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Original Article

Association between “weekend warrior” physical activity and the incidence of neurodegenerative diseases

Yuye Ning [a,b,1], Meilin Chen [b,1], Jiaqi An [c], Manyun Tang [a,d,e], Gary Tse [f,g,h], Jeffrey Shi Kai Chan [h], Changying Zhao [a], Yingying Liu [i], Xinjun Lei [i], Hua Qiang [i], Chuan Bai [i], Hongbing Li [i], Hang Yu [i], Yang Yan [a,*], Duolao Wang [j,*], Guoliang Li [i,*]

[a] Department of Cardiovascular Surgery, The First Affiliated Hospital of Xi'an Jiaotong University, 277 Yanta West Road, Xi'an, China
[b] Innovation Center for Neurological Disorders and Department of Neurology, Xuanwu Hospital, Capital Medical University, Beijing 100053, China
[c] Department of Neurology, The First Affiliated Hospital of Sun Yat-sen University, No. 58, Zhongshan Road 2, Guangzhou, Guangdong 510080, China
[d] Key Laboratory of Surgical Critical Care and Life Support (Xi'an Jiaotong University), Ministry of Education, China
[e] Department of Hepatobiliary Surgery, The Second Affiliated Hospital of Xi'an Jiaotong University, Xi'an, China
[f] Tianjin Key Laboratory of Ionic-Molecular Function of Cardiovascular Disease, Department of Cardiology, Tianjin Institute of Cardiology, Second Hospital of Tianjin Medical University, Tianjin, China
[g] School of Nursing and Health Studies, Hong Kong Metropolitan University, China
[h] Epidemiology Research Unit, Cardiovascular Analytics Group, PowerHealth Research Institute, China
[i] Department of Cardiovascular Medicine, The First Affiliated Hospital of Xi'an Jiaotong University, 277 Yanta West Road, Xi'an, China
[j] Department of Clinical Sciences, Liverpool School of Tropical Medicine, Pembroke Place, Liverpool, L3 5QA, United Kingdom

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ABSTRACT

While guidelines recommend 150 min of moderate to vigorous physical activity (MVPA) weekly to enhance health, it remains unclear whether concentrating these activities into 1–2 days of the week, “weekend warrior” (WW) pattern, has the same benefit for neurodegenerative diseases (NDDs). This study aimed to evaluate the associations of WW pattern and the risk of NDDs. This prospective study was conducted using accelerometer-based physical activity data for a full week from June 2013 to December 2015 in the UK Biobank. These individuals were categorized into distinct physical activity patterns, including the WW pattern (i.e., over 50% or 75% of recommended MVPA achieved over 1–2 days), regular pattern, and inactive pattern. Cox proportional hazards model was used to evaluate the association between physical activity patterns and outcomes. Compared to inactive group, WW pattern and regular pattern was similarly linked to a reduced risk of all-cause dementia (WW: Hazard Ratio [HR]: 0.68, 95% Confidence Interval [CI]: 0.56–0.84; regular: HR: 0.86, 95% CI: 0.67–1.1) and all-cause Parkinsonism (WW: HR: 0.47, 95% CI: 0.35–0.63; regular: HR: 0.69, 95% CI: 0.5–0.95). When the exercise threshold was increased to 75% of MVPA, both patterns still were associated with decreased risk of incident all-cause dementia (WW: HR: 0.61, 95% CI: 0.41–0.91; regular: HR: 0.76, 95% CI: 0.63–0.92) and all-cause Parkinsonism (WW: HR: 0.22, 95% CI: 0.10–0.47; regular: HR: 0.59, 95% CI: 0.46–0.75). Concentrating recommended physical activities into 1–2 days per week is associated with a lower incidence of NDDs.

Introduction

Prior physical activity guidelines advised adults to engage in moderate to vigorous physical activity (MVPA) at least 150 min weekly, or surpassing 300 min for additional health benefits [1,2]. However, the daily demands of employment, familial duties, and other responsibilities often preclude individuals from adhering to these exercise plan during weekdays. Consequently, some people may opt for the “weekend warrior” (WW) pattern, which concentrates recommended levels of physical activity in one or two sessions per week, thus accommodating their constrained schedules [3].

The study conducted by O'Donovan et al., identified that WW pattern experiencing lower all-cause and cause-specific mortality rates than inactive individuals [4]. Santos et al. also provided evidence that significant

* Corresponding authors.
E-mail addresses: yangyan3@xjtu.edu.cn (Y. Yan), Duolao.Wang@lstmed.ac.uk (D. Wang), liguoliang_med@163.com (G. Li).
[1] Yuye Ning and Meilin Chen contributed equally to this work.

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differences were not observed for all-cause mortality between WW and regularly active participants after accounting for total amount of MVPA [5]. Recent meta-analysis concluded that both the WW and regularly active physical activity patterns were independently associated with reduced risks of cardiovascular events [6]. In addition, Khurshid et al. extended this research by defining WW as those who at least accomplish 50% of the guideline-recommended physical activity in one or two sessions per week, which was associated with the reduced risk of atrial fibrillation, myocardial infarction, heart failure, and stroke [7]. And better levels of traditional risk factors like glycated hemoglobin, fibrinogen, C-reactive protein, body mass index (BMI), and systolic blood pressure were observed in the WW pattern compared to inactive individuals [8], as well as reduced Visceral Adiposity Index [9]. These findings collectively underscore the effectiveness of the WW pattern in promoting cardiovascular health and reducing mortality risks, offering a feasible alternative for individuals unable to commit to regularly physical activity.

