPA, moderate to vigorous physical activity; hazard ratios (HR); CI, confident interval
The histogram illustrates the percentage of participants across the range of average daily sedentary behavior. Vertical lines represent the associated dementia risk. HR are plotted on a logarithmic scale, with shaded areas reflecting the 95% CI for the HR
All models adjusted for age, sex, ethnic, Townsend deprivation index, educational attainment, employment status, alcohol and cigarette use, body mass index, and baseline comorbid conditions including cardiovascular disease, hypertension, and diabetes

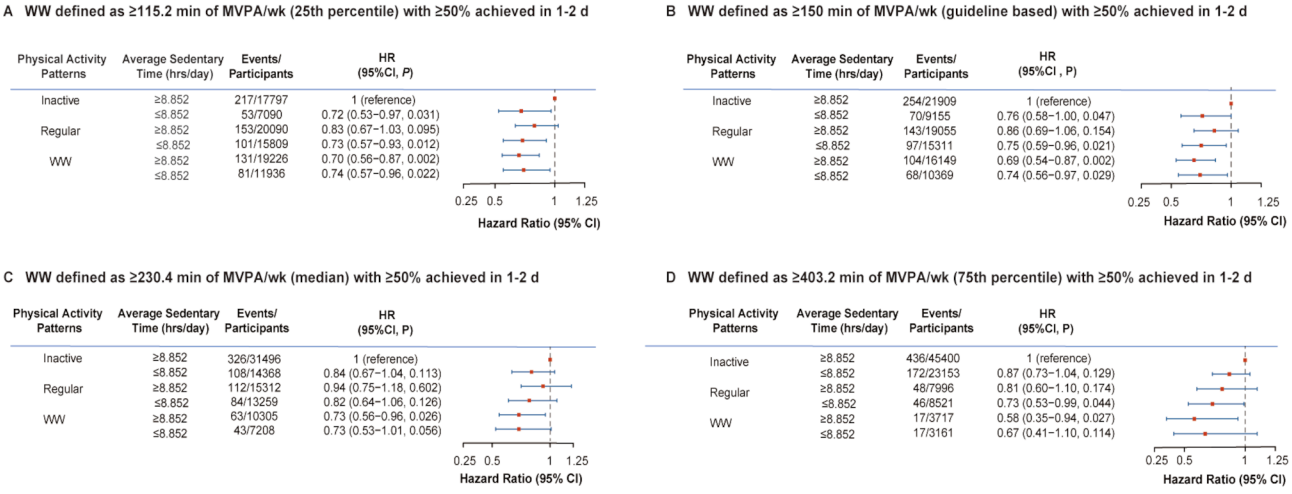

Fig. 3 Association between physical activity patterns, sedentary behavior, and all-cause dementia risk
Abbreviations: MVPA, moderate to vigorous physical activity; WW, Weekend Warrior; HR, hazard ratio; CI, confident interval
Inactive pattern was defined as individuals who engaged in less than thresholds of MVPA per week; WW pattern was involved in individuals who completed 50% MVPA (different thresholds) within 1–2 days per week; and regular pattern was regarded as individuals who distributed MVPA per week, but not WW. All models adjusted for age, sex, ethnic, Townsend Deprivation Index, educational attainment, employment status, alcohol and cigarette use, body mass index, and baseline comorbid conditions including cardiovascular disease, hypertension, and diabetes

more than 50% of MVPA within 1–2 days, the combined analysis indicated that, compared to individuals with long SB time who were inactive, reducing SB time—even while remaining inactive—could lower the risk of dementia by 24% (HR = 0.76, 95% CI: 0.58-1.00, $P = 0.047$). For those who were regularly active, shorter SB time was associated with a lower dementia risk (HR = 0.75, 95% CI: 0.59–0.96, $P = 0.021$), but this association was no longer statistically significant in the group with longer SB time (HR = 0.86, 95% CI: 0.69–1.06, $P = 0.154$). However, regardless of SB time, engaging in the WW pattern was associated with a lower risk of dementia (WW with long SB: HR = 0.69, 95% CI: 0.54–0.87, $P = 0.002$; WW with short SB: HR = 0.74, 95% CI: 0.56–0.97, $P = 0.029$).

