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FULL RESEARCH PAPER
Physical activity

Can incidental physical activity offset the deleterious associations of sedentary behaviour with major adverse cardiovascular events?

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Aims Incidental physical activity as part of daily living may offer feasibility advantages over traditional exercise. We examined the joint associations of incidental physical activity and sedentary behaviour with major adverse cardiovascular events (MACE) risk.

Methods and results Analyses included 22 368 non-exercising adults from the UK Biobank accelerometry sub-study (median age [IQR]: 62.9 [11.6] years; 41.8% male). Physical activity and sedentary behaviour exposures were derived using a machine learning-based intensity and posture classification schema. We assessed the tertile-based joint associations of sedentary behaviour and the following: a) incidental vigorous (VPA), b) incidental moderate to vigorous (MVPA), c) vigorous intermittent lifestyle physical activity (VILPA; bouts lasting up to 1 min), and d) moderate to vigorous intermittent lifestyle physical activity (MV-ILPA; bouts lasting up to 3 min) with MACE risk. Over an 8.0-year median follow-up, 819 MACE events occurred. Compared to the highest physical activity and lowest sedentary time, high sedentary behaviour (>11.4 h/day) with low incidental VPA (<2.1 min/day) had an HR of 1.34 (95% CI: 0.98, 1.84) and low incidental MVPA (<21.8 min/day) had a 1.89 HR (95% CI: 1.42, 2.52) for MACE. Sedentary behaviour was not associated with MACE at medium and high levels of VPA or VILPA. Completing 4.1 min/day of VPA or VILPA may offset the MACE risk associated with high sedentary behaviour. Conversely, 31–65 min of incidental MVPA or 26–52 min of MV-ILPA per day largely attenuated the associations with MACE.

Conclusion Brief intermittent bursts of vigorous incidental physical activity may offset cardiovascular risks from high sedentary behaviour.

Lay summary Literature to date has examined the role of total or leisure time physical activity in mitigating the health risks associated with high sedentary behaviour. However, the vast majority of adults achieve their daily physical activity incidentally through day-to-day activities. In this study of 22 368 adults from the UK Biobank accelerometry sub-study, we provide the first investigation into whether a) incidental vigorous (VPA), b) incidental moderate to vigorous (MVPA), c) vigorous intermittent lifestyle physical activity (VILPA; bouts lasting up to 1 min), and d) moderate to vigorous intermittent lifestyle physical activity (MV-ILPA; bouts lasting up to 3 min) completed through normal daily living can offset the risk of major adverse cardiovascular events (MACE) associated with high sedentary behaviour (>11.4 h per day). We demonstrate that incidental VPA and MVPA may offset the MACE risk associated with high-sedentary behaviour even if accrued in brief bursts lasting <3 min.

- Completing 4.1 min/day of VPA or VILPA may offset the MACE risk associated with high sedentary behaviour.
- A daily duration of 31–65 min of incidental MVPA or 26–52 min of MV-ILPA per day largely attenuated the associations with MACE.

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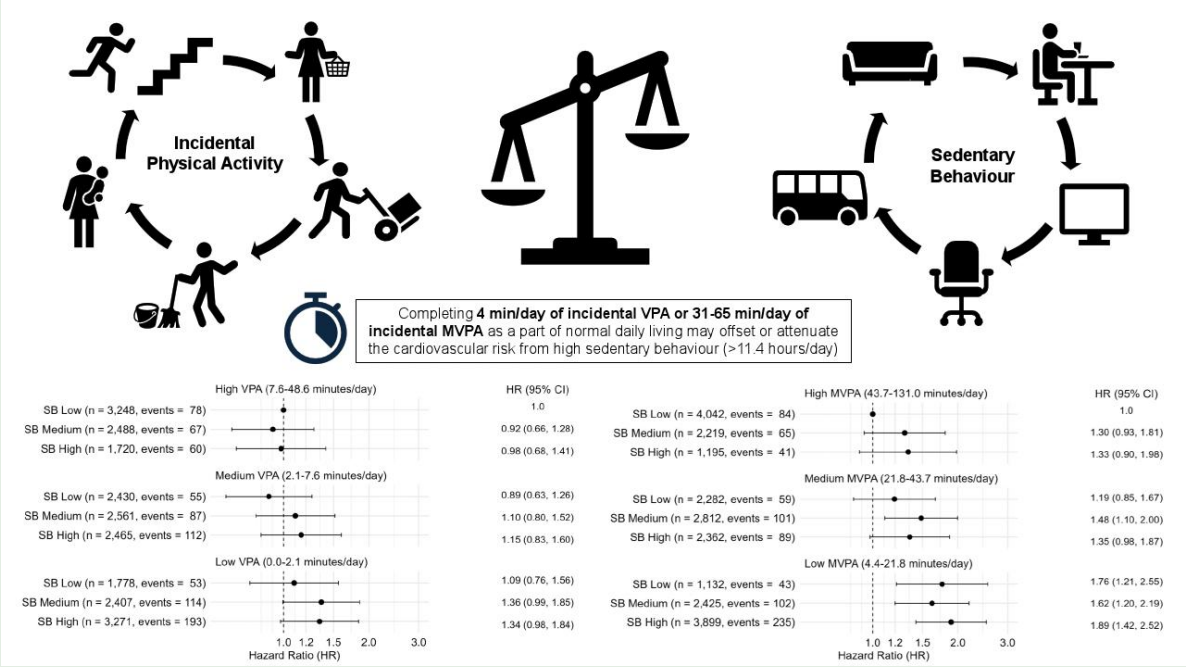
Graphical Abstract



Keywords Lifestyle physical activity • Sedentary behaviour • Cardiovascular disease • Mortality • Cohort studies • Machine learning

