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RESEARCH ARTICLE

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"Weekend warrior" physical activity pattern and risk of incident cancer

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ABSTRACT

Purpose: To investigate the associations between different physical activity patterns, including "weekend warrior" (WW) (i.e. most weekly moderate-vigorous physical activity (MVPA) achieved over 1–2 days)) and regular (MVPA spread more evenly) patterns with the risk of incident cancers.

Methods: We analyzed a prospective cohort of participants in the UK Biobank study who supplied a complete week of accelerometer-based physical activity data from June 1, 2013, to December 23, 2015. We compared three physical activity patterns: (1) active weekend warrior (active WW, ≥150 min of weekly MVPA with ≥50% of the total achieved in 1–2 days), (2) active regular (≥150 min of MVPA and not following an active WW pattern), and (3) inactive (<150 MVPA minutes). Associations between physical activity patterns and all types of prostate, breast, colorectal, and lung cancers were investigated through Cox regression adjusted for several factors.

Results: Overall, 80 896 participants (mean [SD] age, 55.5 [7.8] years; 56%women) with valid measures of accelerometry were included. When fully adjusted, the two active patterns exhibited a similar significant inverse association with lung cancer (WW: hazard ratio [HR], 0.77 [95% CI, 0.61–0.98]; active regular: 0.73 [95% CI, 0.56–0.96;]; inactive: reference), and similar non-significant associations with overall, prostate, breast, and colorectal cancers.

Conclusions: MVPA condensed into 1–2 days and more balanced distributions were associated with similar risk reduction of incident lung cancer, while neither pattern was associated with reduced overall, prostate, breast, and colorectal cancers. Future research should focus on totally inactive subjects to examine cancer risk reduction through MVPA.

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1. Introduction

Physical activity is beneficial for overall health and is generally associated with lower cancer risk, although this association has been observed to be weaker and less consistent than for all-cause mortality and cardiovascular disease [1]. While current guidelines recommend at least 150 weekly minutes of moderate to vigorous physical activity (MVPA), little is known about the association between the different weekly distributions (i.e. patterns) of MVPA and cancer risk. Recent studies suggest that condensed MVPA (i.e. performing most of the weekly MVPA over two days) may have benefits comparable to regular MVPA (i.e. MVPA evenly distributed throughout the week) in reducing the risk of all-cause mortality,

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specific-cause mortality, and cardiovascular disease [2,3]. However, whether the temporal distribution of MVPA influences cancer risk remains unknown. This matter has clinical implications as it could inform decisions regarding the weekly distribution and duration of physical activity sessions aimed at reducing the risk of cancer. In addition to weekly distribution, prior studies have examined diurnal patterns of physical activity in relation to cancer risk, including those using UK Biobank data, and observed that early-plus late-day activity is associated with reduced colorectal cancer risk, beyond the benefits of overall activity [4].

The temporal distribution of physical activity may influence its physiological effects, such as through different impacts on systemic inflammation, insulin sensitivity, or cardiorespiratory recovery dynamics. Concentrated activity bouts over one or two days may elicit distinct acute responses compared to more evenly distributed routines, which could in turn differentially affect cancer-related pathways [5–7]. Understanding whether the temporal distribution of physical activity influences cancer risk may inform public health guidelines and reduce perceived barriers to exercise. For individuals with limited time availability during weekdays, the possibility of concentrating physical activity into fewer days (e.g. weekends) may offer a more achievable and sustainable approach to meeting current recommendations. If such patterns confer similar benefits to more evenly distributed routines, this evidence could support more flexible messaging that promotes activity in diverse formats without compromising health outcomes.

Therefore, we aimed to examine the association between the “weekend warrior” (WW) and regular physical activity patterns with all types of cancer and cancer specific incidence risk in around 80,000 participants from the UK Biobank who wore wrist-based accelerometers.