Studies have highlighted that MVPA is particularly beneficial in reducing the risk of neurodegenerative diseases (NDDs), like Parkinsonism and dementia [10,11]. Cardiovascular diseases and its traditional risk factors are known to be strongly linked with the development of NDDs [12]. The WW pattern has been shown to significantly reduce the risk of cardiovascular events and mortality, which implies potential benefits for NDDs prevention, given the connection between cardiovascular health and NDDs. However, the specific association between the WW pattern and NDDs remains unclear.

Using the UK Biobank dataset, we utilized accelerometer data from over 100,000 participants. We investigated the potential association between the WW pattern under the recommended physical activity and the incidence of dementia and Parkinsonism. We hypothesized that engaging in MVPA predominantly over 1–2 days per week would be associated with a decreased risk of dementia and Parkinsonism.

Materials and Methods

Study population and data collection

This was a prospective, population-based cohort study of participants enrolled in the UK biobank, aged 40–69 years from diverse regions across the United Kingdom spanning from 2006 to 2010 [13]. Participants underwent detailed assessments including touchscreen-based questionnaires, comprehensive physical examinations, and the provision of biological samples (blood, urine, and saliva). From June 2013 to December 2015, 103,662 participants agreed to wear an Axivity AX3 wrist-worn triaxial accelerometer for a week. The device captured acceleration data at 100 Hz within a ±8 g range over seven days. Signals were gravity-calibrated and aggregated into 5-s epochs as mean vector magnitudes. Non-wearing time was defined as any continuous stationary event lasting 60 min or longer, characterized by a standard deviation (SD) of less than 13.0 mg across all three axes of measurement. More details about data collection, validation and processing can be found elsewhere [14]. All participants have provided written informed consent for data collection, analysis, and linkage and ethical approval was obtained from UK National Health Service (NHS) National Research Ethics Service (11/NW/0382). Additional consent was not required prior to individual studies. Our study was approved by Research Committee and conducted using the UK Biobank Resource (Application ID: 152047).

We excluded individuals: (1) who with less than 7 full days of wear time, (2) those without wear data in each 1-h period of the 24-h cycle, (3) those with calibration errors exceeding a tolerance of 10 mg or with abnormally high acceleration values (>100 mg), (4) those who have missing covariates, (5) those have been followed up for less than two years.

Procedure

Routine behaviors in wrist-worn accelerometer data were classified into MVPA, light physical activity, sedentary behavior, and sleep. They were estimated using machine learning models that were trained using wearable cameras and time-use diaries among 152 individuals in free-living conditions [15].

The proportion of time spent in MVPA daily was converted into the number of minutes of MVPA per day. Therefore, the total weekly MVPA minutes for each participant could be quantified. For NDDs, the optimal level of MVPA as measured by accelerometer remains uncertain. We involved the evaluation of multiple thresholds of MVPA. Additionally, the definition of the WW pattern is not conclusively established in current literature. Our approach included the assessment of various definitions of WW, incorporating different percentages of the guideline-recommended MVPA completed at varying thresholds. In our primary analyses, the standard recommendations from the American College of Cardiology, American Heart Association and World Health Organization (≥150 min/week), as well as the extended WHO recommendations for additional benefits (≥300 min/week), were adopted [16]. Participants who did not meet the weekly MVPA threshold were categorized as inactive individuals. Participants who reached the MVPA threshold and concentrated more than 50% or 75% of their total weekly MVPA exercise minutes over 1–2 days were defined as WW pattern [7], while those achieving the threshold but not WW were classified as regular pattern (eTable 1).

Cohort follow-up and ascertainment of outcomes

Outcomes were determined using an ‘algorithm defining results', pinpointing the earliest recorded date of specific health outcomes. This algorithm integrates data from the baseline assessment, hospital admission records, and death registration data. For all-cause dementia, we employed the algorithm outlined in category 47. Dementia was identified using The International Classification of Diseases 10th revision (ICD-10) codes F00, F01, F02, F03, G30, G310, G311, and G318, as well as ICD-9 codes 290, 291, 294, and 331 [17]. All-cause Parkinsonism was ascertained via ICD-10 codes G20-G26, G90, and ICD-9 codes 3320, 3321, and 3330. The UK Biobank Outcome Adjudication Team oversaw the classification of each event [18,19], and positive predictive values for all-cause dementia were 82.5%, for all-cause Parkinsonism were 91%. For each participant, the follow-up duration was calculated from the last date of accelerometer use to either the date of the first endpoint event, death, lost to follow-up, or the date of complete follow-up (eTable 1).

Covariates

In this study, baseline age was determined by combining the participants' date of birth with the date they stopped wearing the accelerometer. Participants self-reported their ethnicity, choosing from White, Black, Asian, or other categories. The Townsend Deprivation Index was used to assess the impact of socioeconomic factors on health outcomes. Educational attainment was gauged by the age at which participants completed full-time education. For those who only reported degree or qualification status, an equivalent age at education completion was determined [20]. Regarding employment, participants were categorized as either being in paid employment/self-employed or being retired/unemployed. Additionally, participants provided self-reports on their smoking and alcohol consumption habits, which were classified as never, previous, or current. Dietary quality was evaluated using health recommendations, which consider the consumption of beneficial foods such as fruits, vegetables, whole grains, fish, shellfish, dairy and vegetable oils, and reduced consumption of refined grains, processed and unprocessed meats and sugary drinks. Diets were classified as healthy or unhealthy based on adherence to at least half of these criteria [21]. The categorization of prevalent hypertension, diabetes, and cardiovascular disease in our study was determined as either 'yes' or ‘no’. This classification was based on self-reported data collected at baseline, which included the use of antihypertensive and diabetes medications (eTable 1).