Introduction

Low levels of physical activity and increased sedentary time are associated with poor metabolic health[1] and, ultimately, a higher risk for cardiovascular disease (CVD) and premature mortality.[2–5] Previous studies have shown that sedentary behaviour and physical activity have joint associations with CVD.[6,7] This evidence suggests that the risk induced by sedentary behaviour may be attenuated or even eliminated with regular moderate to vigorous physical activity (MVPA).[7–9] For example, one of the first device-based studies in this area found that a median of 34.3 min per day of any MVPA (exercise-based and incidental combined) largely attenuated the all-cause mortality risks of high sedentary behaviour time.[7]

Literature to date has primarily explored the joint associations of physical activity and sedentary behaviour by self-reported questionnaires that mostly capture longer bouts (>10 min) of leisure time exercise[2,8] or device-based studies that did not differentiate between incidental physical activity and leisure time exercise.[7,10–12] The most recent public health guidelines acknowledge that 'all activity counts', a recommendation that indirectly encompasses short (e.g. <10 min) bouts of incidental physical activity that occur as a part of everyday living ('lifestyle').[13] For the majority of the adult population, incidental physical activity may be a more feasible and appealing option than structured exercise as it requires minimal time commitment and equipment.[14] Recent population-level evidence from wearable devices has shown that >90% of adult daily physical activity is achieved from 'micropatterns' of incidental physical activity defined as short bursts of intermittent physical activity lasting ≤3 min at a time.[15,16] A growing body of evidence has demonstrated the cardiovascular health benefits of brief bursts of moderate to vigorous incidental physical activity, termed 'vigorous intermittent lifestyle physical activity' (VILPA) and 'moderate to vigorous intermittent lifestyle physical activity' (MV-ILPA).[15,16] For instance, just three 1-min long bursts of VILPA bouts per day were associated with a 48–49% reduction in cardiovascular mortality risk and 38–40% lower risk of all-cause mortality.[15]

While the role of total MVPA[17] and VPA[18] in reducing CVD and mortality risk has been widely explored, there is currently no evidence on whether incidental physical activity can offset the cardiovascular risks associated with increased sedentary time. Additionally, no research has explored whether incidental physical activity accrued as brief bursts lasting <3 min (i.e. VILPA and MV-ILPA) can offset the MACE risk associated with high volumes of sedentary behaviour. Such evidence has major public health relevance as only approximately 20% of adults regularly participate in exercise, with incidental physical activities being the predominant source of health-enhancing movement for the majority of adults in most countries.[19,20]

To address these questions, we explored the joint associations of incidental lifestyle physical activity and sedentary behaviour with MACE risk. We also estimated the daily amounts of VPA, VILPA, MVPA, and MV-ILPA needed to offset or attenuate sedentary behaviour-related MACE risk.

Methods

Study participants

The UK Biobank is an ongoing prospective cohort comprising adults aged 40–69 years at baseline (2006–2010). Participants provided informed consent, and ethical approval was obtained from the National Research Ethics Service for the UK (No. 11/NW/0382). Additional details regarding the design of the UK Biobank can be found elsewhere.[21]

From June 2013 to December 2015, a subsample of 103 684 UK Biobank participants wore a wrist-worn accelerometer for 7 days (Axivity AX3, York, UK).[22] Participants were required to have three valid monitoring days, with one of those days being a weekend day.[15,16,23] We also excluded individuals with incomplete data, participants with cardiovascular disease at baseline (ascertained through self-report and hospital admission records), self-reported inability to walk, and those who reported a MACE or mortality event in the first 2 years of follow-up (see Supplementary material online, *Figure S1*).[15,16]

As in previous studies,[15,16,23] we specifically examined incidental physical activity (activities occurring during normal daily living) by excluding individuals who reported participation in leisure time exercise or more than one recreational walk per week. Recreational exercise and walking were self-reported through a close-ended touch-screen questionnaire that included questions regarding the type, duration, and frequency of exercise (see Supplementary material online, *Table S1*).[15]

Mortality and disease ascertainment

Due to the nature of rolling updates for data linkage, participants were followed through 30 November 2022, where the date and cause of death were identified using the data linkage program with the National Health Service (NHS), Digital of England and Wales and the NHS Central Register and National Records of Scotland. Inpatient hospitalization data were provided by either the Hospital Episode Statistics for England, the Patient Episode Database for Wales, or the Scottish Morbidity Record for Scotland. Instances of MACE were defined as CVD death or incidence of ST-elevated or non-ST elevated myocardial infarction (International Classification of Diseases Version 10: I21, I23, I24, I25, I26, I30, I31, I33, I34, I35, I38, I42, I45, I46, I48), stroke (I60, I61, I63, I64, I67) and heart failure (I11, I13, I50, I51).[24]

Physical activity and sedentary behaviour assessment

Devices were calibrated and initialized to sample data at a rate of 100 Hz before being distributed to participants.[22] Participants were instructed to wear the accelerometer on their dominant hand for seven consecutive days with a valid day classified as >16 h in a 24-h span.[16,23,25,26] The median [IQR] daily wear time was 23.97 [23.91, 24.00] h, and the mean number of valid days was 7.0 [6.6, 7.0]. Participants were excluded from analyses if no sleep data were recorded; accelerometer was poorly calibrated [>10 milli-gravitational units (mg)]; or a faulty accelerometer was distributed (>100 mg). We used a previously validated two-stage random forest intensity and posture classification schema to identify specific activities and intensities from accelerometer data.[27–29] At stage 1, activities were classified as sedentary, standing utilitarian movements (e.g. ironing a shirt, washing dishes), walking activities (e.g. gardening, active commuting, mopping floors), and running/high energetic activities (e.g. active playing with children). At stage 2, walking activities were classified as light (<3 METs), moderate (≥3 to <6MET), and vigorous (≥6 METs).[30] Sleep and non-wear time were determined using a validated algorithm based on relative changes in wrist tilt angle between successive 5 s windows.[27,28] When compared to polysomnography, this algorithm demonstrates an 87% accuracy for the classification of the sleep period time window.[28] For VILPA, we used bouts lasting up to 1 min which was previously shown to be the duration needed to physiologically reach vigorous intensity and, in the present study, corresponds to 90.4% of all bouts.[15,23] For MV-ILPA, we used bouts lasting up to 3 min which has been shown to correspond to the majority of all incidental MVPA (85.0% of all bouts).[16] Further details regarding the methods and accuracy of the classification scheme are provided in the Supplementary Methods.

