Do associations of physical activity and sedentary behaviour with cardiovascular disease and mortality differ across socioeconomic groups? A prospective analysis of device-measured and self-reported UK Biobank data

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ABSTRACT

Objective To examine if individual-level and area-level socioeconomic status (SES) modifies the association of moderate-to-vigorous physical activity (MVPA), domain-specific physical activity and sedentary behaviour with all-cause mortality (ACM) and incident cardiovascular disease (CVD).

Methods We used self-reported (International Physical Activity Questionnaire short form) and accelerometer-measured physical activity and sedentary behaviour data from the UK Biobank. We created an individual-level composite SES index using latent class analysis of household income, education and employment status. The Townsend Index was the measure of area-level SES. Cox proportional hazards regression models stratified across SES were used.

Results In 328 228 participants (mean age 55.9 (SD 8.1) years, 45% men) with an average follow-up of 12.1 (1.4) years, 18 033 deaths and 98 922 incident CVD events occurred. We found an increased ACM risk of low physical activity and high sedentary behaviour and an increased incident CVD risk of low accelerometer-measured moderate-to-vigorous physical activity (ACCEL_MVPA) and high sitting time. We observed statistically significant interactions for all exposures in ACM analyses by individual-level SES ($p<0.05$) but only for screen time in area-level SES–ACM analysis ($p<0.001$). Compared with high self-reported moderate-to-vigorous physical activity (IPAQ_MVPA), adjusted ACM HRs for low IPAQ_MVPA were 1.14 (95% CI 1.05 to .25), 1.15 (95% CI 1.06 to 1.24) and 1.22 (95% CI 1.13 to 1.31) in high, medium and low individual-level SES, respectively. There were higher detrimental associations of low ACCEL_MVPA with decreasing area-level SES for both outcomes and of high screen time with ACM in low area-level SES.

Conclusion We found modest evidence suggesting that the detrimental associations of low MVPA and high screen time with ACM and incident CVD are accentuated in low SES groups.

WHAT IS ALREADY KNOWN ON THIS TOPIC?

⇒ Low socioeconomic status (SES) groups have a higher prevalence of unhealthy lifestyles and may suffer disproportionate harm.
⇒ Studies incorporating composite SES index, multiple domains of physical activity, sedentary behaviour and use of both self-report and device-measured assessments are limited.

WHAT ARE THE NEW FINDINGS?

⇒ Our results suggest that there is a stronger inverse association of self-reported moderate-to-vigorous physical activity (MVPA) with all-cause mortality (ACM) in low compared with high individual-level SES groups.
⇒ We found higher detrimental associations of low accelerometer-measured moderate-to-vigorous physical activity with ACM and incident cardiovascular disease in low area-level SES; patterns were less clear for individual-level SES.
⇒ The detrimental associations of high self-reported screen time with ACM were stronger in low area-level SES.
⇒ Effect modification by SES was less clear for physical activity domains and sitting time.

HOW MIGHT IT IMPACT ON CLINICAL PRACTICE IN THE FUTURE?

⇒ We recommend primary prevention interventions that tackle physical inactivity and excessive sedentary behaviour be tailored to the needs of low SES groups.
⇒ Considering the variability in the interaction effects across SES measures, it may be important to target both low individual-level and area-level SES groups.

BACKGROUND

Socioeconomic inequalities in health are a global challenge.[1 2] They signify a range of differences in socioeconomic status (SES) as determined by an individual's economic and social position in relation to others, based on income, education, employment status or occupation and ethnicity.[1 3] Generally, individuals of low SES or those living in low socioeconomic areas have a higher prevalence of detrimental health-related behaviours[4] and may have less favourable health outcomes such as higher morbidity and mortality.[1 5–8] Even for a similar level of exposure to risk factors, low SES groups may

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suffer worse overall health outcomes (a phenomenon termed as vulnerability hypothesis).[9 10] Overall, low SES may increase both exposure to chronic disease risk factors and increase the vulnerability of morbidity and impaired health on exposure.[11 12]

The relationships between individual-level and area-level SES, physical activity and sedentary behaviour have been extensively researched. Self-reported leisure-time physical activity (LTPA) is positively associated with high individual (education,[13] employment,[14] income[13]) and area-level SES.[13 15] Studies using device-measured physical activity, which captures leisure time as well as occupational and incidental physical activity, have shown both direct[16 17] and inverse[18] associations between physical activity and SES. Of the various SES measures used, some of the most consistent positive associations with physical activity are reported for education.[19] The detrimental associations of physical inactivity and sedentary behaviour with higher risks of cardiovascular diseases (CVDs) and premature mortality are also well established.[20–22]

In considering how to reduce socioeconomic inequalities in health, it is important to understand the interaction between SES and health behaviours in jointly determining future health outcomes.[23 24] The scant evidence on the association between SES, physical activity, sedentary behaviour and health outcomes is unclear[5 6] and less consistent between studies employing self-report and objective physical activity measures.[25] For example, a previous study reported more consistent and stronger associations of education and occupational social class with device-measured physical activity than with self-report.[25] In a UK Biobank analysis, Foster *et al*[5] found a significant interaction between a composite lifestyle behaviour score and area-level SES (Townsend Index) for risk of all-cause mortality (ACM) and CVD mortality, but not CVD incidence.[5] Compared with the most healthy lifestyle, the association of the least healthy lifestyle with ACM was more pronounced in lower area-level SES.[5] Another recent study reported lower ACM and CVD risk among groups with healthy lifestyles, with stronger associations among low individual-level SES.[6] Both studies used composite lifestyle scores comprising multiple behavioural factors (eg, alcohol, smoking and diet).[5 6] The physical activity component was limited to self-reported moderate-to-vigorous physical activity (MVPA)[5] or LTPA,[6] and sedentary behaviour was limited to television (TV) viewing time,[5] which is a poor proxy of overall sedentary time.[26]

Social patterning (differences across the SES spectrum) in physical activity is more prominent for physical activity domains (eg, transportation, occupational, household and leisure-time) than for total physical activity.[27 28] For example, European adults from high SES participate mostly in LTPA.[28] In contrast, adults from low SES mostly participated in occupational physical activity, while no variations by SES were observed for total physical activity and active commuting.[28] Another study reported higher device-measured sedentary behaviour and lower TV viewing among higher SES.[29] No studies, to our knowledge, have examined how SES modifies the association of multiple domains of self-reported and device-measured physical activity and sedentary behaviour with mortality and incident CVD. Differential reporting bias could be more crucial in the context of SES, with another UK cohort (Whitehall II) reporting a weaker correlation between self-reported and device-measured physical activity data in low SES than in high SES groups and for moderate-intensity activities than vigorous activities.[30] In another study, Gorzelitz *et al* concluded that discordance between self-reported and device-measured physical activity data was inversely correlated to educational level.[31] Accelerometry devices can capture very short bouts of MVPA as well as lower-intensity activities performed in any domain and overcome other important limitations of self-report measurements (eg, recall or social desirability bias).[32 33] However, motion sensor devices such as accelerometers cannot capture domain-specific activities and can be logistically challenging to implement in low-resource settings due to higher time and resource requirements.[34] Using both self-reported and device-measured physical activity is recommended for a more complete understanding of the associations of physical activity with prospective health outcomes.[34] Further, understanding the role of SES in determining the associations of total physical activity, domains and sedentary behaviour with health outcomes is essential to narrow health disparities, a gap identified by the 2020 WHO Guideline Development Group.[34]

The primary aim of this study was to examine whether individual-level SES modifies the association of total and domain-specific physical activity and sedentary behaviour with ACM and incident CVD. The secondary aim was to examine the same effect modification by area-level SES. We hypothesised that the detrimental associations of low physical activity and high sedentary behaviour with outcomes would be stronger in low SES (vulnerability hypothesis).

METHODS

Study design and participants

We used data from the UK Biobank, a prospective, population-based cohort study that recruited adults aged 40–69 years between 2006 and 2010.[35] We excluded participants with missing covariates, socioeconomic information or exposures; poor self-rated health; prevalent CVD (self-reported or hospital admission); or an event (death or CVD event) within 2 years of recruitment (online supplemental figures S1 and S2).

Exposures

Online supplemental text S1 provides full descriptions of the exposure variables. Here, we summarise their main attributes:

Questionnaire-based physical activity: Weekly self-reported moderate-to-vigorous physical activity (IPAQ_MVPA) was measured using an adaption of the International Physical Activity Questionnaire short form.[36] It has moderate validity (r=0.52) for measuring MVPA among adults in the UK compared with accelerometer data.[37] Such correlations with accelerometry are higher than most other self-reported instruments.[38] We calculated total weekly IPAQ_MVPA volume (metabolic equivalent (MET)-minutes/week; number of minutes/week×standardised MET value of walking, and moderate and vigorous activities) and categorised participants into three groups: low (<600 MET-min/week), medium (600–3000 MET-min/week) and high (≥3000 MET-min/week).[36]

Device-measured physical activity: Accelerometer-measured moderate-to-vigorous physical activity (ACCEL_MVPA) was derived in a subsample of participants using data from the Axivity AX3 accelerometer worn on their dominant wrist for 24 hours/day for 1 week.[39] We used previously established procedures[40 41] to calibrate data and identify non-wear and only included participants with at least four valid monitoring days (at least one of those days being a weekend). We used a previously validated machine learning activity recognition scheme that uses raw acceleration signals to identify and quantify time spent in different intensities in 10 s windows.[42] Using the total weekly time spent in ACCEL_MVPA, we classified participants into tertiles for this study. The use

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of tertiles provided the optimal balance between physical activity exposure resolution and exposure group size.

Domain-specific physical activity: Weekly household physical activity volume was based on frequency and duration of light and heavy do-it-yourself activities (such as home maintenance, gardening, digging, carpentry, etc) and categorised into tertiles. Weekly LTPA volume was based on the frequency and duration of walking for pleasure, other exercises and strenuous sports[43] and categorised into tertiles.

Sedentary behaviour: The study includes two forms of sedentary behaviours: accelerometer-measured sitting time and self-reported screen time. We categorised participants into tertiles of total weekly sitting time using the information from the Axivity AX3 accelerometer using the same process defined earlier. We created 'screen time' tertiles using self-reported daily hours spent watching TV and non-occupational computer use.[44]

Outcomes

We examined associations with ACM and incident CVD. Incident CVD was defined as an event (fatal or non-fatal attributed to International Classification of Diseases, 10th Revision (codes I00–I99)), after baseline assessment. Participants were followed up until an event or censoring (30 September 2021 for England/Wales and 31 October 2021 for Scotland due to rolling data linkage updates).

Effect modifiers

Online supplemental Text S2 and Table S1 provide detailed descriptions of the socioeconomic indices. In brief, we examined effect modification by two composite socioeconomic indices: individual-level SES index and area-level SES (Townsend Index).[45] The individual-level composite SES index was created using latent class analysis of three socioeconomic variables (household income, education and employment status)[6] and categorised as high, medium and low SES (online supplemental text S2). Since the model with four latent classes failed to converge, we used the model with three latent classes. 'High SES' had a higher proportion of participants with college or university degree and before tax household income of £52 000 or greater (see online supplemental Table S1). The proportion of unemployed, those with less than high school education (labelled as 'none' in the UK Biobank) and those with household income less than £18 000 were higher in class labelled 'low SES'. The Townsend Index is derived from the respondent's postcode and reflects unemployment, non-car ownership, non-home ownership and household overcrowding.[45] We categorised it into thirds using tertiles, where the lowest third indicated high area-level SES.

Covariates

Online supplemental table S2 provides complete descriptions of the covariates. We selected variables a priori from the relevant literature.[5,6] We adjusted analyses for sex, ethnicity, sleep score (derived using morning chronotype, sleep duration, insomnia, snoring and daytime sleepiness),[46] dietary pattern score (from the intake of fruits, vegetables, fish, red meat and processed meat),[47] smoking and alcohol consumption.

Statistical analysis

We used multivariable-adjusted Cox proportional hazards regression stratified by socioeconomic indices, with age (scaled in years) as the underlying time scale. To address the impact of reverse causality, we have excluded the initial 2 years of follow-up and any events within it.[5,39,48,49] The reference groups were the optimum category/tertile of the exposure variables (high physical activity/low sedentary behaviour). Model 1 (main effects) for all exposures was adjusted for the aforementioned covariates, Townsend Index and education. For IPAQ_MVPA and LTPA analyses, we additionally adjusted for screen time; screen time analyses were adjusted for IPAQ_MVPA; ACCEL_MVPA analyses were adjusted for sitting time and vice versa; household physical activity analyses were adjusted for LTPA and screen time. There was no evidence of multicollinearity between the variables entered in the model (variation inflation factor ≤1.16).

Multiplicative interaction terms between exposures and individual-level and area-level SES were included in models 2 and 3, respectively. We evaluated interactions between exposures (physical activity/sedentary behaviour) and socioeconomic indices using likelihood ratio tests comparing models with and without a cross-product term. The p value for interaction was obtained using continuous variables. Proportional hazard assumption was tested using Schoenfeld residuals[50] and was satisfied. For CVD incidence analyses, we used the Fine and Grey subdistribution method[51] to account for competing risks (non-CVD related deaths).

We conducted several sensitivity analyses. First, we additionally adjusted ACM models stratified by individual-level SES for body mass index (BMI). Second, we repeated ACM models for physical activity exposures by adjusting for self-rated health instead of excluding those with poor self-rated health. Third, we excluded the first 3 years of follow-up and events within these years to reduce potential reverse causation.[6] To further check the sensitivity of the estimates, we calculated E-values that indicate the strength of association an unmeasured confounder would need to have with exposure and outcome to explain away the observed exposure–outcome association.[52] All analyses were performed using Stata/MP V.17.0, with two-sided p values of <0.05 considered statistically significant. Study reporting conforms to Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines[53] (see online supplemental STROBE checklist).

Patient and public involvement

Patients and the public were not involved in the design or conduct of this study.

RESULTS

Sample characteristics

We analysed data from 328 228 participants (mean age 55.9 (8.1) years, 45% men). The low, medium and high IPAQ_MVPA levels consisted of 15%, 48.6% and 36.4% participants. Over the mean follow-up period of 12.2 (1.4) years (3 922 258 person-years), 18 033 deaths and 98 922 incident CVD events occurred. Participant characteristics across IPAQ_MVPA and ACCEL_MVPA levels are presented in table 1 and online supplemental table S3). Online supplemental table S4 shows the distribution of exposure variables across individual-level SES.