Table 1
Characteristics of participants by the different thresholds of MVPA per week.

Patient Characteristics	≥150 min of MVPA per week			≥300 min of MVPA per week		
	Inactive[a] (N = 31,514)	Regular[a] (N = 21,053)	WW[a] (N = 40,217)	Inactive[b] (N = 56,830)	Regular[b] (N = 16,319)	WW[b] (N = 19,635)
Demographic and socioeconomic characteristics						
Age, y	64.0 [57.0; 69.0]	61.0 [54.0; 67.0]	63.0 [56.0; 68.0]	64.0 [56.0; 69.0]	61.0 [54.0; 67.0]	63.0 [56.0; 68.0]
Sex, n (%)						
Female	21009 (66.7)	10697 (50.8)	20604 (51.2)	35892 (63.2)	7802 (47.8)	8616 (43.9)
Male	10505 (33.3)	10356 (49.2)	19613 (48.8)	20938 (36.8)	8517 (52.2)	11019 (56.1)
Townsend deprivation index	−2.5 [-3.8;-0.3]	−2.1 [-3.6; 0.5]	−2.6 [-3.9;-0.5]	−2.5 [-3.8;-0.2]	−2.1 [-3.6; 0.5]	−2.7 [-3.9;-0.6]
Ethnic type, n (%)						
White	30423 (96.5)	20329 (96.6)	39193 (97.5)	54938 (96.7)	15787 (96.7)	19220 (97.9)
Black	322 (1.0)	180 (0.9)	264 (0.7)	544 (1.0)	128 (0.8)	94 (0.5)
Asian	443 (1.4)	256 (1.2)	371 (0.9)	740 (1.3)	190 (1.2)	140 (0.7)
Other	326 (1.0)	288 (1.4)	389 (1.0)	608 (1.1)	214 (1.3)	181 (0.9)
Educational attainment, y	18.0 [16.0; 20.0]	20.0 [16.0; 20.0]	20.0 [16.0; 20.0]	18.0 [16.0; 20.0]	20.0 [17.0; 20.0]	20.0 [16.0; 20.0]
Employment status, n (%)						
Paid employment or self-employed	17474 (55.4)	13976 (66.4)	24778 (61.6)	33048 (58.2)	10952 (67.1)	12228 (62.3)
Retired or unemployed	14040 (44.6)	7077 (33.6)	15439 (38.4)	23782 (41.8)	5367 (32.9)	7407 (37.7)
Lifestyle characteristics						
Diet quality, n (%)						
Unhealth	28023 (88.9)	18004 (85.5)	35152 (87.4)	50198 (88.3)	13879 (85.0)	17102 (87.1)
Healthy	3491 (11.1)	3049 (14.5)	5065 (12.6)	6632 (11.7)	2440 (15.0)	2533 (12.9)
Smoking status, n (%)						
Never	17237 (54.7)	12158 (57.7)	23712 (59.0)	32087 (56.5)	9408 (57.7)	11612 (59.1)
Previous	11556 (36.7)	7625 (36.2)	14272 (35.5)	20476 (36.0)	5973 (36.6)	7004 (35.7)
Current	2721 (8.6)	1270 (6.0)	2233 (5.6)	4267 (7.5)	938 (5.7)	1019 (5.2)
Alcohol status, n (%)						
Never	1274 (4.0)	555 (2.6)	911 (2.3)	1945 (3.4)	401 (2.5)	394 (2.0)
Previous	1077 (3.4)	572 (2.7)	922 (2.3)	1703 (3.0)	437 (2.7)	431 (2.2)
Current	29163 (92.5)	19926 (94.6)	38384 (95.4)	53182 (93.6)	15481 (94.9)	18810 (95.8)
MVPA per week, min	72.0 [28.8; 115.2]	432.0 [302.4; 619.2]	288.0 [216.0; 432.0]	129.6 [72.0; 216.0]	504.0 [388.8; 676.8]	432.0 [345.6; 561.6]
Sedentary time per week, h	9.8 [8.6; 11.1]	9.1 [7.8; 10.3]	9.3 [8.1; 10.4]	9.7 [8.4; 10.9]	8.9 [7.7; 10.1]	9.1 [8.0; 10.2]
Clinical, medication and medical history						
Diastolic blood pressure, mmHg	81.5 [75.0; 88.5]	80.5 [74.0; 87.5]	81.0 [74.5; 88.0]	81.5 [75.0; 88.5]	80.5 [74.0; 87.5]	81.0 [74.5; 87.5]
Systolic blood pressure, mmHg	136.0 [124.5; 149.0]	133.5 [122.5; 146.5]	135.0 [123.5; 147.5]	135.5 [124.0; 148.5]	133.5 [122.5; 146.5]	135.0 [123.5; 147.5]
Body mass index, kg/m^2	27.2 [24.4; 30.8]	25.3 [23.0; 27.9]	25.3 [23.0; 27.9]	26.6 [24.0; 29.9]	25.1 [22.9; 27.6]	25.4 [23.2; 27.9]
Hypertension, n (%)	9690 (30.7)	4405 (20.9)	9005 (22.4)	15834 (27.9)	3245 (19.9)	4021 (20.5)
Diabetes, n (%)	1779 (5.6)	550 (2.6)	1021 (2.5)	2559 (4.5)	378 (2.3)	413 (2.1)
Cardiovascular disease, n (%)	1771 (5.6)	611 (2.9)	1385 (3.4)	2695 (4.7)	446 (2.7)	626 (3.2)