In the multivariable-adjusted model, using both the guideline-based threshold (≥ 150 min) and quartile thresholds (≥ 115.2 min/week, ≥ 230.4 min/week, ≥ 403.2 min/week), the WW group consistently demonstrated a similar lower risk of dementia events, even when SB time was long (Fig. 3). As the MVPA threshold

increased, the association between the WW group with short SB time and a lower dementia risk gradually lost statistical significance. In contrast, for those who engaged in regular physical activity with long SB time, no association with reduced dementia risk was observed, regardless of how the thresholds were adjusted. However, the regular activity group with short SB time consistently maintained a stable association with lower dementia risk.

Sensitivity analysis

The results remained consistent when analyzed within the complete dataset that excluded participants with missing covariate values (Supplementary eTable 4). Even after redefining the WW pattern as having 50% or more of MVPA concentrated over the weekend, the association between WW with long SB time and a reduced risk of dementia persisted at the ≥115.2 and ≥150 thresholds (Supplementary eTable 5). Furthermore, when accounting for all-cause mortality as a competing risk using the Fine and Gray hazard model, similar results were observed (Supplementary eTable 6).

Discussion

The primary aim of this study was to investigate whether concentrating the recommended MVPA (150 min/week) into 1–2 days could compensate for the SB to reduce the risk of dementia. We found that compared to inactive individuals with long SB time, the WW pattern was associated with a reduced risk of dementia, regardless of SB duration. In contrast, the regular exercise pattern was associated with a lower dementia risk only when SB time was short, and not when SB time was long. These associations remained consistent even after adjusting for potential baseline confounders or prevalent chronic conditions. The findings from this study suggest that engaging in MVPA just 1 to 2 times per week can mitigate the dementia risk associated with sedentary behavior.

Recent studies have demonstrated an independent association between sedentary time and dementia [4, 5]. Our findings support this conclusion, showing that dementia risk increases with more daily sedentary time, following a non-linear pattern. A previous meta-analysis identified thresholds for all-cause mortality and cardiovascular disease mortality at 6–8 h of total sitting time per day, beyond which the risk increases [17]. Subsequent studies that assessed physical activity and sedentary time using accelerometers have shown that individuals with more than 9.5 h of sedentary time per day face a significantly increased risk of mortality [18]. Our findings are closely aligned with this threshold, which suggests approximately 8.5 h per day.

MVPA has been shown to have positive effects on brain health parameters, such as cognitive abilities, and individuals with higher levels of physical activity have a lower risk of developing dementia compared to those with lower activity levels [19, 20]. Engaging in MVPA is associated with a lower risk of mild cognitive impairment and dementia [21]. The current physical activity and SB guidelines recommend 150–300 min of moderate-intensity exercise per week and advise limiting prolonged sedentary time, suggesting that physical activity should replace sedentary time whenever possible [22]. For instance, participants who are sedentary for more than 10.5 h a day can reduce their mortality risk by taking more than 2,200 steps daily, with the risk decreasing by 39% if they take 9,000 steps daily [23]. Other studies indicate that sitting for more than 12 h a day increases mortality risk by 38%, while engaging in MVPA can mitigate this risk [24]. Replacing sedentary time with equivalent amounts of light, moderate, or vigorous physical activity can reduce the risk of various chronic non-communicable diseases [25]. Similarly, replacing 30 min of leisure-time sedentary behavior with physical activity can lower the risk of developing dementia by 7–18% [26]. Higher overall levels of physical activity are associated with a lower risk of dementia, regardless of sedentary time [27]. However, some studies suggest that individuals with high MVPA may still face a significant risk of dementia if they also engage in high levels of sedentary behavior. Those with the lowest levels of both SB and MVPA may face risks similar to those with the highest levels of both [28]. Additionally, sedentary time has been shown to increase blood pressure and cerebrovascular resistance, known to have long-term negative effects on brain health, particularly in older adults. These effects cannot be mitigated by increasing cognitive activity or regular walking alone [29]. Using accelerometer data, our results showed that among participants who engaged in regular exercise, those with long SB time did not exhibit a reduced risk of dementia. This may be because if the duration or intensity of exercise is insufficient, it might not be enough to counteract the negative effects of SB, indicating higher intensity or more concentrated periods of exercise are necessary.