All-cause mortality

Whole sample

We found detrimental associations of low IPAQ_MVPA (HR 1.15, 95% CI 1.10 to 1.20), low ACCEL_MVPA (HR 1.62, 95% CI 1.39 to 1.89) and low household physical activity (HR 1.06, 95% CI 1.01 to 1.12) with ACM (online supplemental table S5). The HRs for mortality were higher among participants in medium and lowest tertiles of LTPA, compared with those in the

Table 1 Baseline characteristics of participants stratified by level of self-reported MVPA (n=328 228)

Characteristics	Total population (N=328 228)	IPAQ_MVPA (n=3 10 499)			
		High (n=113 053)	Medium (n=150 763)	Low (n=46 683)	P value
Mean age (SD) (years)	55.9±8.1	56.2±8.2	55.6±8.1	55.1±7.8	<0.001
Men	148 522 (45.2)	52 285 (46.2)	68 212 (45.2)	21 873 (46.9)	<0.001
White ethnicity or race	313 783 (95.6)	108 619 (96.1)	144 313 (95.7)	44 393 (95.1)	<0.001
Household income (£)					<0.001
Less than 18 000	65 250 (19.9)	25 634 (22.7)	25 367 (16.8)	7469 (16.0)	
18 000–30 999	82 782 (25.2)	31 830 (28.2)	35 434 (23.5)	10 351 (22.2)	
31 000–51 999	88 932 (27.1)	30 340 (26.8)	41 676 (27.6)	13 256 (28.4)	
52 000–100 000	71 789 (21.9)	20 335 (18.0)	37 255 (24.7)	12 388 (26.5)	
Greater than 100 000	19 475 (5.9)	4914 (4.3)	11 031 (7.3)	3219 (6.9)	
Education					<0.001
None	43 483 (13.2)	18 350 (16.2)	14 578 (9.7)	4640 (9.9)	
O/CSE or equivalent	88 309 (26.9)	33 348 (29.5)	37 505 (24.9)	12 432 (26.6)	
A/NVQ/professional or equivalent	77 006 (23.5)	27 462 (24.3)	34 761 (23.1)	11 006 (23.6)	
College/university	119 430 (36.4)	33 893 (30.0)	63 919 (42.4)	18 605 (39.9)	
Employment					<0.001
Employed	311 760 (95.0)	107 396 (95.0)	143 745 (95.3)	44 382 (95.1)	
Unemployed	16 468 (5.0)	5657 (5.0)	7018 (4.7)	2301 (4.9)	
Townsend Index tertile					<0.001
First	111 076 (33.8)	36 884 (32.6)	52 896 (35.1)	16 539 (35.4)	
Second	110 210 (33.6)	38 274 (33.9)	50 534 (33.5)	15 760 (33.8)	
Third	106 942 (32.6)	37 895 (33.5)	47 333 (31.4)	14 384 (30.8)	
Smoking status					<0.001
Never	182 037 (55.5)	61 552 (54.4)	85 281 (56.6)	25 936 (55.6)	
Previous	113 664 (34.6)	39 835 (35.2)	52 203 (34.6)	15 601 (33.4)	
Current	32 527 (9.9)	11 666 (10.3)	13 279 (8.8)	5146 (11.0)	
Alcohol status					<0.001
Never	11 384 (3.5)	3859 (3.4)	4634 (3.1)	1742 (3.7)	
Previous	9530 (2.9)	3520 (3.1)	3893 (2.6)	1357 (2.9)	
Current	307 314 (93.6)	105 674 (93.5)	142 236 (94.3)	43 584 (93.4)	
Sleep pattern					<0.001
Poor	22 062 (6.7)	7168 (6.3)	9361 (6.2)	3752 (8.0)	
Intermediate	185 713 (56.6)	62 458 (55.2)	84 495 (56.0)	28 091 (60.2)	
Healthy	120 453 (36.7)	43 427 (38.4)	56 907 (37.7)	14 840 (31.8)	
Diet pattern					<0.001
Poor	20 120 (6.1)	6314 (5.6)	8370 (5.6)	4150 (8.9)	
Reasonable	201 082 (61.3)	66 724 (59.0)	92 368 (61.3)	30 747 (65.9)	
Good	107 026 (32.6)	40 015 (35.4)	50 025 (33.2)	11 786 (25.2)	
Body mass index					<0.001
Normal weight	112 801 (34.4)	41 601 (36.8)	53 460 (35.5)	12 892 (27.6)	
Overweight	141 884 (43.2)	49 178 (43.5)	65 555 (43.5)	19 801 (42.4)	
Obesity	73 543 (22.4)	22 274 (19.7)	31 748 (21.1)	13 990 (30.0)	
Self-rated health					
Excellent	61 350 (18.7)	24 460 (21.6)	29 240 (19.4)	5966 (12.8)	<0.001
Good	201 826 (61.5)	69 432 (61.4)	94 153 (62.5)	27 827 (59.6)	
Fair	65 052 (19.8)	19 161 (16.9)	27 370 (18.2)	12 890 (27.6)	

Participants' self-reported moderate-to-vigorous physical activity (IPAQ_MVPA) measured using the IPAQ was categorised as low (<600 MET-min/week), medium (600–<3000 MET-min/week), and high (≥3000 MET-min/week). Townsend Index (including measures of unemployment, non-car ownership, non-home ownership and household overcrowding), derived from respondents' postcode was used as an indicator of area-level SES. We categorised Townsend Index into tertiles where the lowest score indicated the highest area-level SES. Employment status is categorised as employed (includes paid employment or self-employed, retired, paid or voluntary work or student) and unemployed (includes looking after home and/or family, unable to work and unemployed). O/CSE or equivalent is O level/ Certificate of Secondary Education or equivalent. A/NVQ/ professional or equivalent is A level/ National Vocational Qualification, other professional qualifications such as nursing, teaching or equivalent. Sleep pattern is derived using sleep duration, chronotype, insomnia, snoring and dozing. Diet pattern is derived using intake of fruits and vegetables, fish (oily and non-oily), red meat (beef, pork and lamb) and proceeded meat intake. Body mass index is categorised as normal weight (18.5–<25 kg/m^2), overweight (25.0–<30 kg/m^2) and obesity (≥ 30 kg/m^2).
Values in the table are frequencies and percentages unless otherwise stated. Differences between groups was tested using one-way analysis of variance for age and using χ^2 test for other variables.
IPAQ, International Physical Activity Questionnaire; IPAQ_MVPA, self-reported moderate-to-vigorous physical activity; MET, metabolic equivalent; MVPA, moderate-to-vigorous physical activity; SES, socioeconomic status.

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highest LTPA tertile. Participants in the highest screen time and sitting time tertile were at 12% (9%–17%) and 19% (2%–39%) higher hazard of mortality than those in the lowest tertile, respectively (online supplemental table S5). For individual-level SES, we observed significant likelihood ratio tests ($p<0.05$) for all exposures. The multiplicative interaction term was only significant for screen time (p value for screen time×area-level SES<0.001).

Stratified by individual-level SES

Figure 1 shows the stratified association of MVPA and domain-specific physical activity with ACM across individual-level SES. There was no statistically significant association of medium IPAQ_MVPA and ACCEL_MVPA with ACM across all levels of individual-level SES. However, there was a stronger detrimental association of low IPAQ_MVPA with ACM in low SES. For example, compared with high IPAQ_MVPA, ACM HRs for low IPAQ_MVPA were 1.14 (95% CI 1.05 to 1.25) in high SES, 1.15 (95% CI 1.06 to 1.24) in medium SES and 1.22 (95% CI 1.13 to 1.31) in low SES. We observed no clear individual-level SES gradient in the associations of ACCEL_MVPA with ACM, though there was a slightly more pronounced detrimental association of low ACCEL_MVPA in low SES. HRs for low ACCEL_MVPA were 1.80 (95% CI 1.33 to 2.43) in low SES 1.47 (95% CI 1.13 to 1.91) in medium SES and 1.67 (95% CI 1.27 to 2.08) in high SES. Low LTPA was inversely associated with mortality in all groups, with less clear SES patterning. We observed some evidence of higher mortality HRs of medium LTPA among low and medium SES groups only (HR 1.07, 95% CI 0.99 to 1.16 in high SES; HR 1.12, 95% CI 1.04 to 1.20 in medium SES; and HR 1.08, 95% CI 1.01 to 1.15 in low SES). There was no association of household physical activity with ACM across SES groups (figure 1).

We found no evidence of association of sitting time with ACM across all individual-level SES groups (except the highest tertile in medium SES (HR 1.33, 95% CI 1.02 to 1.73) (figure 2). High screen time was detrimentally associated with ACM only among low and high SES groups, with a more pronounced association in high SES. For example, compared with low screen time, ACM HRs for high screen time were 1.10 (95% CI 1.04 to 1.17) in low SES, 1.04 (95% CI 0.98 to 1.11) in medium SES and 1.19 (95% CI 1.11 to 1.28) in high SES (figure 2).

Results were largely consistent with the main models when we further adjusted individual-level SES models of physical activity (online supplemental figure S3) and sedentary behaviour (online supplemental figure S4) for BMI. When we adjusted the main physical activity models for self-rated health (instead of excluding participants with poor self-rated health), the detrimental associations of low IPAQ_MVPA and low LTPA with ACM were attenuated in medium and high SES (online supplemental figure S5). Removing the first 3 years of follow-up did not appreciably change the results obtained in the main analysis (online supplemental figure S6).

Stratified by area-level SES

Low IPAQ_MVPA and ACCEL_MVPA were associated with higher ACM risk in all area-level SES groups (online supplemental figure S7). We observed higher ACM HRs of low ACCEL_MVPA in low and medium SES. For example, HRs for low ACCEL_MVPA were 1.78 (95% CI 1.36 to 2.29), 1.71 (95% CI 1.31 to 2.25) and 1.41 (95% CI 1.08 to 1.84) in low, medium and high area-level SES groups, respectively. The detrimental associations of medium and low tertiles of LTPA were

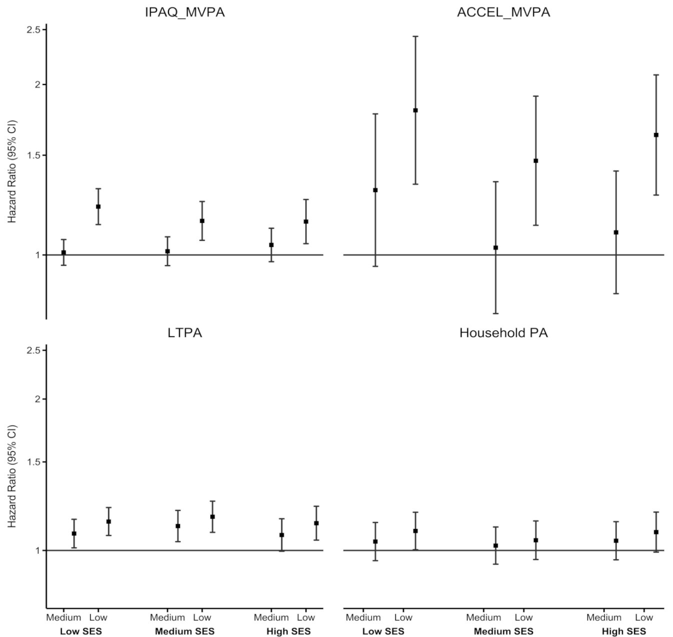

Figure 1 Association of PA with all-cause mortality across individual-level SES. Small squares denote point estimates of the HR, and the bars indicate 95% CIs. Reference: high PA. Y axis is in log scale. Individual-level SES was created using latent class analysis of three socioeconomic factors (household income, education and employment status) and categorised into low, medium and high. IPAQ_MVPA: participants' PA measured using the IPAQ was categorised as low (<600 MET-min/week), medium (600–< 3000 MET-min/week) and high (≥3000 MET-min/week). Low SES: high IPAQ_MVPA (2882/32 501), medium IPAQ_MVPA (2751/30 856,1.01 (0.96–1.06)), low IPAQ_MVPA (997/9208, 1.22 (1.13–1.31)). Medium SES: High (2088/46 120), medium (2447/53 386, 1.01 (0.96–1.08)), low (892/17 658, 1.15 (1.06–1.24)). High SES: high (1280/34 432), medium (2426/66 521, 1.04 (0.97–1.11)), low (784/19 817, 1.14 (1.05–1.25)) ACCEL_MVPA: device-measured total PA was measured using the Axivity AX3 triaxial accelerometer worn on the participant's dominant wrist for a 7-day period. The total number of minutes spent on MVPA (a sum of moderate and vigorous activities) was extracted and categorised into tertile-based thirds. 'Low' indicates the first tertile; 'medium' indicates the second tertile; and 'high' indicates the third tertile. Low SES: high ACCEL_MVPA (70/2695), medium ACCEL_MVPA (109/2884, 1.30 (0.95–1.77)), low ACCEL_MVPA (194/3407, 1.80 (1.33–2.43). Medium SES: high (103/6461), medium (129/6521, 1.03 (0.79–1.35)), low (211/6275, 1.47 (1.13–1.91)). High SES: high (121/9330), medium (142/8699, 1.10 (0.85–1.41)), low (229/7726, 1.67 (1.27–2.08)). LTPA was calculated using the frequency and duration of walking for pleasure, other exercises and strenuous sports in the last 4 weeks and was categorised into tertile-based thirds. Low SES: high LTPA (1811/21 186), medium LTPA (1816/20 970, 1.08 (1.01–1.15)), low LTPA (2041/22 726, 1.14 (1.07–1.22)). Medium SES: high (1430/33 481), medium (1606/35 277, 1.12 (1.04–1.20)), low (1671/36 695, 1.17 (1.09–1.25)). High SES: high (1365/39 621), medium (1428/39 546, 1.07 (0.99–1.16)), low (1252/33 835, 1.13 (1.05–1.22)). Household PA was assessed by asking participants the frequency and duration of light and heavy do-it-yourself activities in the last 4 weeks and categorised into tertile-based thirds. Low SES: high household PA (1419/15 351), medium household PA (1323/14 910, 1.04 (0.95–1.14)), low household PA (1578/16 931, 1.09 (1.00–1.19)). Medium SES: high (1349/26 268), medium (1266/27 675, 1.02 (0.94–1.11)), low (1185/26 505, 1.05 (0.96–1.14)). High SES: high (1153/27 564), medium (1175/31 809, 1.04 (0.96–1.14)), low (1006/28 341, 1.09 (0.99–1.19)). ACCEL_

Figure 1 (Continued)

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MVPA, accelerometer-measured moderate-to-vigorous physical activity; IPAQ, International Physical Activity Questionnaire; IPAQ_MVPA, self-reported moderate-to-vigorous physical activity; LTPA, leisure-time physical activity; MET, metabolic equivalent; MVPA, moderate-to-vigorous physical activity; PA, physical activity; SES, socioeconomic status.

more pronounced in medium SES. We found clear detrimental associations of low household physical activity in the low SES group only (online supplemental figure S7).

We observed a clear gradient of stronger detrimental associations of screen time with ACM with decreasing area-level SES (online supplemental figure S8). For example, compared with the lowest screen time tertile, ACM HRs for high screen time were 1.07 (95% CI 1.01 to 1.14) in high, 1.13 (95% CI 1.06 to 1.20) in medium and 1.22 (95% CI 1.15 to 1.29) in low SES groups. There was no association of sitting time with ACM across all area-level SES groups.