Data are n (%) or median (quartile).
Abbreviations: MVPA, moderate to vigorous physical activity; WW, weekend warrior.
[a] Individuals were classified as weekend warrior group (WW, at or above the 150 min MVPA threshold and ≥50% of total MVPA over 1–2 days), regular exercisers (at or above MVPA threshold but not active WW), and inactive individuals (below MVPA threshold).
[b] Individuals were classified as active weekend warrior (active WW, at or above the 300 min MVPA threshold and ≥50% of total MVPA over 1–2 days), regular exercisers (at or above MVPA threshold but not active WW), and inactive individuals (below MVPA threshold).

Statistical analyses

For the analysis of various PA patterns, characteristics were described using the mean (standard deviation) or median (interquartile range) for continuous variables and frequency (percentage) for categorical variables. In our main analysis, we utilized data after excluding participants with missing values to ensure the integrity and reliability of our findings. Subsequently, to address potential biases arising from these exclusions, we performed a repeated analysis employing multiple imputation techniques. The details regarding missing values in our study are comprehensively summarized (eTable 2). The median follow-up time was calculated using the reverse Kaplan-Meier method.

We employed Cox proportional hazard models adjusted for age, sex, ethnic type, Townsend Deprivation Index, year of education attainment, employment status, smoking and drinking status, diet quality, and comorbidities. Schoenfeld residuals were used to assess the proportional hazards assumption. To mitigate the potential for reverse causality bias in our study, we excluded individuals from the first two years of follow-up. We compared the risk of all-cause dementia and all-cause Parkinsonism within three groups (WW, regular, and inactive pattern) using MVPA thresholds of 150 or 300 min per week. Kaplan-Meier survival curves was employed to provide an intuitive visualization of the risks of outcome events across the three pattern groups.

Additional analyses were conducted as follows: (1) Using quartiles of MVPA minutes completed per week in the cohort as new thresholds (≥25th percentile, ≥50th percentile, ≥75th percentile) and compared the risk of outcome events among inactive, regular, and WW pattern. (2) Using 150 or 300 min per week as MVPA thresholds, we assessed the risk of outcome events for participants who fulfilled 50% or 75% of the total MVPA amount over 1–2 consecutive days. (3) Using 150 or 300 min per week as MVPA thresholds, we repeated analysis of the risk of outcome events for participants who fulfilled 50% of the total MVPA amount on weekends. (4) To mitigate the potential confounding effect of reduced physical activity that could be attributed to undiagnosed, early-stage NDDs, we conducted a repeated analysis of NDD events after excluded data from the first five years of follow-up. (5) We incorporated sedentary time and subsequently conducted the main analysis. (6) We interpolated missing values, aiming to include as much data as possible in the analysis and to minimize potential selection bias. (7) Individuals with chronic diseases frequently were difficult to engage in regular physical activity, we replicated the primary analyses among participants who had hypertension, diabetes, or cardiovascular disease (CVD) at baseline. (8) Given

Table 2
Associations between physical activity pattern and incident of outcome across varying WW definition.

Condition	All-cause dementia (N = 486)		All-cause Parkinsonism (N = 266)	
	Events/Participants	Hazard ratio (95 CI)[a]	Events/Participants	Hazard ratio (95 CI)[a]
WW definition as ≥ 25th percentile (≥115.2 min MVPA/week) and ≥50% of total MVPA over 1–2 days				
Inactive	195/25016	1 (reference)	107/24955	1 (reference)
Regular	97/21426	0.79 (0.62–1.02)	59/21429	0.68 (0.49–0.94)
WW	194/45702	0.66 (0.54–0.81)	100/45664	0.48 (0.37–0.64)
WW definition as ≥25th percentile (≥115.2 min MVPA/week) and ≥75% of total MVPA over 1–2 days				
Inactive	195/25016	1 (reference)	107/24955	1 (reference)
Regular	251/57869	0.71 (0.59–0.86)	145/57846	0.58 (0.45–0.75)
WW	40/9259	0.64 (0.45–0.90)	14/9247	0.32 (0.18–0.56)
WW definition as ≥50th percentile (≥230.4 min MVPA/week) and ≥50% of total MVPA over 1–2 days				
Inactive	298/45955	1 (reference)	159/45871	1 (reference)
Regular	79/18562	0.87 (0.68–1.12)	47/18561	0.78 (0.56–1.09)
WW	109/27627	0.72 (0.58–0.90)	60/27616	0.58 (0.43–0.79)
WW definition as ≥50th percentile (≥230.4 min MVPA/week) and ≥75% of total MVPA over 1–2 days				
Inactive	298/45955	1 (reference)	159/45871	1 (reference)
Regular	175/42286	0.80 (0.66–0.97)	105/42277	0.72 (0.55–0.92)
WW	13/3903	0.55 (0.31–0.96)	2/3900	0.12 (0.03–0.50)
WW definition as ≥75th percentile (≥403.2 min MVPA/week) and ≥50% of total MVPA over 1–2 days				
Inactive	410/71241	1 (reference)	222/71144	1 (reference)
Regular	41/10745	0.86 (0.62–1.19)	24/10746	0.76 (0.50–1.16)
WW	35/10158	0.67 (0.47–0.95)	20/10158	0.55 (0.34–0.87)
WW definition as ≥75th percentile (≥403.2 min MVPA/week) and ≥75% of total MVPA over 1–2 days				
Inactive	410/71241	1 (reference)	222/71144	1 (reference)
Regular	74/19962	0.78 (0.61–1.01)	43/19964	0.67 (0.48–0.93)
WW	2/941	0.36 (0.09–1.45)	1/940	0.26 (0.04–1.87)