2. Methods

2.1. Study design and population

The UK Biobank study is a prospective cohort of approximately 500,000 participants aged 40–69 years enrolled between 2006 and 2010 [8]. Participants provided written informed consent and completed physical examinations by trained staff and touchscreen questionnaires in 22 assessment centers in the UK. Ethical approval was provided by the UK National Health Service and National Research Ethics Service (Ethics Committee reference number: 11/NW/0382). As the UK Biobank data is de-identified and anonymized, the study is exempt from requiring additional institutional ethical approval, in accordance with the UK Health Research Authority guidelines and the UK Biobank Ethics and Governance Framework (https://www.ukbiobank.ac.uk/). However, the study additionally obtained the approval of the Ethics Committee of Research in Humans of the University of Valencia, (registered code 1510464). This study was conducted in accordance with the principles of the Helsinki declaration and its later amendments.

We retrieved data from 103 666 participants from the accelerometer subsample who wore an Axivity AX3 wrist-based triaxial accelerometer for 1 week to assess MVPA [9]. After calibration of the acceleration signals, sensors from accelerometers captured continuous acceleration at 100 Hz with a dynamic range of ±8 g in 5-second epochs [9]. MVPA was defined using a threshold of >100 milligravity units (mg) in Euclidean Norm Minus One (ENMO), as validated in prior research [9]. We excluded participants with missing covariates and insufficient accelerometer wear time (Supplementary Figure 1).

Valid wear time per day for accelerometers was considered as wear time greater than 16 h [10]. Furthermore, to assure enough representativity of the measurement, only participants with three valid measurement days, with at least one of those days being a weekend day, were included in the analyses [10]. Participants wore the accelerometer on their non-dominant wrist. The reliability of the UK Biobank accelerometry data has been previously assessed, showing high agreement when re-evaluated in a subsample of participants four years later ($n = 3400$; Kendall's $W = 0.74$) [11]. For the main analyses, we assessed a MVPA threshold based on current guidelines of aerobic physical activity (≥150 min/week) [12]. For secondary analyses, we used additional thresholds based on the 25th and 75th percentile of MVPA in the sample [3]. We then classified participants as active weekend warrior (WW), when MVPA was equal or above the MVPA threshold and ≥50% of total MVPA was achieved over 1–2 days, active regular when participants achieved MVPA equal or above threshold but not meeting a WW pattern, and inactive for participants below MVPA threshold [13]. This operational definition aligns with previous epidemiological studies on condensed weekly activity patterns [13].

We defined all-cause cancers as an ICD-10 code of C0.0–C9.9 recorded on the cancer registry, death certificate, or hospital admission. We excluded *in situ* (D0.0–D0.9), non-melanoma skin cancer (C49.9), and non-well-defined cancers (D37–D48). Cause-specific cancers were defined using the following ICD-10 codes recorded in the cancer registry, death certificate, or hospital admission: breast cancer (C50), prostate cancer (C61), lung cancer (C34), and colorectal cancer (C18, C19, and C20) (Supplementary Table 1).

The hospital registry-based follow-up was concluded on October 31, 2022, in England, August 31, 2022, in Scotland, and May 31, 2022, in Wales. The end of follow-up for cancer registries was December 31, 2020, for England, November 30, 2021, for Scotland, and December 31, 2016, for Wales. Cancer deaths were defined using the same ICD-10 codes for different endpoints as indicated in the death registry. The death registry comprised all fatalities that occurred prior to November 30, 2022, in England, Scotland, and Wales. Participants were censored at these specified dates, upon experiencing the event of interest, or at the time of their death, whichever occurred first.

2.3. Statistical analyses

We examined associations between physical activity pattern and incident all cause cancer, prostate cancer, breast cancer, colorectal cancer, and lung cancerusing Cox proportional hazards models adjusted for age, sex, racial and ethnic background, tobacco use, Townsend Deprivation Index, alcohol consumption, educational attainment, employment status, self-reported health, diet quality, family history of cancer, body mass index, medication use, prevalent cardiovascular disease, and handgrip (Supplementary Table 2). We estimated the minimum detectable hazard ratio with 80% power and $\alpha = 0.05$ using standard Cox regression assumptions. The study was powered to detect a hazard ratio of 0.90 for total cancer incidence when comparing active versus inactive participants.