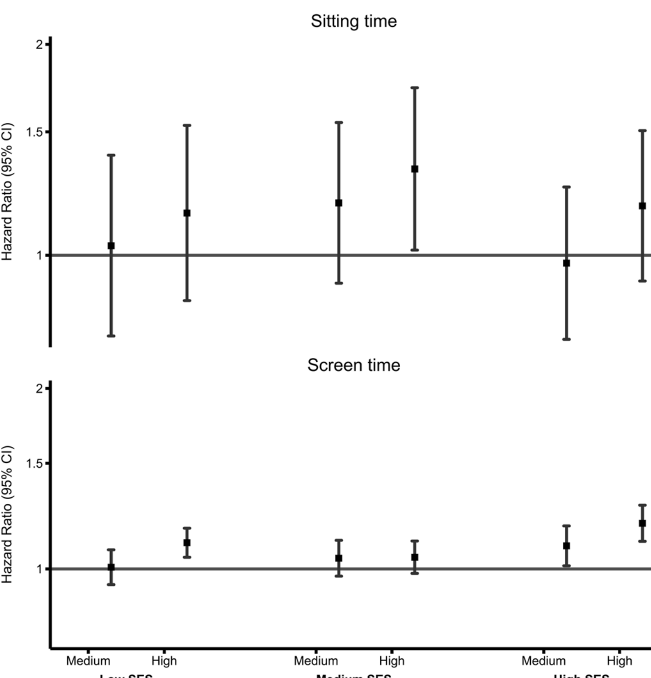

Figure 2 Association of sedentary behaviour with all-cause mortality across individual-level SES. Small squares denote point estimates of the HR, and the bars indicate 95% CIs. 'Low' indicates the first tertile; 'medium' indicates the second tertile; and 'high' indicates third tertile. Reference: lowest/first tertile; Y axis is in log-scale. Individual-level SES was created using latent class analysis of three socioeconomic factors (household income, education and employment status) and was categorised into low, medium and high. Sitting time: device-measured sitting time was measured using the Axivity AX3 triaxial accelerometer worn on participant's dominant wrist for a 7-day period. The total number of minutes of sitting time was extracted and categorised into tertile-based thirds. Low SES: low sitting time (79/2735), medium sitting time (107/2820, 1.03 (0.77–1.39)), high sitting time (187/3431, 1.15 (0.86–1.53)). Medium SES: low (101/7026), medium (140/6340, 1.19 (0.91–1.55)), high (202/5891, 1.33 (1.02–1.73)). High SES: low (114/8394), medium (146/8918, 0.97 (0.76–1.25)), high (232/8443, 1.18 (0.92–1.51)) Screen time: Screen time was derived using daily hours spent watching television and non-occupational and categorised into tertile-based thirds. Low SES: low screen time (2488/30 194), medium screen time (1628/17 857, 1.01 (0.94–1.08)), high screen time (3493/33 018, 1.10 (1.04–1.17)). Medium SES: low (2278/55 968), medium (1401/29 164, 1.04 (0.97–1.12)), high (2096/38 388; 1.04 (0.98–1.11)). High SES: low (2251/71 359), medium (984/23 852, 1.09 (1.01–1.18)), high (1404/28 317, 1.19 (1.11–1.28)). SES, socioeconomic status.

Incident CVD

Whole sample

Compared with high ACCEL_MVPA, participants in medium (HR 1.11, 95% CI 1.05 to 1.17) and lowest (HR 1.14, 95% CI 1.07 to 1.21) tertiles were at an increased incident CVD risk. Our results showed detrimental associations of the highest sitting time tertile (HR 1.11, 95% CI 1.05 to 1.18) with incident CVD (online supplemental table S5). We did not find statistically significant associations of self-reported physical activity and sedentary behaviour exposures with incident CVD. The multiplicative interaction term was not significant for all exposures.

Stratified by individual-level SES

Figure 3 shows the stratified association of MVPA and domain-specific physical activity with incident CVD across individual-level SES. The individual-level SES patterns of the association of IPAQ_MVPA with incident CVD were less clear. We observed clear detrimental associations of the lowest tertile of ACCEL_MVPA in medium and high SES and that of medium tertile in high SES only. For example, HRs for low ACCEL_MVPA were 1.13 (95% CI 0.99 to 1.28) in low SES, 1.14 (95% CI 1.04 to 1.25) in medium SES and 1.15 (95% CI 1.06 to 1.26) in high SES, respectively. There was no association of LTPA and household physical activity with incident CVD across SES groups (figure 3).

Sitting time (except highest tertile in high SES) and screen time were not associated with incident CVD across all individual-level SES groups (online supplemental figure S9). Compared with participants in the lowest sitting time tertile, high SES participants in the highest tertile were at 13% higher hazard of incident CVD (HR 1.13, 95% CI 1.03 to 1.23).

Stratified by area-level SES

We observed a clear SES gradient of association of low ACCEL_MVPA with incident CVD; the detrimental associations became stronger with decreasing area-level SES (online supplemental figure S10). For example, compared with high ACCEL_MVPA, HRs of low ACCEL_MVPA were 1.20 (95% CI 1.09 to 1.32), 1.13 (95% CI 1.03 to 1.24) and 1.14 (95% CI 0.98 to 1.32) in low, medium and high area-level SES, respectively. IPAQ_MVPA, LTPA and household physical activity were not associated with incident CVD across all SES groups (online supplemental figure S10).

The deleterious association of high sitting time tertile with incident CVD was observed in medium SES only (online supplemental figure S11). Screen time was not associated with incident CVD across all area-level SES strata.

We have provided e-values for all significant associations in online supplemental table S6. More than half of all e-values for significant associations in the main analysis had an HR of >1.50. For example, an unmeasured confounder would have to have an association of 3.00 with the exposure and outcome to explain away the observed HR of 1.80 of low ACCEL_MVPA and ACM association in low individual-level SES, but weaker confounding could not do so.

DISCUSSION

This study investigated if SES modifies the association of physical activity and sedentary behaviour with ACM and incident CVD.

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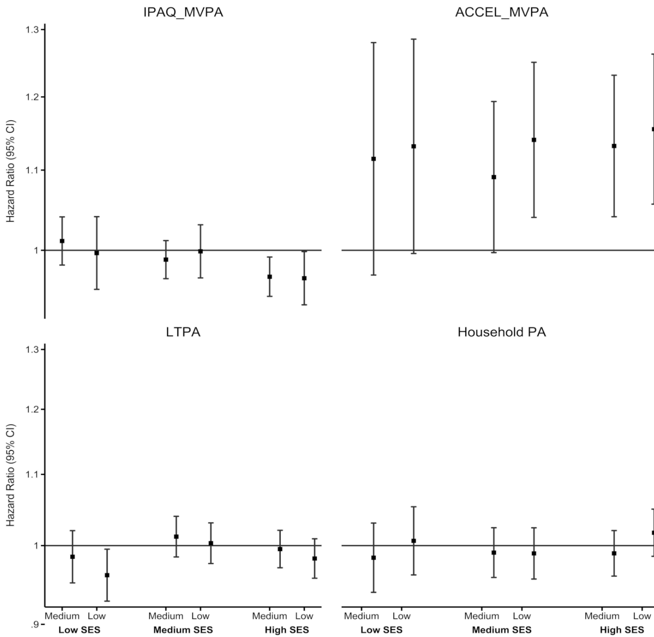

Figure 3 Association of PA with incident CVD across individual-level SES. Small squares denote point estimates of the sub-HR, and the bars indicate 95% CI. Reference: high PA; Y axis is in log scale. Individual-level SES was created using latent class analysis of three socioeconomic factors (household income, education and employment status) and was categorised into low, medium and high. IPAQ_MVPA: participants' PA measured using the IPAQ was categorised as low (<600 MET-min/week), medium (600–<3000 MET-min/week) and high (≥3000 MET-min/week). Low SES: high IPAQ_MVPA (9612/29 796), medium IPAQ_MVPA (9155/28 142, 1.01 (0.98–1.04)), low IPAQ_MVPA (2672/8276, 1.00 (0.95–1.04)). Medium SES: high (13 948/43 887), medium (15 994/50 705, 0.99 (0.97–1.01)), low (5375/16 783, 1.00 (0.97–1.03)). High SES: high (10 658/33 107), medium (20 215/64 038, 0.97 (0.95–0.99)), low (6083/19 105, 0.97 (0.94–1.00)). ACCEL_MVPA: device-measured total PA was measured using the Axivity AX3 triaxial accelerometer worn on the participant's dominant wrist for a 7-day period. The total number of minutes spent on MVPA (a sum of moderate and vigorous activities) was extracted and categorised into tertile-based thirds. 'Low' indicates the first tertile; 'medium' indicates the second tertile; and 'high' indicates third tertile. Low SES: high ACCEL_MVPA (617/2534), medium ACCEL_MVPA (794/2686, 1.11 (0.97–1.28)), low ACCEL_MVPA (1045/3099, 1.13 (0.99–1.28)). Medium SES: high (1281/6234), medium (1023/6238, 1.09 (0.99–1.19)), low (1693/5942, 1.14 (1.04–1.25)). High SES: high (5942/9080), medium (1633/8402, 1.13 (1.04–1.23)), low (1723/7366, 1.15 (1.06–1.26)). LTPA was calculated using the frequency and duration of walking for pleasure, other exercises and strenuous sports in the last 4 weeks and categorised into tertile-based thirds. Low SES: high LTPA (6360/19 384), medium LTPA (6198/19 180, 0.98 (0.95–1.02)), low LTPA (6581/20 802, 0.96 (0.93–0.99)). Medium SES: high (10 034/31 895), medium (10 712/33 502, 1.01 (0.98–1.04)), low (11 114/34 965, 1.00 (0.98–1.03)). High SES: high (12 152/38 123), medium (12 158/38 075, 0.99 (0.97–1.02)), low (10 339/32 599, 0.98 (0.96–1.01)). Household PA was assessed by asking participants the frequency and duration of light and heavy do-it-yourself activities in the last 4 weeks and categorised into tertile-based thirds. Low SES: high household PA (4576/14 106), medium: high household PA (4377/13 657, 0.98 (0.94–1.03)), low: high household PA (5024/15 399, 1.01 (0.96–1.05)). Medium SES: high (7880/24 847), medium (8378/26 283, 0.99 (0.96–1.02)), low (7979/25 241, 0.99 (0.96–1.02)). High SES: High (8364/26 384), medium (9666/30 612, 0.99 (0.96–1.02)), low (8780/27

Figure 3 (Continued)

288, 1.02 (0.99–1.05)).ACCEL_MVPA, accelerometer-measured moderate-to-vigorous physical activity; CVD, cardiovascular disease; IPAQ, International Physical Activity Questionnaire; IPAQ_MVPA, self-reported moderate-to-vigorous physical activity; LTPA, leisure-time physical activity; MET, metabolic equivalent; MVPA, moderate-to-vigorous physical activity; PA, physical activity; SES, socioeconomic status.

We found detrimental associations of low MVPA with ACM and incident CVD and of high screen time with ACM, with some evidence of stronger detrimental associations in low SES groups. Our findings suggested some variability in the interaction effects of SES on exposure–outcome associations, depending on the SES and physical activity measure we tested. SES patterns were clearer for individual-level SES while using self-reported MVPA and for area-level SES while using device-measured MVPA. These findings may inform public health policy and practice by identifying vulnerable individuals and priority target groups for physical inactivity and sedentary behaviour interventions.

SES may influence an individual's access to health information, treatment choices, compliance to treatment regimens, quality of care and social support, resulting in differential prognosis for similar risk factors or health conditions.[54] Previous studies have suggested that low socioeconomic groups may suffer disproportionate harm from unhealthy behaviours such as smoking[10 55] and alcohol consumption.[56] However, there is limited evidence on the interaction of SES and physical activity and sedentary behaviour for prospective health outcomes.[5] Studies using a single individual-level SES measure have shown inconsistent results. For example, Moore *et al*[57] found a stronger beneficial association of higher LTPA with mortality among those with a college education than those with high school or less education (HR 0.62, 95% CI 0.59 to 0.65, vs HR 0.57, 95% CI 0.54 to 0.59). In contrast, Arem *et al* reported no interaction of education and LTPA for mortality risks.[20] In our study, the detrimental associations of low physical activity and high sedentary behaviour were more pronounced in low SES, suggesting that SES may interact with physical activity and sedentary behaviour for mortality and incident CVD risks. This finding supports the vulnerability hypothesis, which suggests unhealthy lifestyles may inflict more harm in low socioeconomic groups[5 10] and is consistent with studies on other unhealthy behaviours such as smoking[10 55] and alcohol consumption.[56]

We found some gradient of stronger detrimental associations of self-reported MVPA with ACM in low individual-level SES, but the patterns were not clear for incident CVD. Though there was detrimental association of low self-reported MVPA in all SES groups, we found some evidence of more pronounced detrimental association in low SES. For example, participants of low, medium and high individual-level SES with low MVPA were at 22%, 15% and 14% higher hazard of ACM, respectively, compared with those with high MVPA (with approximately 50% overlap in the 95% CI of the low and high SES). These findings are in line with previous studies that have shown more consistent and stronger detrimental associations of unhealthy lifestyles in low SES than their affluent counterparts.[5 6] A previous UK Biobank analysis showed a higher mortality risk among those with the least healthy lifestyles in the most deprived fifth compared with the least deprived one (HR 2.47, 95% CI 2.04 to 3.00, vs HR 1.65, 95% CI 1.25 to 2.19).[5] Besides a higher prevalence of unhealthy lifestyle factors,[5 56] other potential explanations for these higher ACM hazards in low SES include exposure to chronic stressors, poor access to information, lower levels of

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social support,[4 5 58] and limited health literacy. Targeted primary prevention interventions aimed at increasing physical activity in low SES groups may partly address socioeconomic inequalities in health. Combining approaches such as 'high-risk strategy' (focusing on those who are physically inactive and/or highly sedentary) and 'vulnerable population approach' (focusing on lower SES groups) might be useful.[59]

Regarding device-measured physical activity, our results showed higher ACM and incident CVD risk of low device-measured MVPA, and these associations were accentuated with decreasing area-level SES. Effect modification by individual-level SES was less clear for device-measured physical activity, where the high SES group had more pronounced detrimental associations with incident CVD. The differential findings between self-reported and device-measured physical activity exposures may be due to differential measurement properties of the two approaches,[60] the selective nature of self-reported physical activity instruments (eg, capturing bouts lasting at least 10 continuous minutes and mostly LTPA) and a weaker correlation of these two measurement approaches in low SES.[30 31]

The socioeconomic patterning of the physical activity domains–mortality association was unclear. Our findings are in agreement with a previous study,[20] which found no statistically significant interaction (p=0.090) by education in the LTPA–mortality associations. At the same time, it contradicts another study[57] that reported stronger beneficial associations of LTPA with mortality among those with higher education. These inconsistencies in the literature highlight the complex role of SES in physical activity domains–outcome associations and suggest the need for future research to better understand the interaction effects of SES and any underlying mechanisms. We observed no association of LTPA and household physical activity with incident CVD across SES groups (for both individual- and area-level SES), which could partly be due to the lack of overall association between these domains and incident CVD in our study (online supplemental table S5). For sedentary behaviour, we found detrimental associations of high screen time with ACM, and these associations became stronger with decreasing area-level SES. In contrast, the effect modification of SES on the associations of sitting time with both outcomes was less clear.