Statistical analysis

In the core analytic sample, we calculated tertiles of each incidental physical activity intensity (VPA, VILPA, MVPA, MV-ILPA) and sedentary behaviour and created a joint exposure variable with nine mutually exclusive categorical combinations with the most active and least sedentary as the referent group. VPA, VILPA, MVPA, MV-ILPA, and sedentary behaviour were categorised into tertiles as follows: VPA (low: 0.0–2.1, medium: 2.1–7.6, high: 7.6–48.6 min/day), VILPA (low: 0.0–2.0, medium: 2.0–6.9, high: 6.9–17.0 min/day), MVPA (low: 4.4–21.8, medium: 21.8–43.7, high: 43.7–131.0 min/day), MV-ILPA (low: 4.3–18.8, medium: 18.8–35.7, high: 35.7–109.0 min/day), and sedentary behaviour (low: 4.1–10.2, medium: 10.2–11.4, high: 11.4–18.3 h/day). We used Cox proportional hazard models to examine the joint associations with MACE risk. All values of all physical activity exposures below the 2.5 percentile and above the 97.5 percentile were Winsorized to minimize the influence of sparse data and outliers. To address competing risks from non-CVD related deaths, we applied a Fine–Gray sub-distribution hazards model.[31] The duration of incidental physical activity needed to completely offset sedentary behaviour risk was defined as the median of the physical activity group where the risk for high sedentary behaviour became non-significant.[7,8] We assessed the proportional hazards assumptions using Schoenfeld residuals, and all models met these criteria.

Core analyses were adjusted for age, sex, educational background, ethnicity, smoking habits, alcohol intake, fruit and vegetable consumption, accelerometry-estimated sleep duration, previous cancer, family history of cardiovascular disease and cancer, and CVD medication including elevated blood lipids, hypertension, and glycaemic control.[15,16,23] To account for the effects of non-exposure-related physical activity, each model was adjusted for the daily duration of intensity bands other than the primary exposure, or when appropriate, other than the primary bout length.[15,16] For example, VILPA analyses were adjusted for moderate physical activity, light physical activity, and VILPA bouts lasting greater than 1 min. For the VILPA and MV-ILPA analysis, the models were adjusted for bout lengths that were longer than the intensity specific bout length of the model's exposure.[15,16] A full description of the covariates used in the analysis can be found in Supplementary material online, *Table S2*.

Additional and sensitivity analyses

Dose–response analyses between VPA, MVPA, and sedentary behaviour time with absolute MACE risk were examined to confirm individual level associations. To examine the role of bout length in offsetting sedentary behaviour risk,[16] we completed joint analyses using varying bout lengths of MV-ILPA, including up to 5 min and up to 10 min in duration. To minimize the risk of reverse causation, we also completed a sensitivity analysis removing those with poor self-reported health, underweight BMI (<18.5 kg/m^2), current smokers, or a frailty index of ≥3. We conducted another sensitivity analysis where the models were additionally adjusted for BMI which may be a potential mediator in these analyses. Lastly, we completed sensitivity analyses, excluding those with reported prevalent cancer at baseline.

All analyses and graphics in this study were conducted using the *survival*, *RMS*, and *ggplot2* packages in R statistical software (v.4.3.1). This study is reported in accordance with the Strengthening the Reporting of Observational Studies in Epidemiology Guidelines (STROBE; Supplementary material online, *Table S3*).

Results

Participant characteristics

The core sample included 22 368 adults (41.8% male) with a median age of 62.9 years [IQR: 56.2, 67.7]. During the median follow-up time of 8.0 years, 819 MACE events occurred. Participant characteristics are detailed across tertiles of sedentary behaviour and physical activity in *Table 1* and Supplementary material online, *Tables S4*–*S5*. Incidence of MACE subtypes by category of sedentary behaviour and physical activity are provided in Supplementary material online, *Table S6*.

Highest risk incidental physical activity and sedentary behaviour combinations

Relative to the referent most physically active and least sedentary group, we observed the highest risk of MACE in participants with the lowest levels for each physical activity exposure (VPA, VILPA, MVPA, MV-ILPA) combined with the highest levels of sedentary behaviour (>11.4 h per day). For example, the HR for the low total incidental VPA (<2.1 min per day) and high sedentary behaviour group was 1.34 (95% CI: 0.98, 1.84; *Figure 1*) and 1.37 (95% CI: 0.99, 1.89; *Figure 2*) for low VILPA (<2.0 min per day). For the low total incidental MVPA (<21.8 min per day) and high sedentary behaviour group, the HR was 1.89 (95% CI: 1.42, 2.52; *Figure 3*) and 1.82 (95% CI: 1.35, 2.45; *Figure 4*) for low MV-ILPA (<18.8 min per day).

Incidental VPA and sedentary behaviour

Compared to the referent group, there were no associations for sedentary behaviour with MACE in the high total incidental VPA category (>7.6 min/day) (*Figure 1*). In the medium total incidental VPA group (2.1–7.6 min/day), the HR for MACE was 1.10 (95% CI: 0.80, 1.52) in the medium sedentary behaviour category and 1.15 (95% CI: 0.83, 1.60) in the high sedentary behaviour category. In the low total incidental VPA duration group (<2.1 min/day), the HR for MACE risk was 1.09 (95% CI: 0.76, 1.56) in the low, 1.36 (95% CI: 0.99, 1.85) in the medium, and 1.34 (95% CI: 0.98, 1.84) in the high sedentary behaviour categories. The median daily incidental VPA duration in the group with low, medium, and high incidental VPA was 0.75, 4.1, and 15.1 min per day, respectively.