To reduce the risk of reverse causation, we excluded participants who experienced cancer within the first 12 months of follow-up, and those with prevalent cancer at baseline. A complete case analysis was performed. A Wald test showed no interaction between physical activity patterns and any of the aforementioned covariates. We examined proportional hazard assumptions using Schoenfeld residuals in the models, and no violations were observed ($p > .05$). Prostate and breast cancer outcomes were analyzed solely for men and women, respectively. To assess the robustness of the main analyses, we also conducted multiple secondary analyses, including different thresholds for WW pattern, Fine–Gray subdistribution hazards models to account for competing mortality risks (deaths due to a cause different from cancer), Nelson-Aalen cumulative hazard function stratified by physical activity pattern, and exclusion of cancer-related deaths.

The estimates are presented as hazard ratios with 95% CIs. Data analyses were conducted from July to August 2023, using Stata version 16.1 (StataCorp).

3. Results

We examined 80,896 individuals (mean [SD] age, 55.5 [7.8] years; 56%women) with valid accelerometry at any point between June 1, 2013, and December 23, 2015. The median follow-up time was 6.0 years (IQR 5.4–6.6). A total of 32,213 participants were in the active WW group (39.8%), 22,162 were in the active regular group (27.4%), and 26,521 were in the inactive group (32.8%) when using the recommended threshold of 150 min of MVPA per week (Table 1). Participants from the active WW category had more MVPA on their two most active days when compared with the remaining five days, while participants from the active regularly distributed MVPA in a more balanced way during the week (Figure 1).

We observed comparable non-significant associations for active WW and active regular MVPA with risk of all cancers, prostate cancer, breast cancer, and colorectal cancer in fully adjusted analyses when compared with their inactive counterparts (Figure 2). In contrast, we observed an inverse significant association between active WW and the risk of lung cancer (hazard ratio [HR], 0.77 [95% CI,

Table 1. Sample characteristics of participants of the weekend warrior pattern and cancer study.

	No. (%)		
Baseline characteristic	Active-WW[a] (*n* = 32,213)	Active-Regular[a] (*n* = 22,162)	Inactive[a] (*n* = 26,521)
Age, mean (SD), y	55.5 (7.7)	54.5 (7.8)	56.3 (7.9)
Sex			
Female	16,412 (51.0%)	11,356 (51.2%)	17,573 (66.3%)
Male	15,801 (49.0%)	10,806 (48.8%)	8,948 (33.7%)
Ethnic background[b]			
Asian	309 (1.0%)	271(1.2%)	407 (1.5%)
Black	75 (0.2%)	76 (0.3%)	102 (0.4%)
Other	461 (1.4%)	414 (1.9%)	480 (1.8%)
White	31,368 (97.4%)	21,401 (96.6%)	25,532 (96.3%)
Tobacco use			
Never	19,274 (59.8%)	12,827 (57.9%)	14,785 (55.8%)
Former	11,149 (34.6%)	7,928 (35.8%)	9,464 (35.7%)
Current	1790 (5.6%)	1407 (6.4%)	2272 (8.6%)
Townsend Deprivation Index[c]	−1.9 (2.7)	−1.3 (3.0)	−1.8 (2.8)
Alcohol consumption			
Never	716 (2.2%)	562 (2.5%)	1,056 (4.0%)
Former	758 (2.4%)	623 (2.8%)	886 (3.3%)
Current	30,739 (95.4%)	20,977 (94.7%)	24,579 (92.7%)
Educational attainment, mean (SD),y	14.9 (5.3)	15.1 (5.3)	13.6 (5.3)
Employed	20,455 (63.5%)	14,952 (67.5%)	15,516 (58.5%)
Self-reported health			
Excellent	8213 (25.5%)	5798 (26.2%)	3983 (15.0%)
Good	19,683 (61.1%)	13,139 (59.3%)	15,713 (59.3%)
Fair	3889 (12.1%)	2880 (13.0%)	5632 (21.2%)
Poor	428 (1.3%)	345 (1.6%)	1193 (4.5%)
Diet quality			
Good	7360 (22.9%)	5508 (24.9%)	5503 (20.8%)
Intermediate	17,451 (54.2%)	11,700 (52.8%)	14,306 (53.9%)
Poor	7402 (23.0%)	4954 (22.4%)	6713 (25.3%)
Family history of cancer	9729 (30.2%)	6622 (29.9%)	8006 (30.2%)
Body mass index, mean (SD), kg/m^2	26.1 (3.9)	25.9 (4.1)	28.1 (5.2)
Medication use			
Blood pressure	4590 (14.3%)	2866 (12.9%)	5619 (21.2%)
Cholesterol	3849 (12.0%)	2465 (11.1%)	4646 (17.5%)
Insulin	141 (0.4%)	121 (0.6%)	280 (1.1%)
Cardiovascular disease	3409 (10.6%)	2185 (9.9%)	3693 (13.9%)
Handgrip, mean (SD), kg	34.0 (11.2)	33.9 (10.6)	30.5 (10.8)
MVPA, mean (SD), min/week			