Our results indicated variability in the interaction effects based on the SES measure used. SES patterns were clearer for individual-level SES (self-reported MVPA) and for area-level SES (device-measured MVPA). A possible explanation is that area-level SES is more reflective of total movement as captured by accelerometry, while individual-level SES reflects better leisure time PA, which is what questionnaires capture mostly. Previous studies have also shown mixed results depending on the SES measure used. Foster *et al*,[5] in their previous UK Biobank analysis, reported a higher disproportionate risk of a least healthy lifestyle on ACM in low individual-level and area-level SES.[5] In contrast, Zhang *et al*[6] reported stronger lifestyles–mortality associations for individual-level SES than that for area-level SES and attributed this to less sensitivity of postcode-derived SES to social causes of health, individual differences, confusion with environmental health determinants and low reliability for heterogenous and mobile communities.[6] However, area-level SES might also contribute to health inequalities through differential access to material resources (physical activity infrastructures, health facilities, etc), crime, overcrowding and differences in individual-level SES (eg, limited access to quality schools).[23] Our findings further add nuance to the literature and highlight the complex role of SES in health behaviours–outcome associations. Taken together, interventions targeting physical inactivity and high sedentary behaviour in low SES groups (individual-level and area-level) might provide the greatest return. We recommend incorporating both individual- and area-level SES measures in future studies to better understand this relationship.

Strengths and limitations

To our knowledge, this is the first study examining the interaction effect of area-level and individual-level socioeconomic indices and domain-specific physical activity and sedentary behaviour with ACM and incident CVD using both self-reported and device-measured data. Using two SES indicators (individual level and area level) provided a comprehensive understanding of possible interaction effects. We accounted for competing risks using a subdistribution hazard model and excluded underweight participants and those with poor self-rated health with possible undiagnosed, subclinical conditions. E-values indicated that it is less likely that the associations we observed are due to unmeasured confounding.

UK Biobank has a low response rate (5.5%) and a higher prevalence of affluent participants of white ethnic background than the general UK population.[61] However, recent evidence shows that physical activity estimates of long-term health outcomes (including ACM and CVD mortality) are not materially affected by poor representativeness and low response rates.[62] Possible misreporting of physical activity participation[31] and covariates between high and low SES might have affected our results. Greater misreporting of physical activity participation in low SES participants[31] might have attenuated the associations, suggesting possibility of even stronger real associations. Despite extensive measures we took (excluding participants with poor self-rated health, prevalent CVD or an event (death or CVD event) within up to 3 years of recruitment), reverse causality is still a possibility, and this study's observational nature limits inferences about causality.

CONCLUSION

Compared with higher SES groups, low SES groups showed modest evidence of more pronounced inverse associations of MVPA with ACM and incident CVD, and direct association of screen time with ACM. Our results suggested some variability in the interaction effects based on the SES and physical activity measures we tested. We observed consistent and clear interactions of individual-level SES in the association of self-reported MVPA with ACM. In comparison, area-level SES showed some evidence of interactions in the associations of device-measured MVPA with both outcomes and of screen time with ACM. Results were less clear for physical activity domains and device-measured sitting time. Public health interventions targeting physical activity and sedentary behaviour might need to focus on both low SES individuals as well as low SES areas for greater returns. Further research is needed to establish this evidence and better understand the mechanisms underlying these findings.

Correction notice This article has been corrected since it published Online First. The size of the figures have been increased for clarity.

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Contributors SP and ES conceptualised the study. SP carried out the analysis and prepared the original manuscript. MA, PP, MH and ES contributed to the composition and editing of the full manuscript over several rounds of revisions. All authors have read and agreed on the final version of the manuscript. SP is the guarantor and accepts full responsibility for the work and the conduct of the study.

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Competing interests None declared.

Patient and public involvement Patients and the public were not involved in the design, conduct, reporting or dissemination plans of this research.

Patient consent for publication Not applicable.

Ethics approval This study involves human participants, and the National Health Service National Research Ethics Service (Ref 11/NW/0382) approved the use of deidentified data from the UK Biobank. The participants consented to the use of deidentified data and health records and gave informed consent to participate in the study before taking part.

Provenance and peer review Not commissioned; externally peer reviewed.

Data availability statement Data may be obtained from a third party and are not publicly available.

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Do associations of physical activity and sedentary behaviour with cardiovascular disease and mortality differ across socioeconomic groups? An analysis of device-measured and self-reported UK Biobank data

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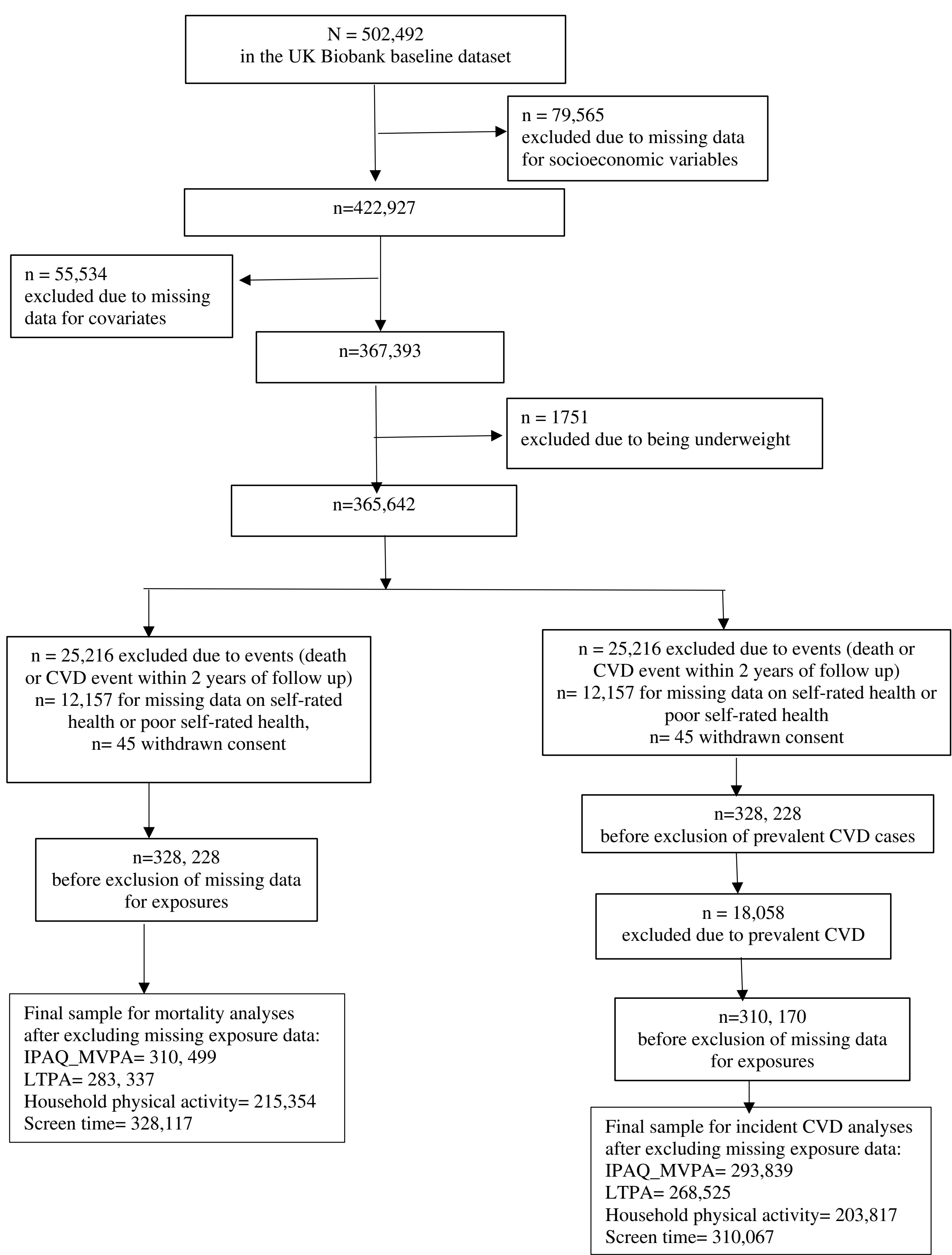
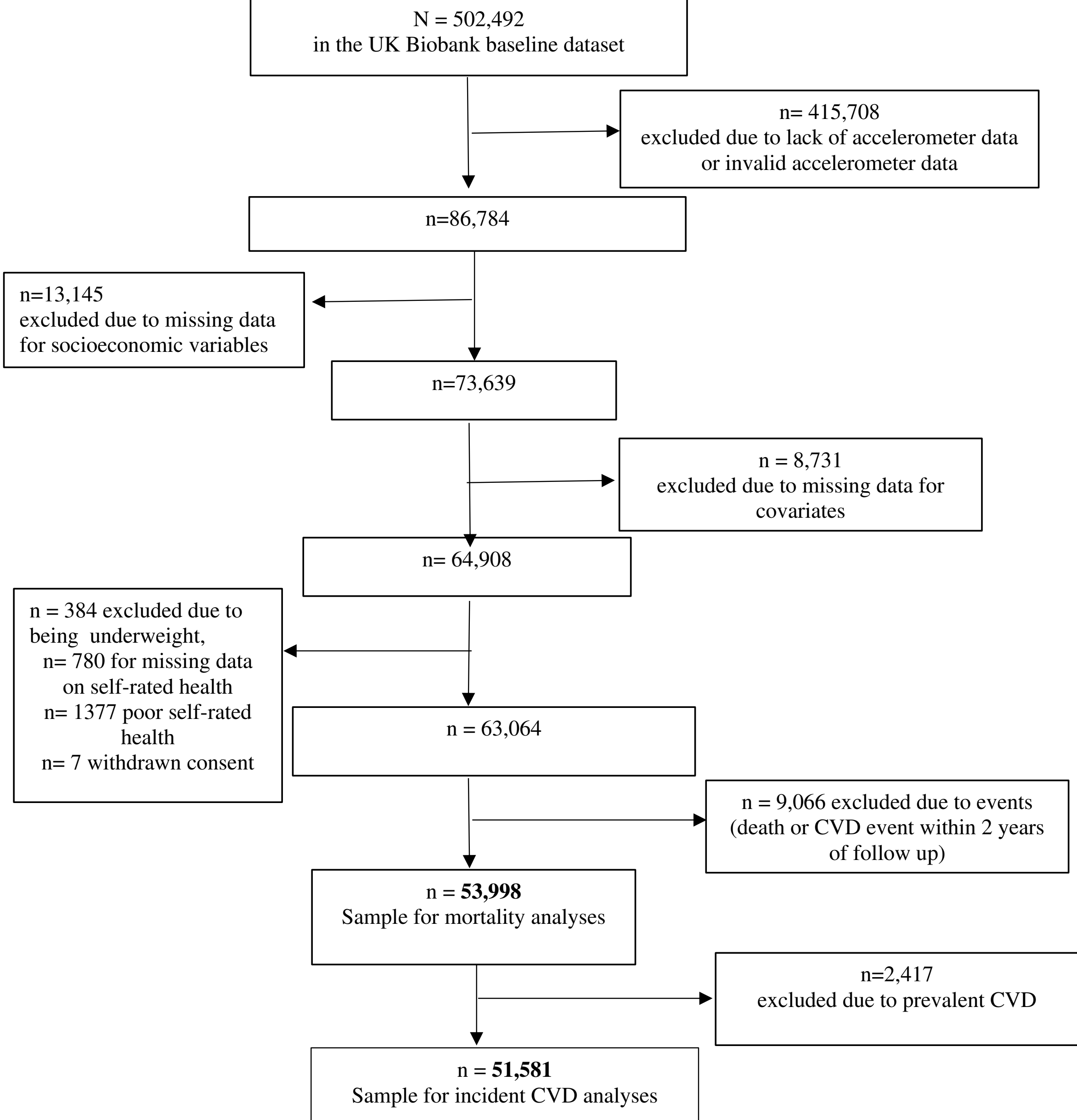
Supplementary Figure S1: Flowchart of sample selection for self-reported exposures



Supplementary Figure S2: Flowchart of sample selection for device-measured exposures



Supplemental Text S1: Description of exposures

Questionnaire-based MVPA: Weekly MVPA was measured using an adapted version of the International Physical Activity Questionnaire (IPAQ) short form. IPAQ collects information on the frequency and duration of walking, moderate and vigorous activities performed over the last seven days[1, 2]. We calculated total weekly MVPA volume (METs-minutes/week) by multiplying the standardised metabolic equivalent of task (MET) value of each activity (3.3 METs for walking, 4 for moderate and 8 for vigorous activities) by the number of minutes per week[2]. Participants were then categorised into three mutually exclusive groups: low (< 600 metabolic equivalent (MET)-min/week), medium (600 to < 3000 MET-min/week), and high (≥ 3000 MET-min/week) PA[3].

Device-measured PA and sitting time: A subsample of the UK Biobank participants (n=103,687) wore an Axivity AX3 triaxial accelerometer on their dominant wrist for a 7-day period between 2013 and 2015[4]. Participants whose accelerometer data could be successfully calibrated were included in this study. We excluded participants with >1% clipped values and implausibly high activity values (average vector magnitude scores of >100 mg). We used previously established procedures[5, 6] to calibrate data and identify non-wear. Participants with sufficient wear time (at least four valid monitoring days, with at least one of those days being a weekend day) were only included. A previously validated scheme that uses raw acceleration signals to identify and quantify time spent in different intensity activities in 10-second windows was used[7]. Using the total time spent in different activities, we classified participants into tertiles of ACCEL_MVPA and sitting time.

Domain-specific physical activity

Household physical activity was assessed by asking participants the frequency and duration of light (such as home maintenance and gardening) and heavy (such as weeding, lawn mowing, digging and carpentry) do-it-yourself activities they engaged in the last four weeks. We used midpoints to convert categorical frequency and duration responses to continuous variables. For example, "2–3 times a week" was set to 2.5 times, and "between 30 minutes and 1 hour" was set to 45 minutes. Monthly frequencies were converted to weekly frequencies (such as "once in the last 4 weeks" was set to "0.25 times per week" and "2-3 times in the last 4 weeks" was set to "0.63 times per week"). The total weekly household PA volume was then calculated by multiplying the frequency, duration and the MET values (3 METs for Light Do-It-Yourself (DIY) and 6.3 METs for heavy DIY)[8] and categorised into tertiles in the analytic sample.

Leisure time physical activity: LTPA was calculated using the frequency and duration of walking for pleasure, other exercises, and strenuous sports in the last 4 weeks[9]. We used a similar process as mentioned above to convert categorical responses to continuous scale. We calculated total weekly LTPA volume by multiplying frequency, duration and the MET values

(3.5 METs for walking for pleasure, 4.0 METs for other exercises and 8.0 METs for strenuous sports)[10] and categorised participants into tertiles for the analyses.

Screen time: Participants reported duration (hours per day) spent watching TV and using computers for non-work-related purposes[11]. Responses of "Do not know" and "Prefer not to answer" were set to missing while "Less than an hour a day" was recorded as 0.5h. We calculated total weekly screen time by multiplying the total daily time spent watching TV and non-occupational computer use by 7 and categorised into tertiles for the analyses. Daily total of screen time was truncated at 16 hours.