VILPA and sedentary behaviour

We found no increased MACE risk associated with high sedentary behaviour in the high VILPA group (>7 min/day; *Figure 2*). In the medium VILPA group (2.0–7.0 min/day), the HR for MACE was 1.07 (95% CI: 0.77, 1.49) in the medium sedentary behaviour category and 1.18 (95% CI: 0.85, 1.64) in the high sedentary behaviour category. Low duration of VILPA (<2.0 min/day) was associated with an increased risk for MACE in the medium (HR: 1.43; 95% CI: 1.04, 1.96) and to a lesser extent high (HR: 1.37; 95% CI: 0.99, 1.89) sedentary behaviour groups. The median daily VILPA duration in the group with low, medium, and high incidental VILPA was 0.75, 4.1, and 12.6 min per day, respectively.

Incidental MVPA and sedentary behaviour

In the high total incidental MVPA (>43.7 min/day) group, no association was found between sedentary behaviour and MACE risk compared to the referent group (*Figure 3*). The medium MVPA (21.8–43.7 min/day) category showed a less clear pattern whereby a statistically significant association was only evident in the medium sedentary behaviour group (HR: 1.48; 95% CI: 1.10, 2.00). All sedentary behaviour categories were associated with higher MACE risk in the low MVPA group (<21.8 min/day), although there was no clear gradient. The median daily MVPA duration in the group with medium and high incidental MVPA was 31.3 and 65.4 min per day, respectively.

MV-ILPA and sedentary behaviour

There was no association between high sedentary behaviour and MACE risk in the high MV-ILPA (>35.7 min/day) category (HR: 1.20; 95% CI: 0.78, 1.83) compared to the referent group. However, in the high MV-ILPA group, the medium sedentary behaviour category was still associated with higher MACE risk (HR: 1.64; 95% CI: 1.21, 2.24; *Figure 4*). MACE risk was more clearly attenuated in the medium MV-ILPA group (18.8–35.7 min/day), whereby the high sedentary behaviour category had an HR of 1.39 (95% CI: 1.01, 1.92) for MACE. All sedentary behaviour categories were associated with higher MACE risk in the low MV-ILPA group (<18.8 min/day). The median daily MV-ILPA duration in the group with medium and high incidental MV-ILPA was 26.2 and 52.2 min per day, respectively.

Additional and sensitivity analyses

In the dose–response analysis, a near linear association was observed for higher incidental VPA and lower absolute MACE risk (see Supplementary material online, *Figure S2*). Higher incidental MVPA exhibited a near linear association with lower absolute MACE risk up to 30 min per day, beyond which the association was less pronounced (see Supplementary material online, *Figure S2*). Conversely, higher sedentary behaviour displayed a linear association with higher risk absolute MACE risk (see Supplementary material online, *Figure S2*). All results were similar for the joint associations of MV-ILPA of bout length (i.e. up to 5 min and up to 10 min) and sedentary behaviour (see Supplementary material online, *Figures S3*–S4). The results did not materially differ when removing those with a frailty score of >3, BMI < 18.5, self-reported poor health, or current smokers (see Supplementary material online, *Figures S5*–S8). When we adjusted the models for BMI, there were no associations between sedentary behaviour and MACE across any VPA or VILPA groups (see Supplementary material online, *Figures S9*–S10). After the incidental MVPA and MV-ILPA models were adjusted for BMI, most associations were attenuated, but remained statistically significant (see Supplementary material online, *Figures S11*–S12). There were no differences in the results when excluding those with prevalent cancer at baseline (see Supplementary material online, *Figures S13*–S16).

Discussion

Main findings

This study provides the first evidence of the potential for incidental physical activity to mitigate the MACE risk associated with high sedentary behaviour times. We found that individuals with low levels of incidental MVPA and high levels of sedentary behaviour had up to a nearly two-fold risk of MACE compared to individuals with low sedentary behaviour and high MVPA. Importantly, we identified that modest amounts of incidental VPA and VILPA (4.1 min/day) may offset the relationship between high sedentary behaviour and MACE risk. Conversely, 31–65 min per day of incidental MVPA or 26–52 min per day of MV-ILPA attenuated some of the associations with MACE risk. These attenuations were clearer and more consistent for total incidental MVPA compared to shorter bouts of MV-ILPA.

Previous work exploring the joint relationship of overall physical activity and sedentary behaviour has primarily focused on all-cause mortality and physical activity with no specific domain or context (i.e. a mixture of physical activity from both structured exercise and activities of daily living).[7,8,11] For example, a waist accelerometry study[7] concluded that a median of 34.3 min per day of overall (exercise and non-exercise combined) MVPA offset the risk of all-cause mortality from a higher sedentary time. Until now, no research has explored the specific role of incidental physical activity in offsetting sedentary behaviour risks of major cardiovascular events. Our study presents the first evidence that feasible amounts of incidental VPA (4.1 min per day) or incidental MVPA (31–65 min per day) may attenuate or eliminate the cardiovascular risks of sedentary behaviour.