Our study results suggest that concentrating more than 50% of the recommended MVPA within 1–2 days (WW pattern), regardless of sedentary time, may reduce the risk of dementia. WW participants engaged in more concentrated and higher-intensity physical activity, indicating that the quality of activity may be more important than the quantity [30]. However, the underlying mechanisms linking the WW pattern, SB, and dementia remain unclear. It has been reported that short-term exercise can increase catecholamine concentrations and blood flow to adipose tissue, which in turn affects lipolysis and fat mobilization [31, 32]. Previous studies have shown that the WW exercise pattern can suppress inflammatory processes and enhance antioxidant capacity, helping to

prevent depressive-like cognitive and behavioral changes [33]. Additionally, concentrated exercise may enhance the expression of neuroprotective growth factors [34]. These potential shared mechanisms may explain the observed results in this study. Future research should focus on elucidating the specific mechanisms underlying these associations, such as the potential link between WW exercise and plasma inflammatory biomarkers.

Furthermore, previous studies have shown that the WW physical activity pattern is more likely to be associated with musculoskeletal injuries and major trauma [35], and may not be suitable for people with dementia or other chronic conditions. It is essential to adjust exercise intensity in a timely manner. Walking training, as a relatively low-intensity exercise, may be safer and more feasible for individuals with dementia. Supervision by a caregiver may be necessary, especially when exercising outdoors or in unfamiliar environments, to ensure that patients continue engaging in appropriate physical activity while avoiding overexertion or physical injury.

Limitations

Our study has several limitations. First, caution is required when interpreting the reliability of physical activity patterns based on one week of data collection, as this time frame may not accurately reflect habitual PA behavior. Second, dementia diagnosis was based on incidental medical encounters, such as hospitalizations, rather than systematic screening procedures. While the reliance on ICD-coded diagnoses ensures consistency, it may lead to variations in visit timing and frequency, potentially resulting in the omission of early or mild dementia cases, thereby introducing bias. Additionally, the phenomenon where participants change their behavior due to awareness of being monitored, known as the Hawthorne effect, could influence the study outcomes. This factor must be considered when evaluating results, as it may distort the true representation of participants' usual PA patterns. Although we explored the association between the WW pattern and outcomes using various guideline-recommended and quartile thresholds, the optimal MVPA threshold for wrist-worn accelerometer measurements remains unclear. Using estimated non-wear time may affect the accuracy of activity measurements, particularly when non-wear time is misclassified or incorrectly attributed. Due to data constraints, our study could not thoroughly investigate the "super weekend warrior" pattern, where over 80% or 90% of the recommended MVPA is achieved within 1–2 days. Furthermore, despite excluding individuals who developed outcomes within 2 years after baseline and conducting preliminary analyses, we cannot entirely rule out the potential impact of reverse causation. While we adjusted for ethnicity, the predominance of White participants in the UK sample may limit the broader applicability of our findings. As with all observational studies, the presence of unmeasured or residual confounding factors cannot be entirely discounted. Participant characteristics and health covariates were selected to be as close to the baseline period associated with the accelerometer measurements as possible. However, some measurement errors and misclassification were inevitably introduced during the assessment period. We were unable to obtain data on the nature of observed activities (leisure, work, or other) corresponding to the accelerometer data, preventing us from recommending the most suitable types of activities. Future studies that capture this information may help to better understand the observed associations.

Conclusions

In summary, engaging in concentrated exercise within a short period is feasible to compensate for a sedentary behavior to risk of dementia, but future research should focus on the potential negative impacts of this exercise pattern.

Abbreviations

BMI	Body mass index
CI	Confidence interval
CVD	Cardiovascular disease
HR	Hazard ratio
ICD-9	9Th revision of the International Statistical Classification of Diseases and Related Health Problems
ICD-10	10Th revision of the International Statistical Classification of Diseases and Related Health Problems
PA	Physical activity
MVPA	Moderate to vigorous physical activity
SB	Sedentary behavior
SD	Standard deviations
WW	Weekend warriors

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s13195-024-01657-8.

Supplementary Material 1

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Author contributions

YYN and MLC conceived the study, contributed to interpretation of the results, and drafted the first manuscript. HY and JPJ contributed to critical revision of the manuscript. JPJ attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted. YYN and MLC have accessed and verified the underlying data. All authors had accepted responsibility for the decision to submit for publication.

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Data availability
No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate
The study was approved by the Northwest Multicenter Research Ethics Committee (16/NW/0274). Informed consent was obtained from all the participants.

Competing interests
The authors declare no competing interests.