Supplemental Text S2: Socioeconomic status

We examined effect modification by two socioeconomic indices: area-level and individual-level SES.

Latent class analysis based on three socioeconomic factors (household income, education level, and employment status) was used to create individual-level SES[12]. In the UK Biobank, participants reported their average total before tax household income as less than £18,000, £18,000 to £30,999, £31,000 to £51,999, £52,000 to £100,000 and greater than £100,000, do not know and prefer not to answer. Participants who selected the last two options (14.3%) were excluded from the main analysis. Education was reported as college or university degree; A levels/AS levels or equivalent; O levels/GCSEs or equivalent; CSEs or equivalent; NVQ, HND, HNC, or equivalent; other professional qualifications; none of the above. Participants reported their employment status as paid employment or self-employed, retired, looking after home and/or family, unable to work, unemployed, unpaid or voluntary work or student. In this study, we re-categorised occupational status as employed or unemployed (unable to work or unemployed). Then, we created an overall individual-level SES variable using latent class analysis with these three variables. Since the model with four latent classes failed to converge, we used the model with three latent classes. As shown in table below, "high SES" had a higher proportion of participants with college or university degree and before tax household income of £52,000 or greater. The proportion of unemployed, those with less than high school education (labelled as 'none' in UK Biobank) and those with household income less than £18,000 were higher in class labelled "low SES". Based on the results of latent class analysis, 88020 (25.9%) participants were categorised as 'low SES', 126730 (37.2%) as 'Medium SES' and 125680 (36.9%) as 'High SES'. The item response probabilities in the model with three classes are provided in the table S1.

Area-level SES was assessed by the Townsend index score (including measures of unemployment, non-car ownership, non-home ownership and household overcrowding), derived from respondent's postcode[13]. We categorised Townsend index into tertiles where the lowest score indicated the least socioeconomic deprivation (high area-level SES).

Supplementary Table S1: Prevalence and characteristics of participants in three latent classes

Item	Latent class 1	Latent class 2	Latent class 3
Prevalence	36.9%	25.9%	37.2%
Occupation			
Employed	0.969	0.852	0.974
Unemployed	0.031	0.148	0.026
Education			
None of the above	0.000	0.368	0.109
College or university degree	0.722	0.149	0.154
A/AS levels or equivalent	0.130	0.078	0.138
O/GCSEs level or equivalent	0.091	0.214	0.336
CSEs or equivalent	0.011	0.061	0.092
NVQ/HND/HNC or equivalent	0.020	0.080	0.097
Other professional qualifications	0.026	0.049	0.075
Income			
Less than £18 000	0.006	0.731	0.042
£18 000-30 999	0.133	0.222	0.388
£31 000-51 999	0.295	0.029	0.407
£52 000-100 000	0.416	0.006	0.164
Greater than £100 000	0.151	0.012	0.000
Categorisation	**High**	**Low**	**Medium**

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Supplementary Table S2: Covariate definitions

Variable	Definition
Sex	Female, male
Ethnicity	White, not white, not reported
Sleep score[14]	Sleep score was defined as the count of healthy sleep characteristics: morning chronotype, adequate sleep duration (7-8 hours/night), never or rare insomnia, never or rare snoring and infrequent daytime sleepiness; and categorized into three groups (healthy, ≥ 5; intermediate, 3-4; and poor: ≤ 2)
Dietary pattern score[15]	Dietary pattern score was created using intake of fruits and vegetables, fish (oily and non-oily), red meat (beef, pork and lamb) and processed meat intake[15]. Meeting category specific guidelines (>4.5 servings of fruits and vegetables per day, >= 2 times per week of fish intake, <2 times of processed meat per week, <5 times of red meat intake per week) was allocated 1 point and total diet score was categorised as poor (0-1), reasonable (2-3) and good (4).
Smoking status	Never, previous, current
Alcohol consumption	Never, previous, current
Body mass index[16]	BMI was calculated as weight (kg) divided by height (m^2) using measurements taken by trained staff and categorised as underweight (<18.5kg/m^2), normal weight (18.5 to <25 kg/m^2), overweight (25.0 to <30 kg/m^2) and obesity (≥ 30 kg/m^2)[16]
Self-rated health	Self-rated health was assessed by asking “In general how would you rate your overall health?” and categorised as excellent, good, fair, and poor.

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Supplementary Table S3: Baseline characteristics of participants by level of device-measured MVPA

	Total (n= 53, 998)	Device-measured MVPA (ACCEL_MVPA)			p-value
		Highest tertile (n= 18,486)	Medium tertile (n= 18,104)	Lowest tertile (n= 17,408)	
Mean age (SD) (years)	55.7 ± 7.8	54.3 ± 7.7	55.6 ± 7.8	57.4 ± 7.6	<0.001
Men	23,701 (43.9%)	8,852 (47.9%)	8,078 (44.6%)	6,771 (38.9%)	<0.001
White ethnicity or race	52,405 (97.0%)	17,923 (97.0%)	17,599 (97.2%)	16,883 (97.0%)	0.290
Household income (£)					<0.001
Less than 18,000	7,290 (13.5%)	2,159 (11.7%)	2,336 (12.9%)	2,795 (16.1%)	
18,000 to 30,999	12,760 (23.6%)	4,025 (21.8%)	4,226 (23.3%)	4,509 (25.9%)	
31,000 to 51,999	15,810 (29.3%)	5,480 (29.6%)	5,328 (29.4%)	5,002 (28.7%)	
52,000 to 100,000	14,070 (26.1%)	5,266 (28.5%)	4,750 (26.2%)	4,054 (23.3%)	
Greater than 100,000	4,068 (7.5%)	1,556 (8.4%)	1,464 (8.1%)	1,048 (6.0%)	
Education					<0.001
None	3,734 (6.9%)	1,120 (6.1%)	1,196 (6.6%)	1,418 (8.1%)	
O/CSE or equivalent	12,893 (23.9%)	4,363 (23.6%)	4,349 (24.0%)	4,181 (24.0%)	
A/NVQ/professional or equivalent	12,656 (23.4%)	4,175 (22.6%)	4,230 (23.4%)	4,251 (24.4%)	
College/University	24,715 (45.8%)	8,828 (47.8%)	8,329 (46.0%)	7,558 (43.4%)	
Employment					0.220
Unemployed	2,172 (4.0%)	761 (4.1%)	691 (3.8%)	720 (4.1%)	
Employed	51,826 (96.0%)	17,725 (95.9%)	17,413 (96.2%)	16,688 (95.9%)	
Townsend Index tertile					0.080
1	18,139 (33.6%)	6,309 (34.1%)	6,092 (33.7%)	5,738 (33.0%)	
2	18,065 (33.5%)	6,208 (33.6%)	6,028 (33.3%)	5,829 (33.5%)	
3	17,794 (33.0%)	5,969 (32.3%)	5,984 (33.1%)	5,841 (33.6%)	
Smoking status					<0.001
Never	30,852 (57.1%)	10,933 (59.1%)	10,388 (57.4%)	9,531 (54.8%)	
Previous	19,480 (36.1%)	6,513 (35.2%)	6,535 (36.1%)	6,432 (36.9%)	
Current	3,666 (6.8%)	1,040 (5.6%)	1,181 (6.5%)	1,445 (8.3%)	
Alcohol status					<0.001
Never	1,449 (2.7%)	441 (2.4%)	458 (2.5%)	550 (3.2%)	
Previous	1,346 (2.5%)	435 (2.4%)	453 (2.5%)	458 (2.6%)	
Current	51,203 (94.8%)	17,610 (95.3%)	17,193 (95.0%)	16,400 (94.2%)	
Sleep pattern					<0.001
Poor	3,206 (5.9%)	895 (4.8%)	1,053 (5.8%)	1,258 (7.2%)	
Intermediate	29,494 (54.6%)	9,594 (51.9%)	9,857 (54.4%)	10,043 (57.7%)	
Healthy	21,298 (39.4%)	7,997 (43.3%)	7,194 (39.7%)	6,107 (35.1%)	
Diet pattern					<0.001
Poor	2,782 (5.2%)	862 (4.7%)	933 (5.2%)	987 (5.7%)	
Reasonable	33,158 (61.4%)	11,364 (61.5%)	11,155 (61.6%)	10,639 (61.1%)	
Good	18,058 (33.4%)	6,260 (33.9%)	6,016 (33.2%)	5,782 (33.2%)	
Body mass index					<0.001
Normal weight	21,642 (40.1%)	9,019 (48.8%)	7,250 (40.0%)	5,373 (30.9%)	
Overweight	22,402 (41.5%)	7,304 (39.5%)	7,706 (42.6%)	7,392 (42.5%)	
Obese	9,954 (18.4%)	2,163 (11.7%)	3,148 (17.4%)	4,643 (26.7%)	
Self-rated health					<0.001
Excellent	12,610 (23.4%)	5,269 (28.5%)	4,230 (23.4%)	3,111 (17.9%)	
Good	33,287 (61.6%)	11,179 (60.5%)	11,320 (62.5%)	10,788 (62.0%)	

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Fair	8,101 (15.0%)	2,038 (11.0%)	2,554 (14.1%)	3,509 (20.2%)	

Device-measured physical activity was measured using the Axivity AX3 triaxial accelerometer worn on participant's dominant wrist for a 7-day period. A previously validated scheme that uses raw acceleration signals to identify and quantify time spent in different intensity activities in 10-second windows was used[7]. Using the total weekly time spent in MVPA, we classified participants into tertiles. Townsend index (including measures of unemployment, non-car ownership, non-home ownership and household overcrowding), derived from respondent's postcode is used as an indicator of area-level SES. We categorised Townsend index into tertiles where the lowest score indicated the least socioeconomic deprivation. Employment status is categorised as employed (includes paid employment or self-employed, retired, paid or voluntary work or student) and unemployed (includes looking after home and/or family, unable to work and unemployed). Sleep pattern is derived using sleep duration, chronotype, insomnia, snoring and dozing. Diet pattern is derived using intake of fruits and vegetables, fish (oily and non-oily), red meat (beef, pork, and lamb) and proceeded meat intake. BMI is categorised as normal weight (18.5 to <25 kg/m2), overweight (25.0 to <30 kg/m2) and obesity (≥ 30 kg/m2).

Values in the table are frequencies and percentages unless otherwise stated. Difference between groups was tested using one-way ANOVA for age and using chi-square test for other variables.

Supplementary Table S4: Distribution of exposures across individual-level socioeconomic status

	Total	Individual-level SES			p-value
		Low	Medium	High	
Self-reported MVPA (IPAQ_MVPA)	310,499	72,565	117,164	120,770	<0.001
Median (Q1-Q3) MET-minutes /week	2079(970-4170)	2586(1155.6-5118)	2213(990-4530)	1777(876-3306)	
High	113,053 (36.4%)	32,501 (44.8%)	46,120 (39.4%)	34,432 (28.5%)	
Medium	150,763 (48.6%)	30,856 (42.5%)	53,386 (45.6%)	66,521 (55.1%)	
Low	46,683 (15.0%)	9,208 (12.7%)	17,658 (15.1%)	19,817 (16.4%)	
Device-measured MVPA (ACCEL_MVPA)	53,998	8,986	19,257	25,755	<0.001
Median (Q1-Q3) minutes/week	169.5(93.83-280.67)	150(80.17-261.17)	166.8(93-278.33)	178.83(99.83-288.33)	
High	18,486 (34.2%)	2,695 (30.0%)	6,461 (33.6%)	9,330 (36.2%)	
Medium	18,104 (33.5%)	2,884 (32.1%)	6,521 (33.9%)	8,699 (33.8%)	
Low	17,408 (32.2%)	3,407 (37.9%)	6,275 (32.6%)	7,726 (30.0%)	
Household physical activity	215,354	47,192	80,448	87,714	<0.001
Median (Q1-Q3) MET-minutes/week	297.67(102.94-730.35)	283.5(85.05-787.5)	297.67(112.5-741.1)	297.67(118.13-708.75)	
High	69,183 (32.1%)	15,351 (32.5%)	26,268 (32.7%)	27,564 (31.4%)	
Medium	74,394 (34.5%)	14,910 (31.6%)	27,675 (34.4%)	31,809 (36.3%)	
Low	71,777 (33.3%)	16,931 (35.9%)	26,505 (32.9%)	28,341 (32.3%)	
Leisure time physical activity (LTPA)	283,337	64,882	105,453	113,002	<0.001
Median (Q1-Q3) MET-minutes/week	541.88(196.88-1102.5)	499.61(189-1102.5)	499.61(189-1102.5)	573.75(231.52-1143.75)	
High	94,288 (33.3%)	21,186 (32.7%)	33,481 (31.7%)	39,621 (35.1%)	
Medium	95,793 (33.8%)	20,970 (32.3%)	35,277 (33.5%)	39,546 (35.0%)	
Low	93,256 (32.9%)	22,726 (35.0%)	36,695 (34.8%)	33,835 (29.9%)	
Screen time	328,117	81,069	123,520	123,528	<0.001
Median (Q1-Q3) hours/week	24.5(17.5-35)	28(21-35)	24.5(17.5-35)	21(14-28)	
High	99,723 (30.4%)	33,018 (40.7%)	38,388 (31.1%)	28,317 (22.9%)	
Medium	70,873 (21.6%)	17,857 (22.0%)	29,164 (23.6%)	23,852 (19.3%)	
Low	157,521 (48.0%)	30,194 (37.2%)	55,968 (45.3%)	71,359 (57.8%)	
Sitting time	53,998	8,986	19,257	25,755	<0.001
Median (Q1-Q3) hours/week	82.61(74.76-89.94)	84.0(75.66-91.65)	81.76(73.76-89.32)	82.78(75.18-89.76)	
High	17,765 (32.9%)	3,431 (38.2%)	5,891 (30.6%)	8,443 (32.8%)	
Medium	18,078 (33.5%)	2,820 (31.4%)	6,340 (32.9%)	8,918 (34.6%)	
Low	18,155 (33.6%)	2,735 (30.4%)	7,026 (36.5%)	8,394 (32.6%)	