Table 1 Participant baseline characteristics by category of sedentary behaviour

	Low sedentary behaviour	Moderate sedentary behaviour	High sedentary behaviour	Overall
Sample	7456	7456	7456	22 368
MACE events, *n* %	186 (2.5%)	268 (3.6%)	365 (4.9%)	819 (3.7%)
MACE follow-up, years	8.10 [7.52, 8.61]	8.00 [7.45, 8.50]	7.89 [7.39, 8.42]	8.01 [7.45, 8.51]
Age, years	61.18 [54.45, 66.47]	62.83 [56.17, 67.61]	64.59 [58.04, 68.98]	62.85 [56.16, 67.73]
Male, *n* %	2848 (38.2%)	3057 (41.0%)	3445 (46.2%)	9350 (41.8%)
Vigorous physical activity, minutes/day	6.12 [2.25, 14.50]	4.25 [1.50, 10.25]	2.69 [0.75, 7.00]	4.12 [1.38, 10.50]
Vigorous physical activity under 1 min, minutes/day	5.62 [2.12, 12.50]	3.88 [1.38, 8.88]	2.50 [0.75, 6.25]	3.88 [1.29, 9.12]
Moderate to vigorous physical activity, minutes/day	46.78 [28.66, 74.44]	30.29 [18.33, 47.89]	20.87 [11.70, 35.03]	31.27 [17.56, 52.43]
Moderate to vigorous physical activity up to 3 min, minutes/day	40.57 [25.79, 62.22]	25.57 [16.26, 38.36]	17.50 [10.43, 27.36]	26.19 [15.55, 42.29]
Moderate physical activity, minutes/day	36.54 [22.62, 57.45]	23.47 [14.33, 36.34]	16.21 [9.13, 26.90]	24.17 [13.74, 39.98]
Light physical activity, minutes/day	126.28 [81.00, 179.24]	86.07 [60.52, 126.48]	67.17 [49.44, 97.21]	88.37 [59.55, 136.14]
Sedentary behaviour, hours	9.43 [8.80, 9.86]	10.84 [10.54, 11.15]	12.26 [11.83, 12.92]	10.84 [9.86, 11.83]
Sleep, hours	7.63 [7.03, 8.21]	7.37 [6.78, 7.95]	6.84 [6.14, 7.47]	7.30 [6.62, 7.91]
Fruit and vegetable intake, servings per day	7.00 [5.00, 9.00]	7.00 [5.00, 9.00]	6.50 [5.00, 9.00]	7.00 [5.00, 9.00]
Smoking history, *n* %	—	—	—	—
Never	4314 (57.9%)	4277 (57.4%)	4093 (54.9%)	12684 (56.7%)
Former	2501 (33.5%)	2534 (34.0%)	2619 (35.1%)	7654 (34.2%)
Current	641 (8.6%)	645 (8.7%)	744 (10.0%)	2030 (9.1%)
Alcohol consumption, *n* %	—	—	—	—
Never	253 (3.4%)	261 (3.5%)	330 (4.4%)	844 (3.8%)
Previous consumer	240 (3.2%)	218 (2.9%)	274 (3.7%)	732 (3.3%)
Within guidelines	4437 (59.5%)	4502 (60.4%)	4460 (59.8%)	13 399 (59.9%)
Above guidelines	2526 (33.9%)	2475 (33.2%)	2392 (32.1%)	7393 (33.1%)
Education, *n* %	—	—	—	—
College/university	2511 (33.7%)	2835 (38.0%)	2962 (39.7%)	8308 (37.1%)
Advanced placement	966 (13.0%)	947 (12.7%)	926 (12.4%)	2839 (12.7%)
GCSE	1729 (23.2%)	1612 (21.6%)	1546 (20.7%)	4887 (21.8%)
Certificate of secondary education	512 (6.9%)	371 (5.0%)	290 (3.9%)	1173 (5.2%)
NVQ/HND/HNC	455 (6.1%)	425 (5.7%)	465 (6.2%)	1345 (6.0%)
Other	1283 (17.2%)	1266 (17.0%)	1267 (17.0%)	3816 (17.1%)
Previous cancer, *n* %	509 (6.8%)	652 (8.7%)	706 (9.5%)	1867 (8.3%)
Parental history of CVD, *n* %	3923 (52.6%)	4115 (55.2%)	4079 (54.7%)	12 117 (54.2%)
Parental history of cancer, *n* %	1885 (25.3%)	1856 (24.9%)	1969 (26.4%)	5710 (25.5%)
Ethnicity, *n* %	—	—	—	—
Other	262 (3.5%)	276 (3.7%)	346 (4.6%)	884 (4.0%)
White	7194 (96.5%)	7180 (96.3%)	7110 (95.4%)	21 484 (96.0%)
Medication use, *n* %	—	—	—	—
Cholesterol lowering	786 (10.5%)	963 (12.9%)	1286 (17.2%)	3035 (13.6%)
Blood pressure lowering	979 (13.1%)	1245 (16.7%)	1603 (21.5%)	3827 (17.1%)
Insulin	36 (0.5%)	46 (0.6%)	78 (1.0%)	160 (0.7%)
Frailty index >3, *n* %	39 (0.5%)	53 (0.7%)	99 (1.3%)	191 (0.9%)
Self-rated health, *n* %	—	—	—	—
Excellent	1201 (16.1%)	1119 (15.0%)	967 (13.0%)	3287 (14.7%)
Good	4622 (62.0%)	4536 (60.8%)	4312 (57.8%)	13 470 (60.2%)
Fair	1389 (18.6%)	1511 (20.3%)	1792 (24.0%)	4692 (21.0%)
Poor	222 (3.0%)	272 (3.6%)	364 (4.9%)	858 (3.8%)
Body mass index, kg/m^2	25.80 [23.30, 28.90]	26.70 [24.00, 29.87]	27.70 [24.90, 31.30]	26.70 [24.00, 30.00]

Values represent median (IQR) unless stated otherwise. Sedentary behaviour is shown grouped by tertiles of low (4.1–10.2 h/day), moderate (10.2–11.4 h/day), and high (11.4–18.3 h/day). General Certificate of Secondary Education (GCSE); National Vocational Qualifications (NVQ); Higher National Diploma (HND); Higher National Certificate (HNC).