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References

1. McDade EM. Alzheimer Disease. Continuum (Minneap Minn). 2022;28(3):648–75.
2. Livingston G, Huntley J, Liu KY, Costafreda SG, Selbæk G, Alladi S, et al. Dementia prevention, intervention, and care: 2024 report of the Lancet standing Commission. Lancet. 2024;404(10452):572–628.
3. Yang L, Cao C, Kantor ED, Nguyen LH, Zheng X, Park Y, et al. Trends in Sedentary Behavior among the US Population, 2001–2016. JAMA. 2019;321(16):1587–97.
4. Yan S, Fu W, Wang C, Mao J, Liu B, Zou L, et al. Association between sedentary behavior and the risk of dementia: a systematic review and meta-analysis. Translational Psychiatry. 2020;10(1):112.
5. Raichlen DA, Aslan DH, Sayre MK, Bharadwaj PK, Ally M, Maltagliati S, et al. Sedentary behavior and Incident Dementia among older adults. JAMA. 2023;330(10):934–40.
6. Huang SY, Li YZ, Zhang YR, Huang YY, Wu BS, Zhang W, et al. Sleep, physical activity, sedentary behavior, and risk of incident dementia: a prospective cohort study of 431,924 UK Biobank participants. Mol Psychiatry. 2022;27(10):4343–54.
7. Stillman CM, Esteban-Cornejo I, Brown B, Bender CM, Erickson KI. Effects of Exercise on Brain and Cognition Across Age Groups and Health States. Trends Neurosci. 2020;43(7):533–43.
8. Zou L, Herold F, Cheval B, Wheeler MJ, Pindus DM, Erickson KI, et al. Sedentary behavior and lifespan brain health. Trends Cogn Sci. 2024;28(4):369–82.
9. Tarp J, Fagerland MW, Dalene KE, Johannessen JS, Hansen BH, Jefferis BJ, et al. Device-measured physical activity, adiposity and mortality: a harmonised meta-analysis of eight prospective cohort studies. Br J Sports Med. 2022;56(13):725–32.
10. Khurshid S, Al-Alusi MA, Churchill TW, Guseh JS, Ellinor PT. Accelerometer-derived Weekend Warrior Physical Activity and Incident Cardiovascular Disease. JAMA. 2023;330(3):247–52.
11. Ning Y, Chen M, An J, Tang M, Tse G, Chan JSK et al. Association between weekend warrior physical activity and the incidence of neurodegenerative diseases. Neurotherapeutics: J Am Soc Experimental Neurother. 2024:e00430.
12. Dos Santos M, Ferrari G, Lee DH, Rey-López JP, Aune D, Liao B, et al. Association of the Weekend Warrior and other leisure-time physical activity patterns with all-cause and cause-specific mortality: a Nationwide Cohort Study. JAMA Intern Med. 2022;182(8):840–8.
13. O'Donovan G, Petermann-Rocha F, Ferrari G, Lee IM, Hamer M, Stamatakis E, et al. Associations of the 'weekend warrior' physical activity pattern with all-cause, cardiovascular disease and cancer mortality: the Mexico City prospective study. Br J Sports Med. 2024;58(7):359–65.
14. Sudlow C, Gallacher J, Allen N, Beral V, Burton P, Danesh J, et al. UK biobank: an open access resource for identifying the causes of a wide range of complex diseases of middle and old age. PLoS Med. 2015;12(3):e1001779.
15. Doherty A, Jackson D, Hammerla N, Plötz T, Olivier P, Granat MH, et al. Large Scale Population Assessment of Physical Activity using wrist worn accelerometers: the UK Biobank Study. PLoS ONE. 2017;12(2):e0169649.
16. Walmsley R, Chan S, Smith-Byrne K, Ramakrishnan R, Woodward M, Rahimi K, et al. Reallocation of time between device-measured movement behaviours and risk of incident cardiovascular disease. Br J Sports Med. 2021;56(18):1008–17.
17. Patterson R, McNamara E, Tainio M, de Sá TH, Smith AD, Sharp SJ, et al. Sedentary behaviour and risk of all-cause, cardiovascular and cancer mortality, and incident type 2 diabetes: a systematic review and dose response meta-analysis. Eur J Epidemiol. 2018;33(9):811–29.
18. Ekelund U, Tarp J, Steene-Johannessen J, Hansen BH, Jefferis B, Fagerland MW, et al. Dose-response associations between accelerometry measured physical activity and sedentary time and all cause mortality: systematic review and harmonised meta-analysis. BMJ (Clinical Res ed). 2019;366:l4570.