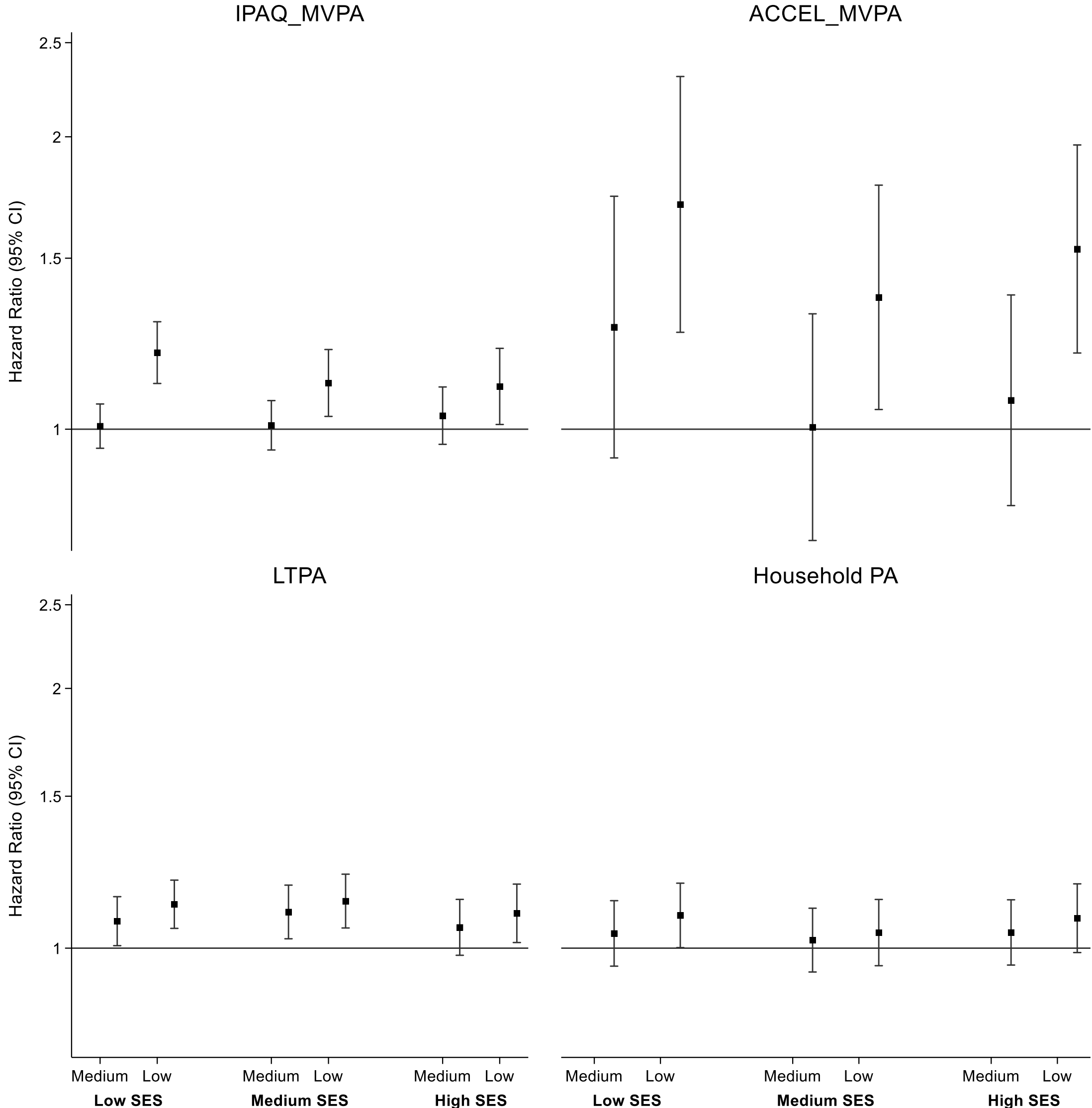
Participants self-reported physical activity measured using the International Physical Activity Questionnaire was categorised as low (< 600 metabolic equivalent (MET)-min/week), medium (600 to < 3000 MET-min/week), and high (≥ 3000 MET-min/week). Device-measured MVPA and sitting time was measured using the Axivity AX3 triaxial accelerometer worn on participant's dominant wrist for a 7-day period. Household physical activity was based on frequency and duration of light (e.g., home maintenance, gardening) and heavy (e.g., weeding, lawn mowing, digging, carpentry) do-it-yourself activities. Leisure-time physical activity was derived from the frequency and duration of walking for pleasure, other exercises, and strenuous sports. Screen time was derived using daily hours spent watching TV and non-occupational and categorised into tertiles. Individual-level SES was created using latent class analysis of three socioeconomic factors (household income, education, and employment status) and categorised into low, medium, and high. Values in the table are frequencies and percentages unless otherwise stated. Difference between groups was tested using chi-square test.

Supplementary Table S5: Association of physical activity and sedentary behaviour with all-cause mortality and incident CVD (main effects)

	All-cause mortality		Incident CVD	
	Events /N	**Adjusted HR (95% CI)**	**Events /N**	**Adjusted HR (95% CI)**
Self-reported MVPA (IPAQ_MVPA)	16,547/310,499		93,712/ 293,839	
High	6,250/113,053	Ref	34,218/106,790	Ref
Medium	7,624 /150,763	1.01 (0.97-1.04)	45,364/142,885	0.99 (0.97-1.00)
Low	2,673/46,683	1.15 (1.10-1.20)	14,130/44,164	0.98 (0.97-1.01)
Device-measured MVPA (ACCEL_MVPA)	1,308/53,998		11,683/51,581	
High	294/18,486	Ref	3,303/17,848	Ref
Medium	380/18,104	1.13 (0.96-1.32)	3,919/17,326	1.11 (1.05-1.17)
Low	634/17,408	1.62 (1.39-1.89)	4,461/16,407	1.14 (1.07-1.21)
Leisure time physical activity (LTPA)	14,420/283,337		85,648/268,525	
High	4,606/94,288	Ref	28,546/89,402	Ref
Medium	4,850/95,793	1.08 (1.04-1.13)	29,068/90,757	1.00 (0.98-1.01)
Low	4,964/93,256	1.14 (1.09-1.18)	28,034/88,366	0.98 (0.97-1.00)
Household physical activity	11,454/215,354		65,024/203,817	
High	3,921/69,183	Ref	20,820/65,337	Ref
Medium	3,764/74,394	1.02 (0.97-1.08)	22,421/70,552	0.99 (0.97-1.01)
Low	3,769/71,777	1.06 (1.01-1.12)	21,783/67,928	1.00 (0.98-1.03)
Screen time	18,023/328,117		98,887/310,067	
High	6,993/99,723	1.12 (1.09-1.17)	29,561/92,596	1.00 (0.98-1.02)
Medium	4,013/70,873	1.05 (1.01-1.09)	21,329/66,765	1.00 (0.99-1.02)
Low	7,017/157,521	Ref	47,997/150,706	Ref
Sitting time	1,308/53,998		11,683/51,581	
High	621/17,765	1.19 (1.02-1.39)	4,628/16,724	1.11 (1.05-1.18)
Medium	393/18,078	1.05 (0.90-1.22)	3,835/17,316	1.03 (0.96-1.09)
Low	294/18,155	Ref	3,220/17,541	Ref

Participants self-reported physical activity measured using the International Physical Activity Questionnaire was categorised as low (< 600 metabolic equivalent (MET)-min/week), medium (600 to < 3000 MET-min/week), and high (≥ 3000 MET-min/week). Device-measured MVPA and sitting time was measured using the Axivity AX3 triaxial accelerometer worn on participant's dominant wrist for a 7-day period. Household physical activity was based on frequency and duration of light (e.g., home maintenance, gardening) and heavy (e.g., weeding, lawn mowing, digging, carpentry) do-it-yourself activities. LTPA was derived from the frequency and duration of walking for pleasure, other exercises, and strenuous sports. Screen time was derived using daily hours spent watching TV and non-occupational and categorised into tertiles. All analyses were adjusted for sex, ethnicity, sleep pattern, dietary score, smoking, alcohol, townsend index and education. For IPAQ_MVPA and LTPA analyses, we additionally adjusted for screen time; screen time analyses were adjusted for IPAQ_MVPA; Household physical activity analyses were adjusted for LTPA and screen time. ACCEL_MVPA analyses were adjusted for sitting time and vice versa and for baseline CVD and cancer. Deaths due to other causes were treated as competing risks in incident CVD analyses.

Figure S3: Sensitivity analysis: Association of physical activity with all-cause mortality across individual-level socioeconomic status: further adjustment for body mass index



Small squares denote point estimates of the hazard ratio, and the bars indicate 95% confidence interval. Y axis is in log-scale. Reference: High physical activity, SES= Socioeconomic status, IPAQ_MVPA: Self-reported moderate vigorous physical activity (MVPA), ACCEL_MVPA: Device-measured MVPA, LTPA: Leisure-time physical activity. Individual-level SES was created using latent class analysis of three socioeconomic factors (household income, education, and employment status) and categorised into low, medium, and high.

IPAQ_MVPA: Participants physical activity measured using the International Physical Activity Questionnaire was categorised as low (< 600 metabolic equivalent (MET)-min/week), medium (600 to < 3000 MET-min/ week), and high (≥ 3000 MET-min/week).

Low SES: High IPAQ_MVPA (2,882/32,501), Medium IPAQ_MVPA (2,751/30,856;1.01 (0.96-1.06)), Low IPAQ_MVPA (997/9,208; 1.20 (1.11-1.29))

Medium SES: High (2,088/46,120), Medium (2,447/53,386; 1.01 (0.95-1.07)), Low (892/17,658; 1.11(1.03-1.21)) High SES: High (1,280/34,432), Medium (2,426/66,521; 1.03(0.96-1.10)), Low (784/19,817; 1.11(1.01-1.21))

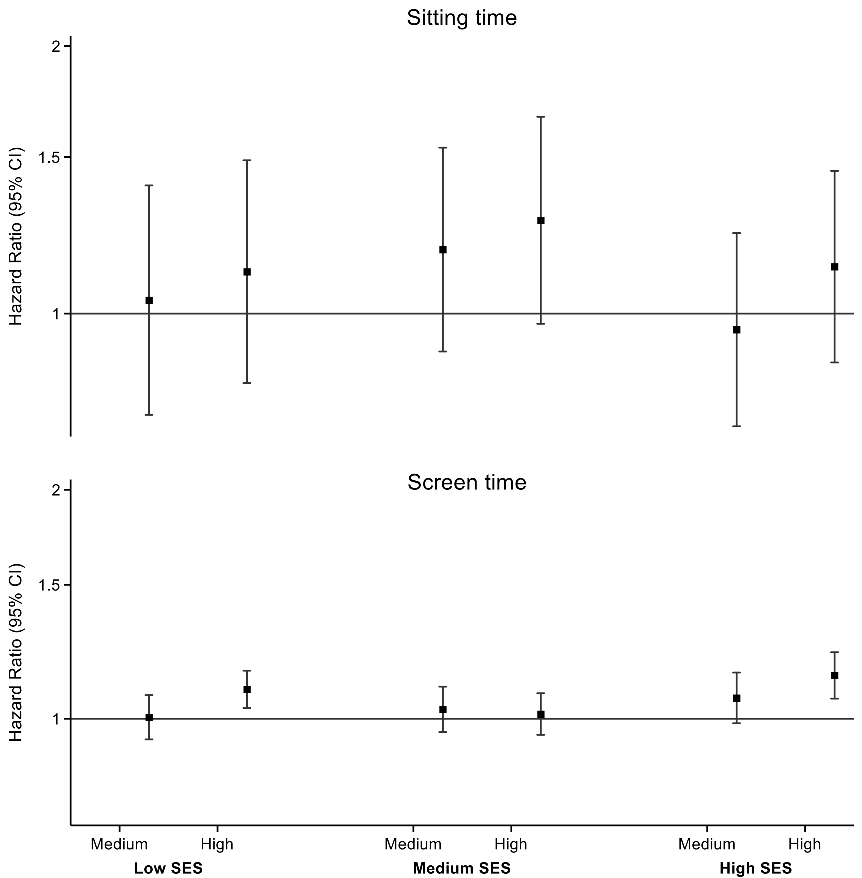
ACCEL_MVPA: Device-measured total physical activity was measured using the Axivity AX3 triaxial accelerometer worn on participant's dominant wrist for a 7-day period. Total minutes spent on MVPA (a sum of moderate and vigorous activities) was extracted and categorised into tertile-based thirds. 'Low' indicated the first tertile, 'Medium' indicated second tertile and 'High' indicated third tertile.
Low SES: High ACCEL_MVPA (70/2,695), Medium ACCEL_MVPA (109/2,884; 1.27(0.93-1.74)), Low ACCEL_MVPA (194/3,407; 1.70(1.26-2.30)
Medium SES: High (103/6,461), Medium (129/6,521; 1.00(0.77-1.31)), Low (211/6,275; 1.37(1.05-1.78))
High SES: High (121/9,330), Medium (142/8,699; 1.07(0.83-1.37)), Low (229/7,726; 1.53(1.20-1.96))

LTPA was calculated using the frequency and duration of walking for pleasure, other exercises, and strenuous sports in the last 4 weeks and categorised into tertile-based thirds.
Low SES: High LTPA (1,811 /21,186), Medium LTPA (1,816/ 20,970; 1.07(1.01-1.15)), Low LTPA (2,041/ 22,726; 1.12(1.05-1.20))
Medium SES: High (1,430/ 33,481), Medium (1,606/ 35,277; 1.10(1.02-1.18)), Low (1,671/ 36,695; 1.13(1.05-1.22))
High SES: High (1,365/ 39,621), Medium (1,428/ 39,546; 1.06(0.98-1.14)), Low (1,252/ 33,835; 1.10(1.01-1.19))

Household physical activity was assessed by asking participants the frequency and duration of light and heavy do-it-yourself activities in the last four weeks and categorised into tertile-based thirds.
Low SES: High household physical activity (1,419/ 15,351), Medium household physical activity (1,323/14,910; 1.04(0.95-1.13)), Low household physical activity (1,578/ 16,931; 1.09(1.00-1.19))
Medium SES: High (1,349/ 26,268), Medium (1,266/ 27,675; 1.02(0.94-1.11)), Low (1,185/ 26,505; 1.04(0.95-1.14))
High SES: High (1,153/ 27,564), Medium (1,175/ 31,809; 1.04(0.96-1.14)), Low (1,006/ 28,341; 1.08(0.99-1.19))

All analyses were adjusted for sex, ethnicity, sleep score, dietary pattern score, smoking, alcohol consumption and body mass index. IPAQ_MVPA and LTPA analyses were additionally adjusted for screen time (derived using daily hours of TV viewing and non-occupational computer use), ACCEL_MVPA for device- measured sitting time and household physical activity analyses for LTPA and screen time.

Figure S4: Sensitivity analysis: Association of sedentary behaviour with all-cause mortality across individual-level socioeconomic status: further adjustment for body mass index



Small squares denote point estimates of the hazard ratio, and the bars indicate 95% confidence interval. Y axis is in log-scale. 'Low' indicated the first tertile, 'Medium' indicated second tertile and 'High' indicated third tertile. Reference: Lowest/first tertile

SES= Socioeconomic status. Individual-level SES was created using latent class analysis of three socioeconomic factors (household income, education, and employment status) and categorised into low, medium, and high.

Sitting time: Device-measured sitting time was measured using the Axivity AX3 triaxial accelerometer worn on participant's dominant wrist for a 7-day period. Total minutes of sitting time was extracted and categorised into tertile-based thirds.