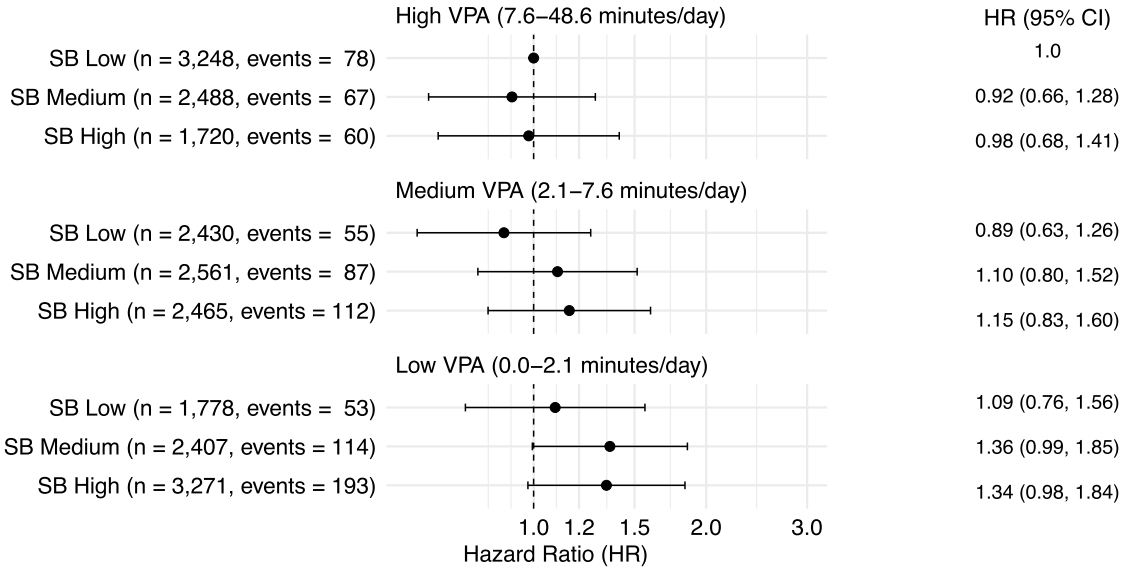


Figure 1 Joint associations of total incidental VPA and sedentary behaviour with MACE ($n = 22\,368$; MACE events: 819). Model is adjusted for age, sex, ethnicity, education, smoking status, fruit and vegetable consumption, sleep duration, alcohol intake, moderate physical activity, light physical activity, prevalent cancer, familial history of cardiovascular disease and cancer, and medication (cholesterol, insulin, and hypertension). VPA was categorized into tertiles of low (0.0–2.1 min/day), medium (2.1–7.6 min/day), and high (7.6–48.6 min/day). Sedentary behaviour (SB) is shown grouped by tertiles of low (4.1–10.2 h/day), medium (10.2–11.4 h/day), and high (11.4–18.3 h/day). Vigorous physical activity (VPA); major adverse cardiovascular event (MACE).

A wealth of literature has demonstrated the potent association of vigorous exercise with cardiovascular health and all-cause mortality risk.[25,32] In the present study, we found a more pronounced and consistent reduction in MACE risk from participation in incidental VPA compared to incidental MVPA. These findings are supported by previous work demonstrating that brief bouts of physical activity, particularly those accumulated at higher intensities, are associated with lower cardiovascular risk.[15,16,33] The present findings also show that total incidental MVPA had a clearer attenuation of MACE risk associated with sedentary behaviour compared to shorter MV-ILPA bouts. This finding aligns with recent work demonstrating that accumulating MVPA in longer bouts (5 to <10 min) may enhance cardiovascular risk reduction compared to shorter bouts (<1 min).[16,33]

Previous UK Biobank work[15,16] showed that much of incidental physical activity (92% of VPA and 87.2% of MVPA) is accrued in very short bouts lasting up to 1 min (VPA) and up to 3 min (MVPA) in length. Brief bursts of vigorous activity may counteract the cardiometabolic health consequences of sedentary behaviour by preserving or improving VO_2 max, body composition, blood pressure, and glycaemic control in a time efficient manner.[34] These findings may be explained, in part, by the positive associations between brief bouts of VPA and preserved or improved glucose and lipid metabolism,[35] as well as endothelial function.[36] These cardiometabolic effects of intermittent vigorous intensity activity provide several mechanistic explanations for how just 4.1 min/day of VPA or VILPA could potentially offset the MACE risk associated with sedentary behaviour.

From a public health standpoint, our findings offer additional insight into incidental physical activity as a potentially feasible option for reducing the cardiovascular detriments of increased workplace or leisure-time sedentary behaviour[37,38] adults who are not willing or able to habitually exercise in leisure time. The majority of incidental VPA in this study (85.0% of all bouts) was accrued in intermittent VILPA bursts of activity lasting <1 min in duration, but this was still sufficient to attenuate MACE risk. VILPA provides a potentially attractive alternative to exercise as it may be more easily incorporated into daily living and overcomes the multiple exercise participation barriers, such as the need for equipment, time commitment, or space.[14,39] This may have major public health relevance for various populations who encounter common barriers to physical activity and occupy high sedentary lifestyles, such as office workers, individuals with long-sitting commute times, or elderly individuals.[14,39,40] Our results inform future guidelines by highlighting the potential impact of incidental physical activity and by indicating that very low amounts of VPA or VILPA may be sufficient for offsetting the risks of a sedentary lifestyle. Further research is needed to examine these relationships across a more diverse range of demographics and health conditions, including those with pre-existing cardiovascular disease, cancer, or genetic predispositions.