Abbreviations: MVPA, moderate to vigorous physical activity; WW, weekend warrior.
[a] All models adjusted for age, sex, ethnic, Townsend Deprivation Index, alcohol and cigarette use, diet quality, educational attainment, employment status and baseline comorbid conditions including cardiovascular disease, hypertension, and diabetes.

the potential for death as a competing risk in our study, we employed a competing risks regression as outlined by Fine and Gray.

All analyses were performed using R statistical software (version 4.3.1). Exclusion of 1 in 95%CI was considered statistically significant. This study was reported in accordance with the STROBE guideline.

Results

A total of 92,784 participants were finally enrolled in this study (mean [SD] age, 61.88 [7.87] years; 40,474 [43.62%] men; 52, 310 [56.38%] women) (Fig. 1). Based on the guideline threshold recommending at least 150 min of MVPA per week, participants were stratified into three groups: 40,217 (43.34%) were categorized under the WW pattern, 21,053(22.69%) under the regular pattern, and 31,514(33.97%) under the inactive pattern. When the threshold was set as 300 min of MVPA weekly, 19,635 (21.16%) were in the WW pattern, 16,319 (17.58%) were regular pattern and 56,830 (61.25%) were inactive pattern. The baseline characteristics of all participants stratified by different patterns were shown in Table 1.

Compared to the inactive group, the WW group demonstrated a younger demographic, a higher male prevalence, superior socioeconomic standing, and greater educational attainment. Additionally, they displayed a heightened employment rate, more favorable self-reported health status, a reduced BMI, and decreased blood pressure. The prevalence of hypertension, diabetes, and CVD was also lower in the WW group. Additional information on the baseline characteristics of the included participants and excluded participants was displayed in eTable 3.

MVPA patterns and risks of outcomes

Participants diagnosed with dementia or Parkinsonism either prior to enrollment or within two years post-enrolment were excluded during the accelerometer assessment, resulting in effective sample sizes of 92,144 or 92,048, respectively (Fig. 1). After a median observation duration of 8.85 years, incidences of dementia and Parkinsonism emerged at 6.03 (95% CI: 5.52–6.59) and 3.30 (95% CI: 2.93–3.72) cases per 10,000 person-years, respectively.

After adjusting for sociodemographic, lifestyle covariates, and comorbidities, the WW pattern, when achieving 50% of the guideline-recommended activity (≥150 min or ≥300 min) over 1–2 days, was associated with a lower risk of dementia (≥150 min: HR 0.68, 95% CI 0.56–0.84; ≥300 min: HR 0.65, 95% CI 0.50–0.85) and Parkinsonism (≥150 min: HR 0.47, 95% CI 0.35–0.63; ≥300 min: HR 0.58, 95% CI 0.41–0.82) (Fig. 2A and B). This trend mirrors the findings in the regularly group, where adherence to either of the guideline-recommended activity thresholds associated with lower risk for Parkinsonism, irrespective of the intensity distribution across the week.

The definition of WW was refined to include both the attainment of guideline-specified thresholds and achieving 75% of the activity over 1–2 days. In multivariable-adjusted models, the WW pattern persistently showed a lower risk for dementia (≥150 min: HR 0.61, 95% CI 0.41–0.91; ≥300 min: HR 0.34, 95% CI 0.14–0.82) and Parkinsonism (≥150 min: HR 0.22, 95% CI 0.10–0.47; ≥300 min: HR 0.20, 95% CI 0.05–0.80) (Fig. 3A and B). Analogous trends were discerned within the regular pattern. The cumulative incidence of dementia and parkinsonism events are illustrated in eFigure 1 and eFigure 2, which depict the outcomes for individuals completing either 50% or 75% of the recommended MVPA — equivalent to 150 minutes per week — over 1-2 days, and those achieving 300 minutes per week under similar conditions.

Supportive and sensitivity analyses

In models adjusted for multiple variables and stratified by MVPA quartiles, the WW pattern, characterized by exceeding MVPA percentiles of 25th, 50th, and 75th and completing 50% or 75% of the total exercise within 1–2 days, consistently demonstrated a lower risk for both dementia (≥115.2 min: HR 0.66, 95% CI 0.54–0.81; ≥230.4 min: HR 0.72, 95% CI 0.58–0.90; ≥403.2 min: HR 0.67, 95% CI 0.47–0.95) and Parkinsonism (≥115.2 min: HR 0.48, 95% CI 0.37–0.64; ≥230.4 min: HR 0.58, 95% CI 0.43–0.79; ≥403.2 min: HR 0.55, 95% CI 0.34–0.87) (Table 2).