Low SES: Low sitting time (79/2,735), Medium sitting time (107/2,820; 1.03(0.77-1.39)), High sitting time (187/3,431; 1.11(0.83-1.49))

Medium SES: Low (101/7,026), Medium (140/6,340; 1.18 (0.91-1.54)), High (202/5,891; 1.27(0.97-1.66)) High SES: Low (114/8,394), Medium (146/8,918; 0.96 (0.75-1.23)), High (232/8,443; 1.13 (0.88-1.45))

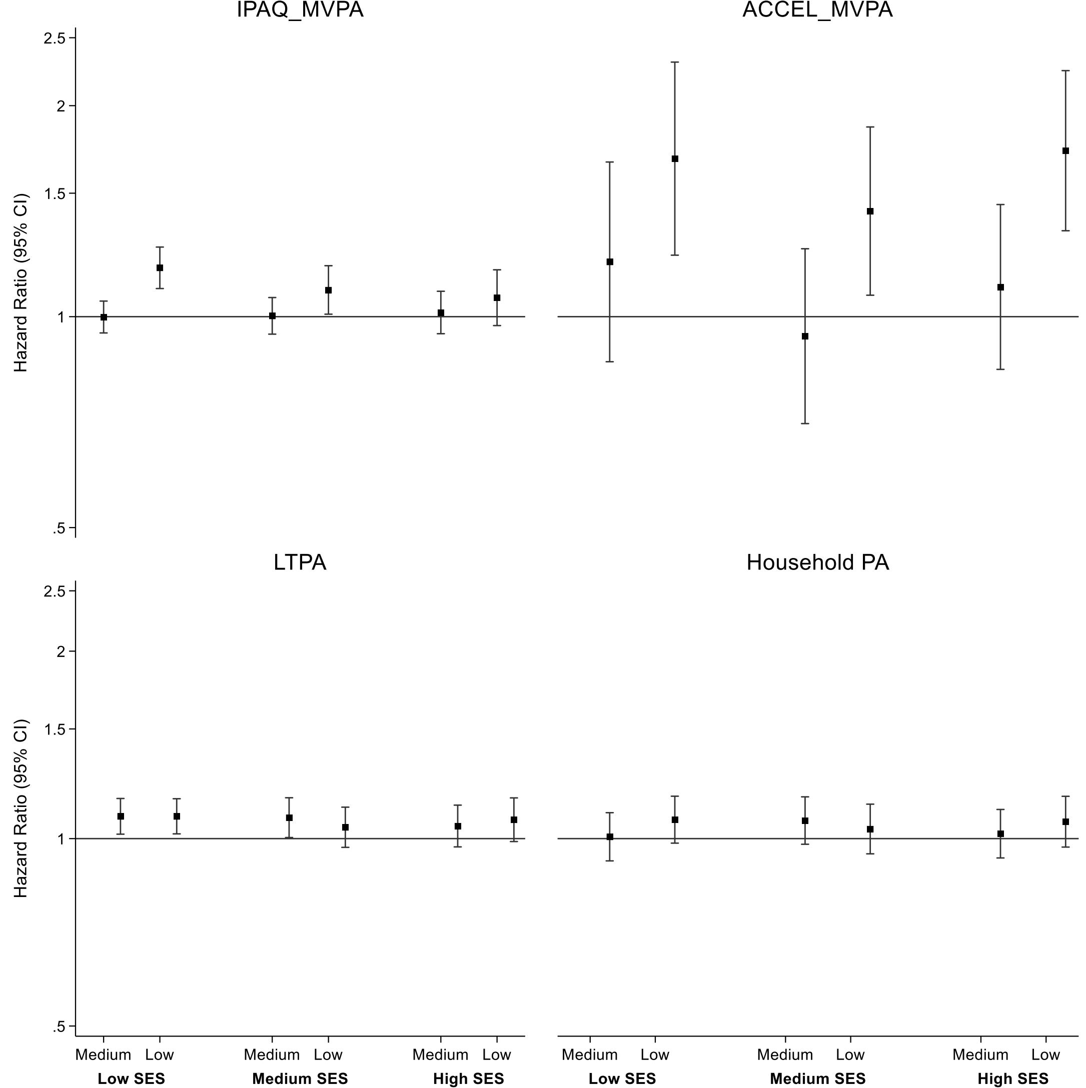
Screen time: Screen time was derived using daily hours spent watching TV and non-occupational and categorised into tertile-based thirds.

Low SES: Low screen time (2,488/30,194), Medium screen time (1,628/17,857; 1.00(0.94-1.07)), High screen time (3,493/33,018; 1.09(1.03-1.16))

Medium SES: Low (2,278/55,968), Medium (1,401/ 29,164; 1.03(0.96-1.10)), High (2,096/ 38,388; 1.01(0.95-1.08)) High SES: Low (2,251/ 71,359), Medium (984/23,852; 1.06(0.99-1.15)), High (1,404/28,317; 1.14(1.06-1.22))

All analyses were adjusted for sex, ethnicity, sleep score, dietary pattern score, smoking, alcohol consumption and body mass index. Sitting time analyses were additionally adjusted for device-measured MVPA and screen time analyses for self-reported MVPA.

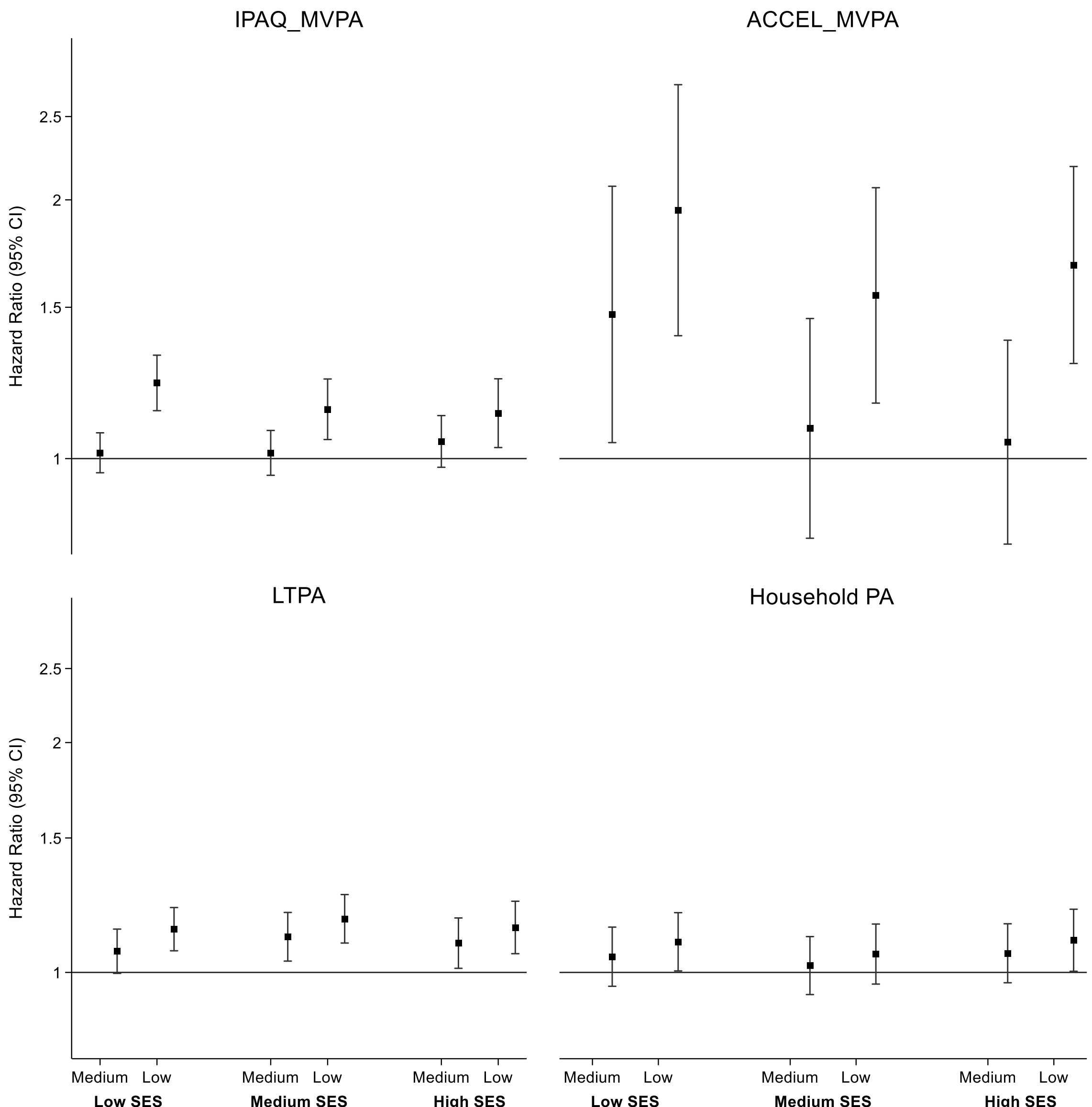
Figure S5: Sensitivity analyses: Association of physical activity with all-cause mortality across individual-level socioeconomic status: additional adjustment for self-rated health



Small squares denote point estimates of the hazard ratio, and the bars indicate 95% confidence interval. Y axis is in log-scale. Reference: High physical activity. SES= Socioeconomic status, IPAQ_MVPA: Self-reported moderate vigorous physical activity (MVPA), ACCEL- MVPA: Device-measured MVPA, LTPA: Leisure-time physical activity. Individual-level SES was created using latent class analysis of three socioeconomic factors (household income, education, and employment status) and categorised into low, medium, and high. IPAQ_MVPA was measured using the International Physical Activity Questionnaire was categorised as low (< 600 metabolic equivalent (MET)-min/week), medium (600 to < 3000 MET-min/week), and high (≥ 3000 MET- min/week). ACCEL_MVPA: Device-measured total PA was measured using the Axivity AX3 triaxial accelerometer worn on participant's dominant wrist for a 7-day period. Total minutes spent on MVPA (ACCEL- MVPA: a sum of moderate and vigorous activities) was extracted and categorised into tertile-based thirds. 'Low' indicated the first tertile, 'Medium' indicated second tertile and 'High' indicated third tertile. LTPA was calculated using the frequency and duration of walking for pleasure, other exercises, and strenuous sports in the last 4 weeks and categorised into tertile-based thirds. Household physical activity was assessed by asking participants the frequency and duration of light and heavy do-it-yourself activities in the last four weeks and categorised into tertile-based thirds.

All analyses were adjusted for sex, ethnicity, sleep score, dietary pattern score, smoking, alcohol consumption and self-rated health. IPAQ_MVPA and LTPA analyses were additionally adjusted for screen time (derived using daily hours of TV viewing and non-occupational computer use), ACCEL_MVPA for device- measured sitting time and household physical activity analyses for LTPA and screen time. Participants with poor self-rated health were not excluded from this sample.

Figure S6: Sensitivity analyses: Association of physical activity with all-cause mortality across individual-level socioeconomic status: initial 3 years of follow-up and any events within it excluded



Small squares denote point estimates of the hazard ratio, and the bars indicate 95% confidence interval. Y axis is in log-scale. Reference: High physical activity. SES= Socioeconomic status, IPAQ_MVPA: Self-reported moderate vigorous physical activity (MVPA), ACCEL_MVPA: Device-measured MVPA, LTPA: Leisure-time physical activity. Individual-level SES was created using latent class analysis of three socioeconomic factors (household income, education, and employment status) and categorised into low, medium, and high. IPAQ_MVPA was measured using the International Physical Activity Questionnaire was categorised as low (< 600 metabolic equivalent (MET)-min/week), medium (600 to < 3000 MET-min/week), and high (≥ 3000 MET-min/week). ACCEL_MVPA: Device-measured total physical activity was measured using the Axivity AX3 triaxial accelerometer worn on participant's dominant wrist for a 7-day period. Total minutes spent on MVPA (ACCEL_MVPA: a sum of moderate and vigorous activities) was extracted and categorised into tertile-based

thirds. 'Low' indicated the first tertile, 'Medium' indicated second tertile and 'High' indicated third tertile. LTPA was calculated using the frequency and duration of walking for pleasure, other exercises, and strenuous sports in the last 4 weeks and categorised into tertile-based thirds. Household physical activity was assessed by asking participants the frequency and duration of light and heavy do-it-yourself activities in the last four weeks and categorised into tertile-based thirds.

All analyses were adjusted for sex, ethnicity, sleep score, dietary pattern score, smoking and alcohol consumption. IPAQ_MVPA and LTPA analyses were additionally adjusted for screen time (derived using daily hours of TV viewing and non-occupational computer use), ACCEL_MVPA for device-measured sitting time and household physical activity analyses for LTPA and screen time.

Paudel S, *et al. Br J Sports Med* 2023;0:1–10. doi: 10.1136/bjsports-2022-105435

Figure S7: Association of physical activity with all-cause mortality across area-level socioeconomic status

Small squares denote point estimates of the hazard ratio, and the bars indicate 95% confidence interval. Y axis is in log-scale. Reference: High physical activity. SES= Area-level socioeconomic status, IPAQ_MVPA: Self-reported moderate vigorous physical activity. (MVPA), ACCEL_MVPA: Device-measured MVPA, LTPA: Leisure-time physical activity. Townsend index, derived from respondent's postcode, was used as an indicator of area-level SES and categorised into tertiles with the lowest score indicating highest SES.

IPAQ_MVPA: Participants physical activity measured using the International Physical Activity Questionnaire was categorised as low (< 600 metabolic equivalent (MET)-min/week), medium (600 to < 3000 MET-min/ week), and high (≥ 3000 MET-min/week).