Strengths and limitations

Our study used a validated machine learning-based classifier[15,16,23] that offers a higher resolution of physical activity and sedentary behaviour. We were able to study domain-specific associations of incidental physical activity by conducting analyses with adults who do not exercise. The long follow-up period and exclusion of participants with previous cardiovascular disease, self-rated poor health, underweight BMI (<18.5), high frailty index score, or an event in the first 2 years of follow-up greatly reduced the risk of reverse causation. Despite these precautionary measures, the potential for reverse causation remains. There was also a temporal difference of 5.5 years between the baseline collection questionnaire of leisure time exercise, which was used to classify exercising vs. non-exercising individuals, and the collection of accelerometry data. However, these questions have previously been shown to have a high stability over time (88%) across the 6095 participants who had repeat examinations closer to the

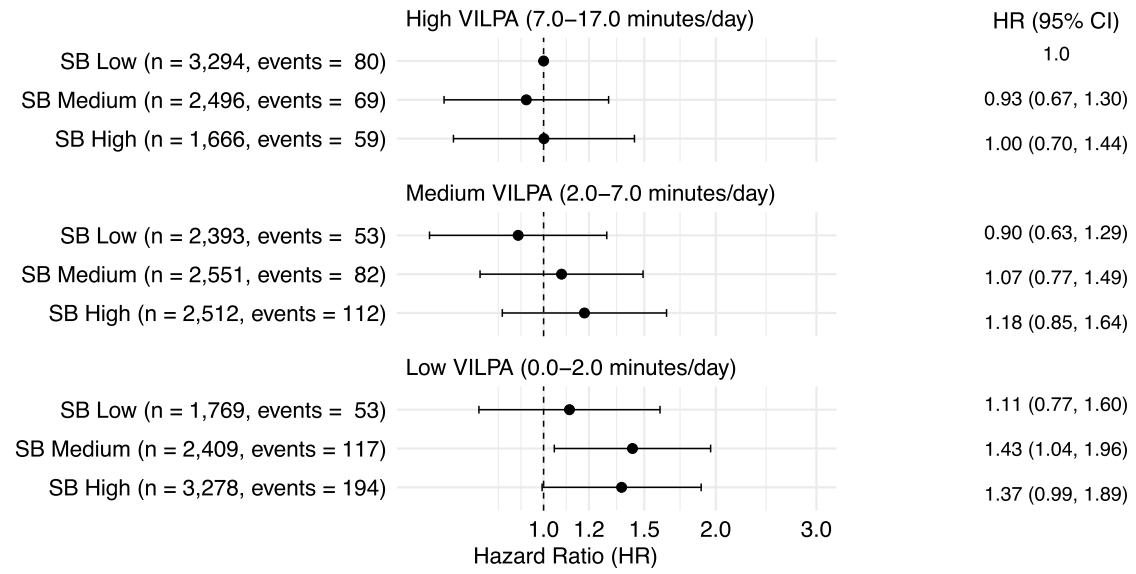


Figure 2 Joint associations of VILPA up to 1 min and sedentary behaviour with MACE (n = 22 368; MACE events: 819). Model is adjusted for age, sex, ethnicity, education, smoking status, fruit and vegetable consumption, sleep duration, alcohol intake, moderate physical activity, light physical activity, vigorous physical activity over 1 min, prevalent cancer, familial history of cardiovascular disease and cancer, and medication (cholesterol, insulin, and hypertensive). VILPA was categorized into tertiles of low (0.0–2.0 min/day), medium (2.0–6.9 min/day), and high (6.9–17.0 min/day). Sedentary behaviour (SB) is shown grouped by tertiles of low (4.1–10.2 h/day), medium (10.2–11.4 h/day), and high (11.4–18.3 h/day). Vigorous intermittent lifestyle physical activity (VILPA); major adverse cardiovascular event (MACE).