After increasing the MVPA threshold to 50% over 1–2 consecutive days, both the WW and regular patterns remained were consistent

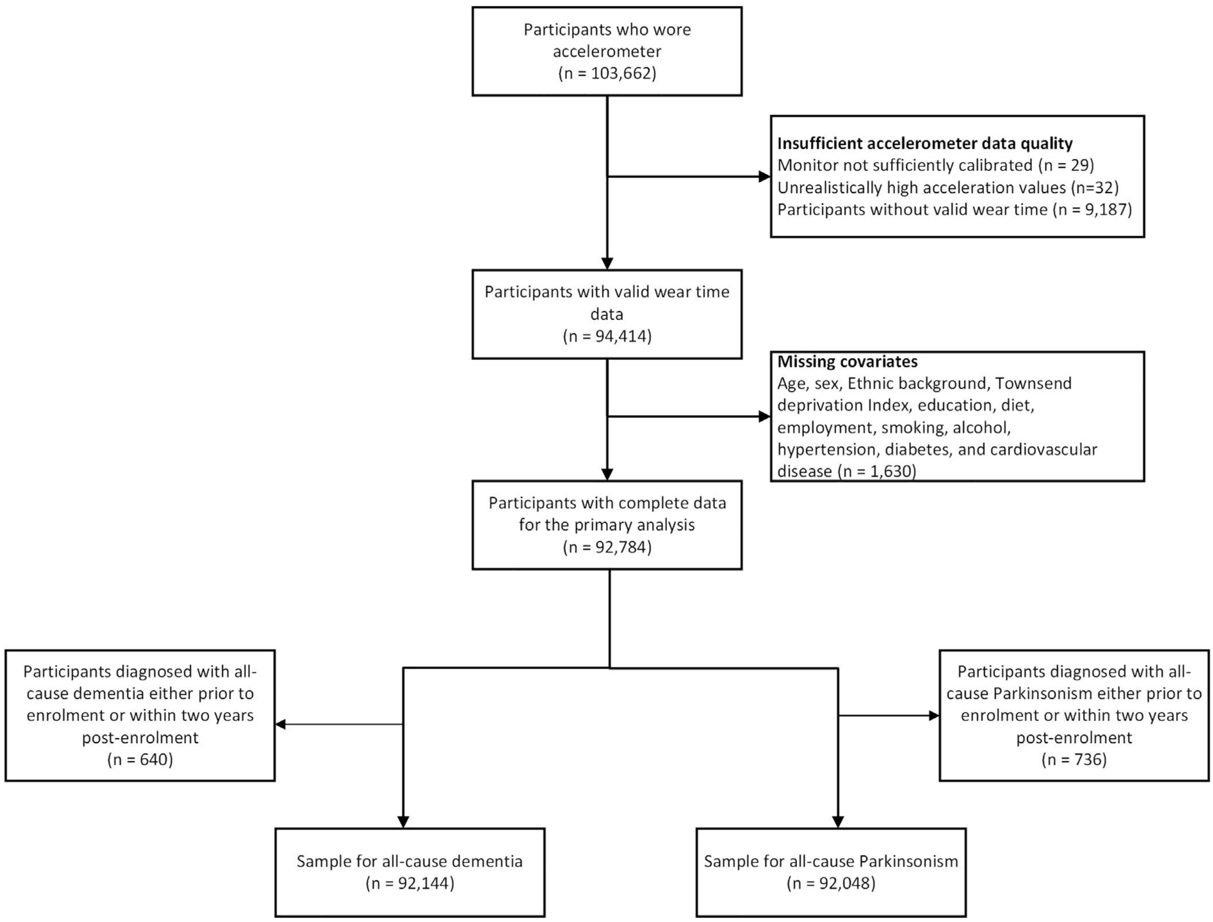

Fig. 1. Flow diagram of participants.

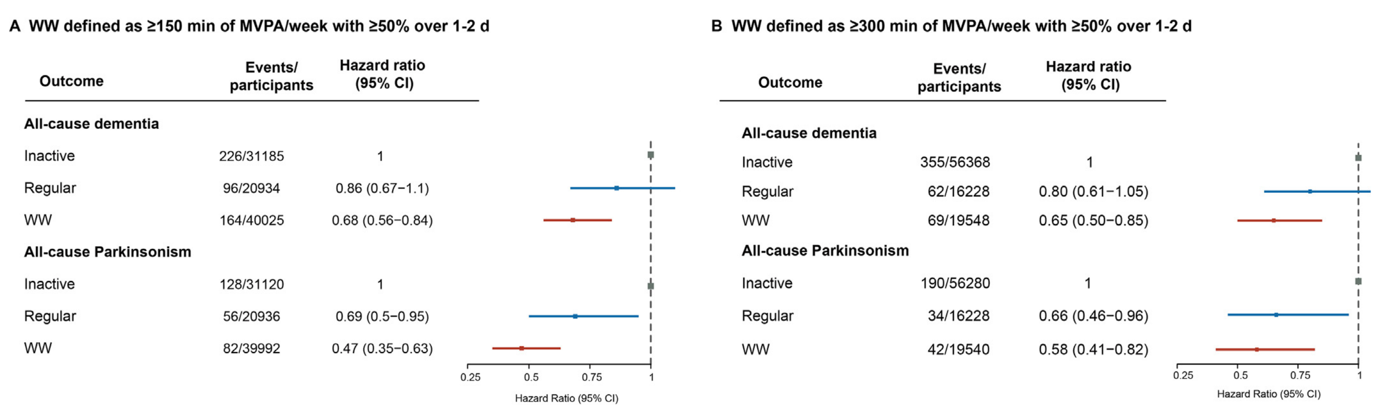

Fig. 2. Associations Between WW pattern (≥150 or ≥300 min/wk with ≥50% over 1–2 days) and Incidence of Dementia and Parkinsonism over 1–2 Days, Adjusted for Multiple Variables. The figure categorizes participants into three groups: weekend warriors (WW), regular, and inactive—with the inactive pattern as the reference. Panel A depicts the correlation of exercise patterns with outcomes when reaching 50% of a 150-min threshold over 1–2 days. Panel B demonstrates the correlation when 50% of a 300-min threshold is achieved within the same period. The presented forest plots include 95% confidence intervals.