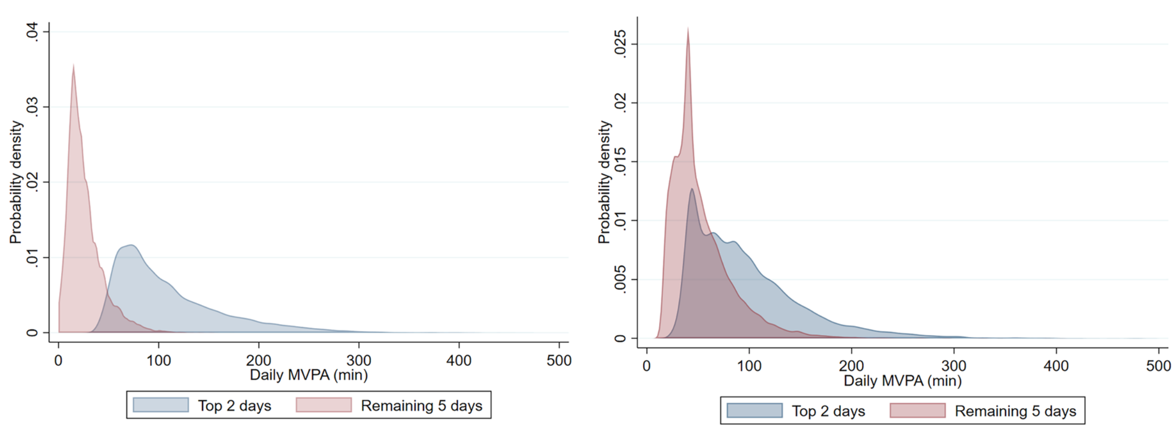

Figure 1. Distribution of moderate to vigorous physical activity (MVPA) on top 2 days versus remaining 5 days among active individuals at or above the recommended threshold of 150 min or more of MVPA per week. (A) Weekend warrior pattern. (B) Regular pattern. Distribution of daily MVPA on the 2 most active days of the week (blue), versus the remaining 5 days (red), among individuals with activity at or above the recommended MVPA (n = 54 375). A, Individuals meeting criteria for weekend warrior activity (MVPA equal or above 150 weekly minutes and ≥50% of total MVPA achieved over 1-2 days.) are displayed. B, Active regular individuals not meeting criteria for weekend warrior activity are displayed.

0.61–0.98]) and between active regular the risk of lung cancer ([HR], 0.73 [95% CI, 0.56–0.96]). These findings were consistent when other physical activity thresholds were used for the analyses (Supplementary Figures 2 and 3), competing risks (Supplementary Figure 4), and cumulative hazard