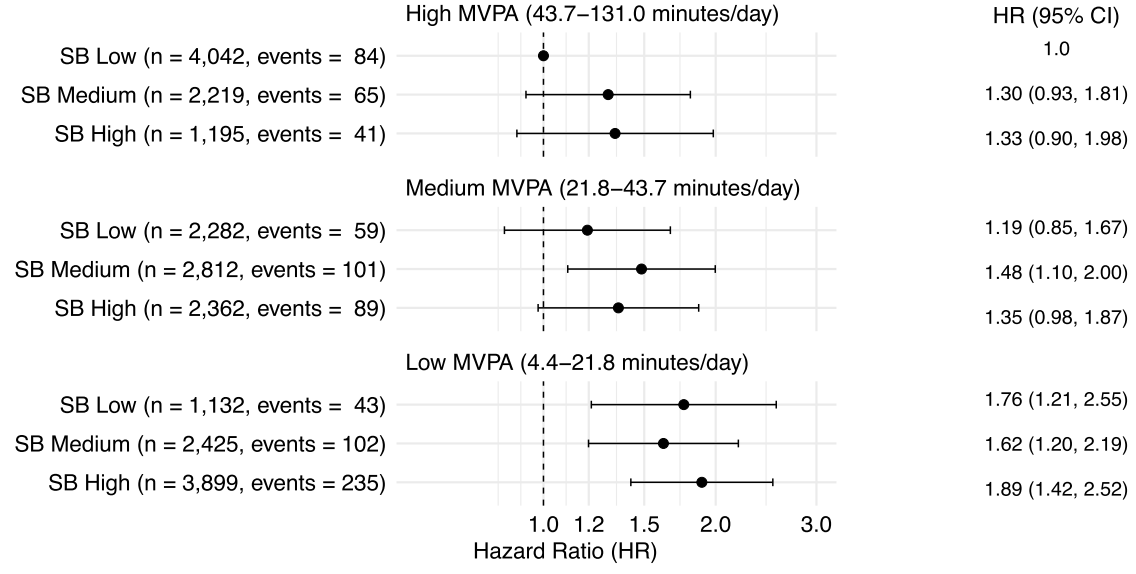


Figure 3 Joint associations of total incidental MVPA and sedentary behaviour with MACE (n = 22 368; MACE events: 819). Model is adjusted for age, sex, ethnicity, education, smoking status, fruit and vegetable consumption, sleep duration, alcohol intake, light physical activity, prevalent cancer, familial history of cardiovascular disease and cancer, and medication (cholesterol, insulin, and hypertension). MVPA was categorized into tertiles of low (4.4–21.8 min/day), medium (21.8–43.7 min/day), and high (43.7–131.0 min/day). Sedentary behaviour (SB) is shown grouped by tertiles of low (4.1–10.2 h/day), medium (10.2–11.4 h/day), and high (11.4–18.3 h/day). Moderate-to-vigorous physical activity (MVPA); major adverse cardiovascular event (MACE).

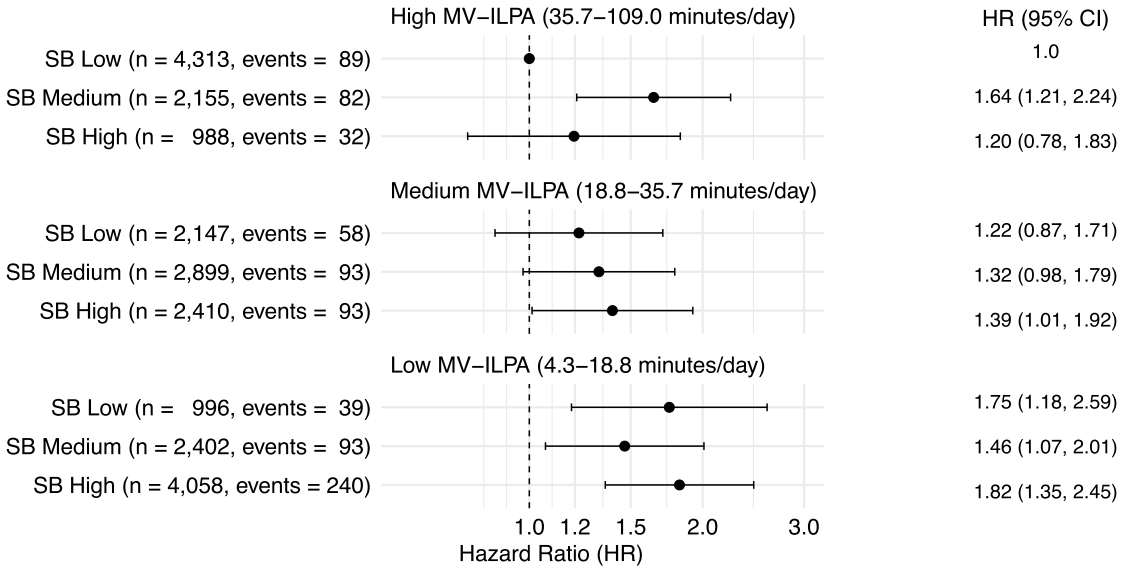


Figure 4 Joint associations of total MV-ILPA up to 3 min and sedentary behaviour with MACE (n = 22 368; MACE events: 819). Model is adjusted for age, sex, ethnicity, education, smoking status, fruit and vegetable consumption, sleep duration, alcohol intake, moderate to vigorous physical activity over 3 min, light physical activity, prevalent cancer, familial history of cardiovascular disease and cancer, and medication (cholesterol, insulin, and hypertensive). MV-ILPA was categorized into tertiles of low (4.3–18.8 min/day), medium (18.8–35.7 min/day), and high (35.7–109.0 min/day). Sedentary behaviour (SB) is shown grouped by tertiles of low (4.1–10.2 h/day), medium (10.2–11.4 h/day), and high (11.4–18.3 h/day). Moderate-to-vigorous intermittent lifestyle physical activity (MV-ILPA); major adverse cardiovascular event (MACE).

accelerometer measurements.[15] Although our two-level machine learning-based physical activity classifier had an 86.4% accuracy across all activities (e.g. sitting, walking, standing utilitarian, or running),[15,16,23,25] certain activities, such as carrying heavy loads or walking uphill, may be more prone to misclassification. Lastly, this study is subject to the inherent limitations of observational studies, and, as such, causality cannot be fully supported by these findings.

Conclusion

This study provides the first evidence that incidental physical activity accrued through normal activities of daily living is associated with the attenuation or elimination of the cardiovascular risk from sedentary behaviour. A daily duration of 4.1 min of incidental VPA or VILPA may offset the increased risk of MACE associated with high sedentary behaviour (>11.4 h/day). Conversely, 31–65 min per day of MVPA or 26–52 min per day of MV-ILPA attenuated some of the associations with MACE risk. Our findings, if replicated by future observational studies and trials, support interventions aimed at mitigating the health risks of sedentary lifestyles through maximizing opportunities for incidental physical activity of moderate to vigorous intensity during everyday living.

Supplementary material

Supplementary material is available at *European Journal of Preventive Cardiology*.

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Authors contribution

NK, MA, RK: conceptualisation, methodology, software, formal analysis, validation, visualisation, and writing—original draft. AK, AA, AS, ES: conceptualisation, methodology, and writing—review and editing. ES: funding acquisition, project administration, resources, supervision, and writing—review and editing. All authors read and approved the final manuscript.

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Conflict of interest: ES is a paid consultant and holds equity in Complement Theory Inc., a US-based company whose products and services relate to physical activity. All other authors disclose no conflict of interest for this work.

Data availability

The data that support the findings of this study are available from the UK Biobank, but restrictions apply to the availability of these data, which were used under license for the current study, and so are not publicly available. Data are however available from the authors upon reasonable request and with permission of the UK Biobank.

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