(eTable 4). However, when the definition of WW patterns involved the accumulation of more than 75% of MVPA within 1–2 consecutive days, under a threshold of 150 min, WW patterns remain associated with Parkinsonism but not with dementia. At a higher threshold of 300 min, WW patterns did not exhibit a relation to either Parkinsonism or dementia risk (eTable 4). We redefined WW as individuals who engage in more than 150 min of MVPA per week and complete over 50% of their weekly exercise on weekends. As shown in eTable 5, we still observed a protective association between the WW pattern and reduced risk of dementia and Parkinsonism, compared to those with inactive group. However, when we adjusted the MVPA threshold to 300 min, the association was no longer statistically significant. After excluding the initial five years of follow-up, the WW pattern remain associated with a lower risk of both outcomes. This was observed when either 50% or 75% of MVPA was completed at the 150-min threshold. However, the results did not demonstrate stability at the 300-min threshold, indicating variability in the protective influence of WW patterns based on the duration of MVPA (eTable 6). Moreover, even after additionally adjusting for

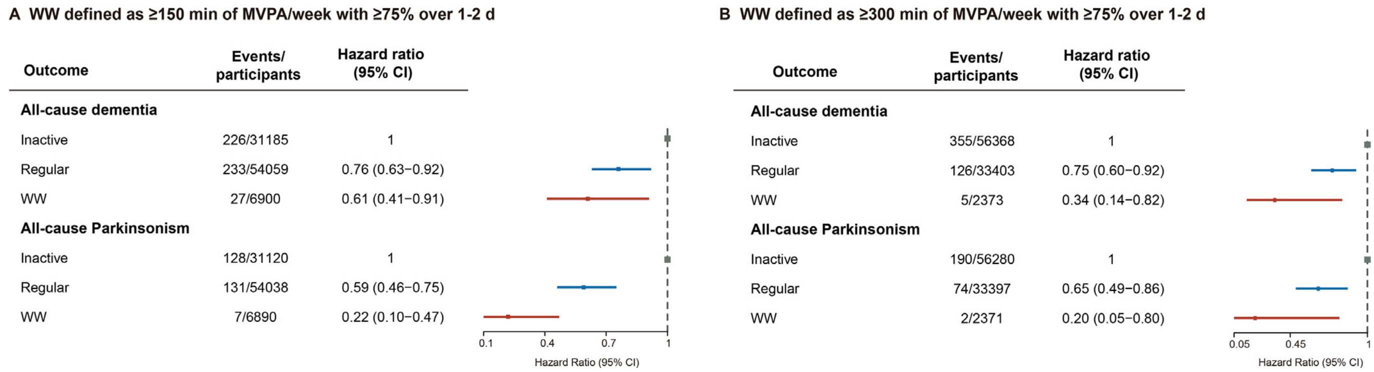

Fig. 3. Associations Between WW pattern (≥150 or ≥300 min/wk with ≥75% over 1–2 days) and Incidence of Dementia and Parkinsonism Over 1–2 Days, Adjusted for Multiple Variables. Panel A showcases the relationship between exercise patterns and outcomes upon achieving 75% of a 150-min threshold within 1–2 consecutive days. Panel B delineates the same for a 300-min threshold. Both figures incorporate forest plots with 95% confidence intervals.

sedentary time on top of the pre-existing covariates, the conclusions remained steadfast (eTable 7). After conducting the main analyses again, this time interpolating the missing data using multiple interpolation techniques, the WW pattern continued to be associated with a decreased risk of the two outcomes (eTable 8). After adjusting for relevant covariates, WW pattern was still significantly associated with outcomes in the presence of the competing risk of death (eTable 9).

Discussion

This study evaluated the relationship between the WW pattern and the subsequent risk of NDDs (dementia and Parkinsonism) in adults. The main findings indicated that amongst individuals who met the guideline-prescribed weekly MVPA durations (either the standard 150 min/week or the extended 300 min/week), concentrating 50% of their exercise over 1–2 days or 1–2 consecutive days, associated with lower risk of NDDs. Our findings also indicated that participants engaging in the WW pattern and those following a regular pattern of MVPA had a comparable risk of NDDs. This suggests that the distribution of MVPA—whether concentrated over fewer days (as in the WW pattern) or spread out over more days—may offer similar benefits. The significance of this study lies in its proposal of a low-frequency, high-intensity physical activity concentrated in a short time span for busy individuals to meet their exercise needs. When MVPA was increased to 75% over 1–2 days, it was associated with a reduced risk of NDDs at both thresholds, but no significant protective effect was seen at 300 min if 1–2 consecutive days were completed. This suggests that while increased MVPA can be beneficial, there may be a limit to its protective effect, particularly at higher durations of physical activity.