19. Ludyga S, Gerber M, Pühse U, Looser VN, Kamijo K. Systematic review and meta-analysis investigating moderators of long-term effects of exercise on cognition in healthy individuals. Nat Hum Behav. 2020;4(6):603–12.
20. Petermann-Rocha F, Lyall DM, Gray SR, Gill JMR, Sattar N, Welsh P, et al. Dose-response association between device-measured physical activity and incident dementia: a prospective study from UK Biobank. BMC Med. 2021;19(1):305.
21. Nguyen S, LaCroix AZ, Hayden KM, Di C, Palta P, Stefanick ML, et al. Accelerometer-measured physical activity and sitting with incident mild cognitive impairment or probable dementia among older women. Alzheimer's Dement J Alzheimer's Assoc. 2023;19(7):3041–54.
22. Bull FC, Al-Ansari SS, Biddle S, Borodulin K, Buman MP, Cardon G, et al. World Health Organization 2020 guidelines on physical activity and sedentary behaviour. Br J Sports Med. 2020;54(24):1451–62.
23. Ahmadi MN, Rezende LFM, Ferrari G, Del Pozo Cruz B, Lee IM, Stamatakis E. Do the associations of daily steps with mortality and incident cardiovascular disease differ by sedentary time levels? A device-based cohort study. Br J Sports Med. 2024;58(5):261–8.
24. Sagelv EH, Hopstock LA, Morseth B, Hansen BH, Steene-Johannessen J, Johansson J, et al. Device-measured physical activity, sedentary time, and risk of all-cause mortality: an individual participant data analysis of four prospective cohort studies. Br J Sports Med. 2023;57(22):1457–63.
25. Cao Z, Xu C, Zhang P, Wang Y. Associations of sedentary time and physical activity with adverse health conditions: outcome-wide analyses using isotemporal substitution model. EClinicalMedicine. 2022;48:101424.
26. Sun Y, Chen C, Yu Y, Zhang H, Tan X, Zhang J, et al. Replacement of leisure-time sedentary behavior with various physical activities and the risk of dementia incidence and mortality: a prospective cohort study. J Sport Health Sci. 2023;12(3):287–94.
27. Zhong Q, Zhou R, Huang YN, Chen HW, Liu HM, Huang Z, et al. The independent and joint association of accelerometer-measured physical activity and sedentary time with dementia: a cohort study in the UK Biobank. Int J Behav Nutr Phys Act. 2023;20(1):59.
28. Du Z, Sato K, Tsuji T, Kondo K, Kondo N. Sedentary behavior and the combination of physical activity associated with dementia, functional disability, and mortality: a cohort study of 90,471 older adults in Japan. Prev Med. 2024;180:107879.
29. Maasakkers CM, Melis RJF, Kessels RPC, Gardiner PA, Olde Rikkert MGM, Thijssen DHJ, et al. The short-term effects of sedentary behaviour on cerebral hemodynamics and cognitive performance in older adults: a cross-over design on the potential impact of mental and/or physical activity. Alzheimers Res Ther. 2020;12(1):76.
30. Swain DP, Franklin BA. Comparison of cardioprotective benefits of vigorous versus moderate intensity aerobic exercise. Am J Cardiol. 2006;97(1):141–7.
31. Dreher SI, Irmler M, Pivovarova-Ramich O, Kessler K, Jürchott K, Sticht C, et al. Acute and long-term exercise adaptation of adipose tissue and skeletal muscle in humans: a matched transcriptomics approach after 8-week training-intervention. Int J Obes (Lond). 2023;47(4):313–24.

32. Trevellin E, Scorzeto M, Olivieri M, Granzotto M, Valerio A, Tedesco L, et al. Exercise training induces mitochondrial biogenesis and glucose uptake in subcutaneous adipose tissue through eNOS-dependent mechanisms. Diabetes. 2014;63(8):2800–11.
33. Öztürk ÇÇ, Ataoğlu SN, Arvas A, Tokol H, Yaprak H, Gürel S, et al. Weekend warrior exercise model for protection from chronic mild stress–induced depression and ongoing cognitive impairment. Acta Neurobiol Exp. 2023;83(1):10–24.
34. Min J, Cao Z, Duan T, Wang Y, Xu C. Accelerometer-derived 'weekend warrior' physical activity pattern and brain health. Nat Aging. 2024;4(10):1394–402.
35. Roberts DJ, Ouellet JF, McBeth PB, Kirkpatrick AW, Dixon E, Ball CG. The weekend warrior: fact or fiction for major trauma? Can J Surg. 2014;57(3):E62–8.

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