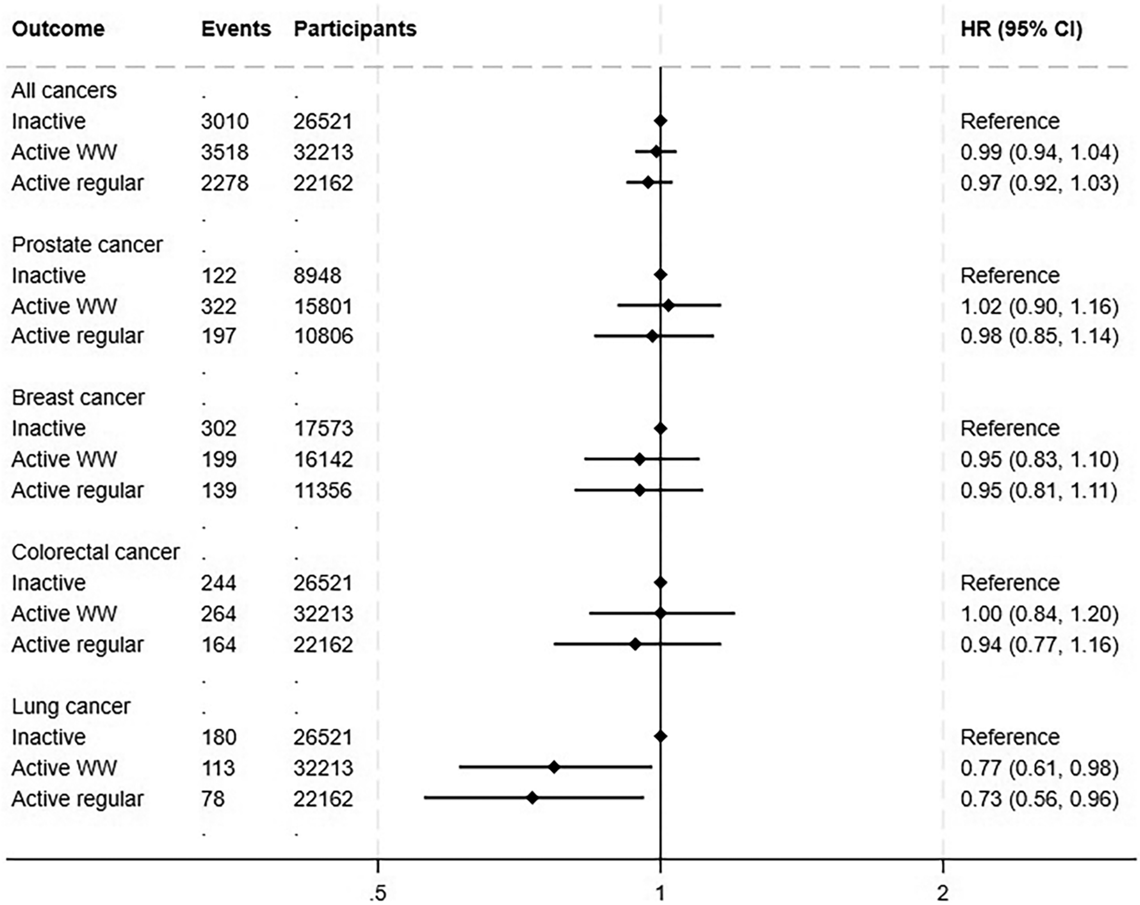

Figure 2. Associations between moderate to vigorous physical activity (MVPA) pattern and incident cancer. Associations between physical activity pattern and all types, prostate, breast, colorectal and lung cancer (fully adjusted model). Three physical activity patterns are compared: inactive (reference), active weekend warrior (WW) (MVPA equal or above 150 weekly minutes and ≥50% of total MVPA achieved over 1–2 days.), and active regular (achieving MVPA equal or above 150 weekly minutes without following a WW pattern). Bars depict 95%CIs.

functions (Supplementary Figures 5–9). When excluding cancers identified only *via* death certificates, results were consistent with the primary findings (not published).

4. Discussion

We found that MVPA condensed into 1–2 days (WW) compared with a more balanced weekly distribution of MVPA was associated with comparable risk reduction of incident lung cancer, while neither pattern was associated with reduced overall, prostate, breast, and colorectal cancers. Thus, our findings support the notion that WW and regular MVPA patterns confer comparable health benefits.

The present results extend prior research reporting comparable associations of active WW and active regular patterns with other outcomes, such as all-cause mortality, cause-specific mortality, and cardiovascular incidence [2,3]. Specifically, the present findings suggest that engagement in MVPA, irrespective of pattern, may provide similar benefits for reducing lung cancer risk. Nevertheless, owing to the more flexible schedule of active WW, this pattern may be more feasible for certain individuals (e.g. those without less free time during the weekdays or with less energy due to their work) and specific interventions aimed at specific populations.