Although it's widely recognized that physical activity offers numerous health advantages [22,23], clear recommendations on the optimal distribution of exercise time—such as frequency and duration per week—remain elusive. Moreover, the question of whether different activity patterns yield similar health benefits continues to be a subject of debate. Presently, relevant studies have shown that WW patterns are associated with a variety of health benefits such as reduced risk of cardiovascular disease, metabolic syndrome, and death [5,7,24,25]. Previous studies have shown that WW pattern and regular pattern participants exhibited comparable rates of all-cause and cause-specific mortality, indicating that the distribution of physical activity—whether dispersed across multiple days or concentrated within fewer days—does not significantly impact mortality outcomes when the total volume of activity remains constant [4,5]. This observation of benefit extended across various levels of total activity and was not confined to individuals who achieved the guideline-recommended levels of physical activity [26]. In addition, even when physical activity was concentrated in one or two sessions per week, a significant reduction in psychological distress was observed in comparison to the inactive control group [27]. And WW and other equivalent PA intensity patterns may be sufficient to reduce the risk of depressive symptoms [28]. Recent research also underscores that if exercise volume and intensity are sufficient, WW pattern may reap cardiovascular benefits like those spread evenly throughout the week, with risk reduction ranging between 17% and 38% [7]. Cumulatively, the evidence leans toward the potential health benefits of the WW pattern in reducing mortality. As delineated above, the ‘WW pattern confers health enhancements and positively influences diverse outcomes.

However, its effects on the risk of dementia or Parkinson's disease remain unexplored. There is no standardised definition of WW pattern, and multiply of the above studies used exercise questionnaires. Self-reports data are prone to both recall bias and overestimation of overall physical activity [29], and often exhibit poorly correlation with actual energy expenditure [30]. Given wearable accelerometers offer a more objective and consistent measure of physical activity, we used the WW pattern definition from previous studies [7]. Our study extends previous research by quantifying associations between objective physical activity measured by wrist-worn accelerometers and the incidence of dementia or Parkinsonism. The distinction of our research from prior studies lies in the comprehensive consideration of sedentary behaviors and co-morbidities. Consequently, it has become evident that the implementation of the WW pattern requires prudence, particularly in individuals with chronic diseases. Our findings indicate that the WW pattern does not correlate with a diminished risk of NDDs in such populations. Therefore, brief, high-intensity exercise bouts, typical of the WW pattern, may not be suitable for these groups, necessitating a more integrated approach to their management. Furthermore, our analysis reveals that even after adjusting for sedentary time, the WW pattern maintains its association with a reduced risk of NDDs, underscoring its potential benefits in mitigating these risks.

Strengths and limitations

The UK Biobank presents a robust, prospective cohort of middle-aged adults, enriched with extensive data on potential confounders. In our analysis, we opted for accelerometer-measured PA data to minimize inaccuracies inherent in self-reported data. Nevertheless, several limitations warrant consideration: (1) The reliability of interpreting physical activity patterns from a single week of data collection is questionable, as this timeframe may not accurately reflect habitual PA behaviors. Additionally, the phenomenon of participants altering their behavior due to the awareness of being monitored—known as the Hawthorne effect—could significantly influence the outcomes of the study. This factor must be considered when evaluating the results, as it may skew the true representation of participants' regular PA patterns. (2) Definitions of WW patterns using accelerometers are less clear, but the results of multiple definitions are consistent. Even though we used both thresholds recommended by multiple guidelines as well as quartile thresholds to explore the correlation between WW pattern and NDDs, the optimal MVPA threshold applicable to wrist accelerometer measurements of NDDs remains unclear. (3) Owing to the constraints in data volume, our study could not delve into the investigation of the ‘Super Weekend Warrior’ pattern, which involves achieving over 80% or 90% of the recommended MVPA over 1–2 days. (5) Although we excluded individuals who manifested an outcome within 2- or 5-years post-baseline and conducted the primary analysis, we still cannot eliminate the potential influence of reverse causality. (6) While we adjusted for ethnicity, the predominantly white composition of the UK sample may constrain broader applicability. (7) As with all observational studies, the presence of unmeasured or residual confounders cannot be completely negated. (8) Even when selecting follow-up information closer to the time of accelerometer measurement, it is regrettable that some covariates were still anchored to a more distant baseline. (9) We did not control for genetic polymorphisms, such as *Apolipoprotein E* and *Leucine-rich repeat kinase 2*, linked to dementia and Parkinson's risk, which may influence the observed associations.

Among those adhering to the guideline-prescribed weekly MVPA durations (either the standard 150 min/week or the extended 300 min/week), our study found that individuals who concentrated 50% of their exercise within 1–2 days span experienced a lower dementia and Parkinsonism risks. Our research illuminates the ‘weekend warrior’ paradigm, suggesting a more flexible physical activity strategy that may have protective effects against neurodegenerative diseases.

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Author contributions

GLL, YYN, and MLC conceived the study, contributed to interpretation of the results, and drafted the first manuscript. MYT and CYZ did statistical analyses. JQA, GT, JSKC, YYL, XJL, HQ, CB, HBL, HY, YY, and DLW contributed to critical revision of the manuscript. GLL attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted. MYT and CYZ have accessed and verified the underlying data. All authors had access to the data and accept responsibility for the decision to submit for publication.

Data availability

The UK Biobank is an open access resource. This research was conducted under license from the UK Biobank, application number 152047. Data are available upon application to UK Biobank; see http://ukbiobank.ac.uk/register-apply/.

Ethics approval

Ethical approval for the cohort was most recently renewed in 2021 by the National Health Service (NHS) Health Research Authority in 2021 (21/NW/0157). All participants provided written informed consent.

Declaration of competing interest

We declare no competing interests.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.neurot.2024.e00430.

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