In contrast to common beliefs and some prior findings, the present study could not document a significant risk reduction of all types of cancer and specific types of cancer such as prostate, breast, and colorectal cancer, irrespective of the type of physical activity pattern. Although our study did not find a statistically significant association between physical activity patterns and incident breast cancer, this finding contrasts with the broader literature, which supports an inverse association between physical activity and cancer risk. The discrepancy may reflect differences in exposure definitions, follow-up duration, or residual confounding in our analysis. However, the present study was designed to compare the WW and regular MVPA patterns. Thus, the third group (reference group) was not totally inactive but defined as those who did not achieve 150 weekly minutes of MVPA. Weekly MVPA lower than recommended may still be useful for reducing cancer risk, as prior research observed brief bouts of physical activity (1 or 2 min of daily vigorous physical activity) [14] and levels of MVPA over recommended levels may not make enough difference regardless of the physical activity pattern. This is in agreement with prior research that observed no significant or weak risk reductions for different specific types of cancer, such as breast cancer with higher physical activity levels [15,16]. Similarly, an umbrella review on this topic observed different levels of evidence for the inverse association of physical activity depending on the type of cancer, and only colon and breast cancers were supported with high-quality evidence when mixing cancer incidence and mortality [17]. Results on the association between MVPA and cancer usually differed among studies depending on the outcome and the population. For example, a recent study on short vigorous intermittent physical activity (i.e. non-recreational daily accumulated bouts of 1-2 min) measured through accelerometry showed a consistent inverse association with cancer incidence in non-exercisers [14], which suggests that greater benefits may be obtained with sedentary populations.

4.1. Clinical implications

This study provides several important clinical implications:

First, it emphasizes the significance of MVPA in reducing the risk of lung cancer. Both the 'weekend warrior' pattern and the more evenly distributed active regular pattern showed similar significant inverse associations with lung cancer risk. This suggests that individuals who engage in concentrated physical activity over a few days or spread it out more evenly throughout the week may experience similar benefits in terms of lung cancer prevention.

Second, although we did not observe statistically significant associations between MVPA patterns and the incidence of breast or colorectal cancer in this cohort, physical activity remains a key modifiable factor with proven benefits across multiple health domains. Our findings reinforce the importance of promoting physical activity among inactive populations, particularly given the protective associations observed for total cancer incidence. Overall, these findings support the integration of physical activity promotion into clinical practice and public health initiatives as part of comprehensive cancer prevention strategies. Encouraging individuals to engage in regular physical activity, whether through concentrated efforts over a few days or more evenly distributed patterns, may offer significant benefits in terms of lung cancer prevention and other cancer types.

4.2. Limitations

This study has several limitations. First, individuals may have modified their behavior during the period when they wore accelerometers. Second, even though optimal MVPA thresholds using accelerometers are unclear [18], our findings were consistent when using different thresholds below and well over current physical activity recommendations. Third, as the UK Biobank is not a representative sample of the UK adult population, generalizations to other populations should be made with caution. Particularly, the final study sample tended to be slightly younger, more likely to be female, have higher levels of education, lower body mass index, and healthier lifestyle profiles compared to those who did not participate in the accelerometry sub-study and the UK adult population [9,19]. Fourth, a longer follow-up period as well as higher statistical power would have provided more accurate estimates. Finally, menopausal status, a potentially relevant modifier in the association between physical activity and breast cancer risk, could not be included due to substantial missing data in the cohort. Future studies with more complete reproductive history variables are needed to explore potential effect modification.

5. Conclusions

Physical activity condensed into one to two days per week compared with a more balanced weekly distribution was associated with similar risk reductions of incident lung cancer, while neither pattern was associated with reduced overall, prostate, breast, and colorectal cancers. Future research may elucidate the threshold at which physical activity significantly reduces the risk of all types and specific types of cancers.

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Author contributions

CRediT: **Lars Louis Andersen**: Conceptualization, Supervision, Writing – review & editing; **Laura López-Bueno**: Conceptualization, Writing – review & editing; **Luis Suso-Martí**: Writing – review & editing; **Rodrigo Núñez-Cortés**: Writing – review & editing; **José Francisco López-Gil**: Writing – review & editing; **Joaquín Calatayud**: Conceptualization, Supervision, Writing – review & editing.

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Data availability statement

Due to the nature of the research, due to legal restrictions, supporting data is not available. This research has been conducted using the UK Biobank Resource under Application Number 98633. Rubén López-Bueno retrieved the data for the present study from https://www.ukbiobank.ac.uk/, which is available upon application request.

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