Low SES: High IPAQ_MVPA (1,915/36,884), Medium IPAQ_MVPA (2,455/52,896; 0.97(0.92-1.03)), Low IPAQ_MVPA (847/16,539; 1.11(1.02-1.19))

Medium SES: High (1,994/38,274), Medium (2,476/50,534; 1.03(0.97-1.09)), Low (868/15,760; 1.18(1.09-1.28)) High SES: High (2,341/37,895), Medium (2,693/47,333; 0.97(0.91-1.02)), Low (958/14,384; 1.11(1.02-1.21))

ACCEL_MVPA: Device-measured total physical activity was measured using the Axivity AX3 triaxial accelerometer worn on participant's dominant wrist for a 7-day period. Total minutes spent on MVPA (a sum of

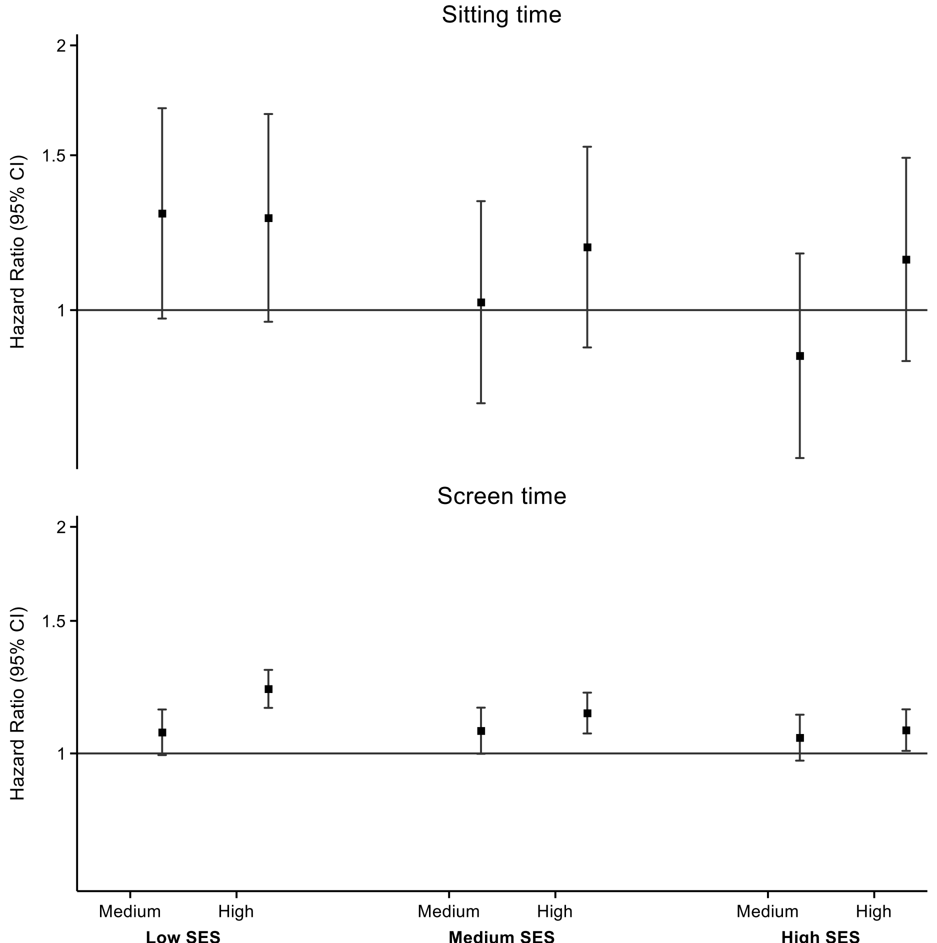
moderate and vigorous activities) was extracted and categorised into tertile-based thirds. 'Low' indicated the first tertile, 'Medium' indicated second tertile and 'High' indicated third tertile.
Low SES: High ACCEL_MVPA (95/5,969), Medium ACCEL_MVPA (124/5,984; 1.09 (0.83-1.44)) and Low ACCEL_MVPA (240/5,841; 1.78 (1.36-2.29))
Medium SES: High (93/6,208), Medium (136/6,028; 1.33 (1.01-1.74)) and Low (203/5,829; 1.71 (1.31-2.25))
High SES: High (106/6,309), Medium (120/6,092; 1.00 (0.76-1.31)) and Low (191/5,738; 1.41 (1.08-1.84))

LTPA was calculated using the frequency and duration of walking for pleasure, other exercises, and strenuous sports in the last 4 weeks and categorised into tertile-based thirds.
Low SES: High LTPA (1,507/27,169), Medium LTPA (1,637/ 29,129; 1.04 (0.97-1.12)) and Low LTPA (1,873/ 31,824; 1.10 (1.03-1.18))
Medium SES: High (1,488/32,248), Medium (1,629/32,571; 1.14 (1.06-1.22)) and Low (1,570/31,120; 1.16(1.08-1.24)) High SES: High (1,611/34,871), Medium (1,584/34,093;1.06(0.99-1.14)) and Low (1,521/30,312; 1.16(1.08-1.25))

Household physical activity was assessed by asking participants the frequency and duration of light and heavy do-it-yourself activities in the last four weeks and categorised into tertile-based thirds.
Low SES: High household physical activity (1,062/ 17,428), Medium household physical activity (1,173/ 20,702;1.08 (0.98-1.19)) and low household physical activity (1,395/ 23,204; 1.13(1.03-1.24))
Medium SES: High (1,391/ 24,692), Medium (1,283/ 25,932; 1.04(0.95-1.13)) and Low (1,210/ 24,508; 1.03(0.94-1.12))
High SES: High (1,468/ 27,063), Medium (1,308/ 27,760; 0.97(0.90-1.06)) and Low (1,164/ 24,065; 1.06(0.97-1.15))

All analyses were adjusted for sex, ethnicity, sleep score, dietary pattern score, smoking and alcohol consumption. IPAQ_MVPA and LTPA analyses were additionally adjusted for screen time (derived using daily hours of TV viewing and non-occupational computer use), ACCEL_MVPA for device-measured sitting time and household physical activity analyses for LTPA and screen time.

Figure S8: Association of sedentary behaviour with all-cause mortality across area-level socioeconomic status



Small squares denote point estimates of the hazard ratio, and the bars indicate 95% confidence interval. Y axis is in log-scale. 'Low' indicated the first tertile, 'Medium' indicated second tertile and 'High' indicated third tertile. Reference: Lowest/first tertile. SES= Socioeconomic status, Sitting time: Device-measured sitting time. Townsend index, derived from respondent's postcode, was used as an indicator of area-level SES and categorised into tertiles with the lowest score indicating highest SES.

Sitting time: Device-measured sitting time was measured using the Axivity AX3 triaxial accelerometer worn on participant's dominant wrist for a 7-day period. Total minutes of sitting time was extracted and categorised into tertile-based thirds.

Low SES: Low sitting time (84/5,653), Medium sitting time (141/5,750; 1.29(0.98-1.70)) and High sitting time (234/6,391; 1.27(0.97-1.67))

Medium SES: Low (102/6,198), Medium (132/6,089; 1.02(0.78-1.33)) and High (198/5,778; 1.18(0.91-1.53))

High SES: Low (108/6,304), Medium (120/6,239; 0.89(0.68-1.16)) and 189/5,596; 1.14(0.87-1.49))

Screen time: Screen time was derived using daily hours spent watching TV and non-occupational computer use and categorised into tertile-based thirds.

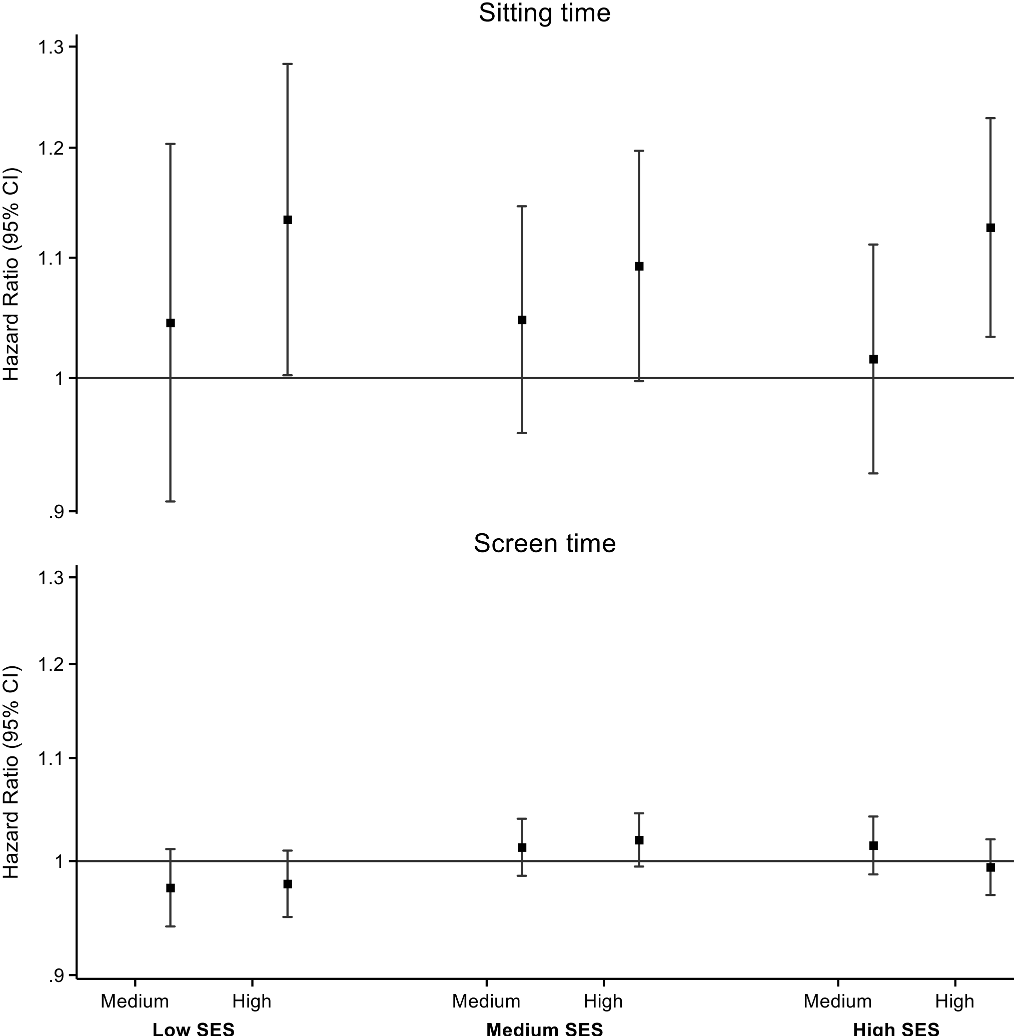
Low SES: Low screen time (2,483/49,887), Medium screen time (1,360/21,838; 1.07(0.99-1.14) and High screen time (2,831/35,167; 1.22(1.15-1.29))

Medium SES: Low (2,268/53,110), Medium (1,343/24,184; 1.07(1.00-1.15) and High (2,182/32,880; 1.13(1.06-1.20))

High SES: Low (2,266/54,524), Medium (1,310/24,851; 1.05(0.98-1.12) and High (1,980/31,676; 1.07(1.01-1.14))

All analyses were adjusted for sex, ethnicity, sleep score, dietary pattern score, smoking and alcohol consumption. Sitting time analyses were additionally adjusted for device-measured MVPA and screen time analyses for self-reported MVPA.

Figure S9: Association of sedentary behaviour with incident CVD across individual-level socioeconomic status



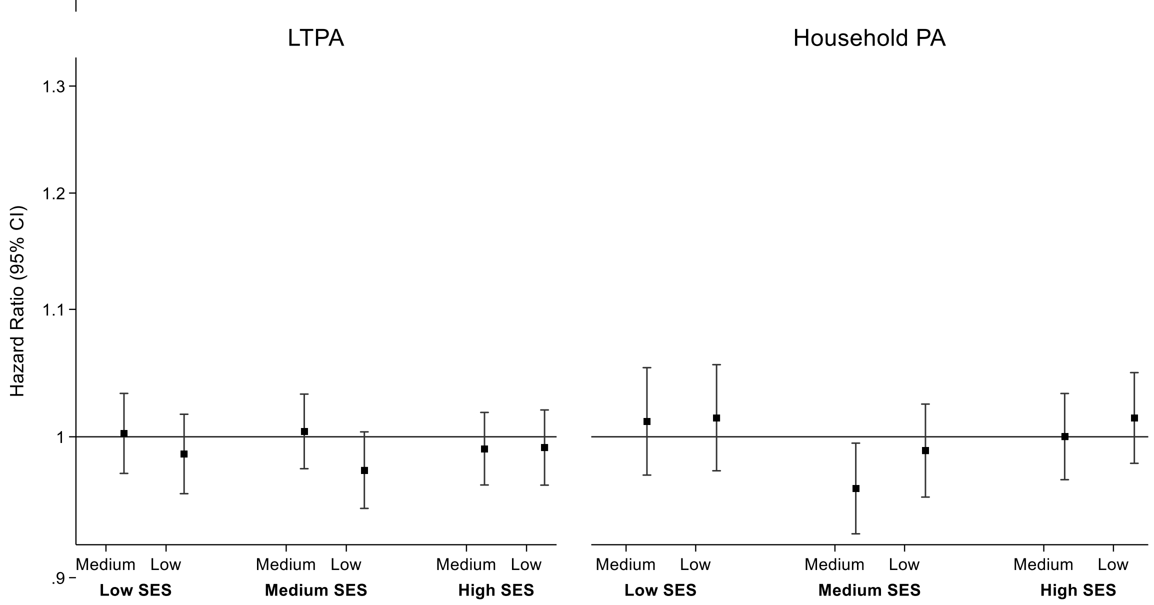
Small squares denote point estimates of the sub-hazard ratio, and the bars indicate 95% confidence interval. Y axis is in log-scale. 'Low' indicated the first tertile, 'Medium' indicated second tertile and 'High' indicated third tertile. Reference: Lowest/first tertile. SES= Socioeconomic status, Sitting time: Device-measured sitting time. Individual-level SES was created using latent class analysis of three socioeconomic factors (household income, education, and employment status) and categorised into low, medium, and high.
Sitting time: Device-measured sitting time was measured using the Axivity AX3 triaxial accelerometer worn on participant's dominant wrist for a 7-day period. Total minutes of sitting time was extracted and categorised into tertile-based thirds.
Low SES: Low sitting time (628/2,568), Medium sitting time (773/2,629; 1.04(0.91-1.20)), High sitting time (1,055/3,122; 1.13(1.00-1.28))
Medium SES: Low (1,336/6,798), Medium (1,485/6,065; 1.05(0.96-1.14)), High (1,645/5,551; 1.09(1.00-1.20))
High SES: Low (1,256/ 8,175), Medium (1,577/8,622; 1.01(0.93-1.11)), High (1,928/8,051; 1.13(1.03-1.23))

Screen time: Screen time was derived using daily hours spent watching TV and non-occupational and categorised into tertile-based thirds.

Low SES: Low screen time (9,097/27,939), Medium screen time (5,214/16,256; 0.98(0.94-1.01)), High screen time (9,564/29,632; 0.98(0.95-1.01))
Medium SES: Low (16,935/53,632), Medium (8,816/27,693; 1.01(0.97-1.04)), High (11,490/36,063; 1.02(0.99-1.04))
High SES: Low (21,965/69,135), Medium (7,299/22,816; 1.01(0.99-1.04)), High (8,507/26,901; 0.99(0.97-1.02))

All analyses were adjusted for sex, ethnicity, sleep score, dietary pattern score, smoking and alcohol consumption. Sitting time analyses were additionally adjusted for device-measured MVPA and screen time analyses for self-reported MVPA. Deaths due to other causes were treated as competing risks.

Figure S10: Association of physical activity with incident CVD across area-level socioeconomic status



Small squares denote point estimates of the sub-hazard ratio, and the bars indicate 95% confidence interval. Y axis is in log-scale. Reference: High physical activity. SES= Area-level socioeconomic status, IPAQ_MVPA: Self-reported moderate vigorous physical activity (MVPA), ACCEL_MVPA: Device-measured MVPA, LTPA: Leisure-time physical activity. Townsend index, derived from respondent's postcode, was used as an indicator of area-level SES and categorised into tertiles with the lowest score indicating highest SES.

IPAQ_MVPA: Participants physical activity measured using the International Physical Activity Questionnaire was categorised as low (< 600 metabolic equivalent (MET)-min/week), medium (600 to < 3000 MET-min/ week), and high (≥ 3000 MET-min/week).

Low SES: High IPAQ_MVPA (11,430/35,638), Medium IPAQ_MVPA (14,320/44,687; 1.01(0.98-1.03)), Low IPAQ_MVPA (4,246/13,453; 0.98(0.94-1.01))

Medium SES: High (11,603/36,145), Medium (15,185/47,988; 0.98(0.96-1.01)), Low (4,805/14,973;0.99 (0.96-1.03))
High SES: High (11,185/ 35,007), Medium (15,859/50,210; 0.98(0.96-1.00)), Low (5,079/15,738; 0.99(0.96-1.03))

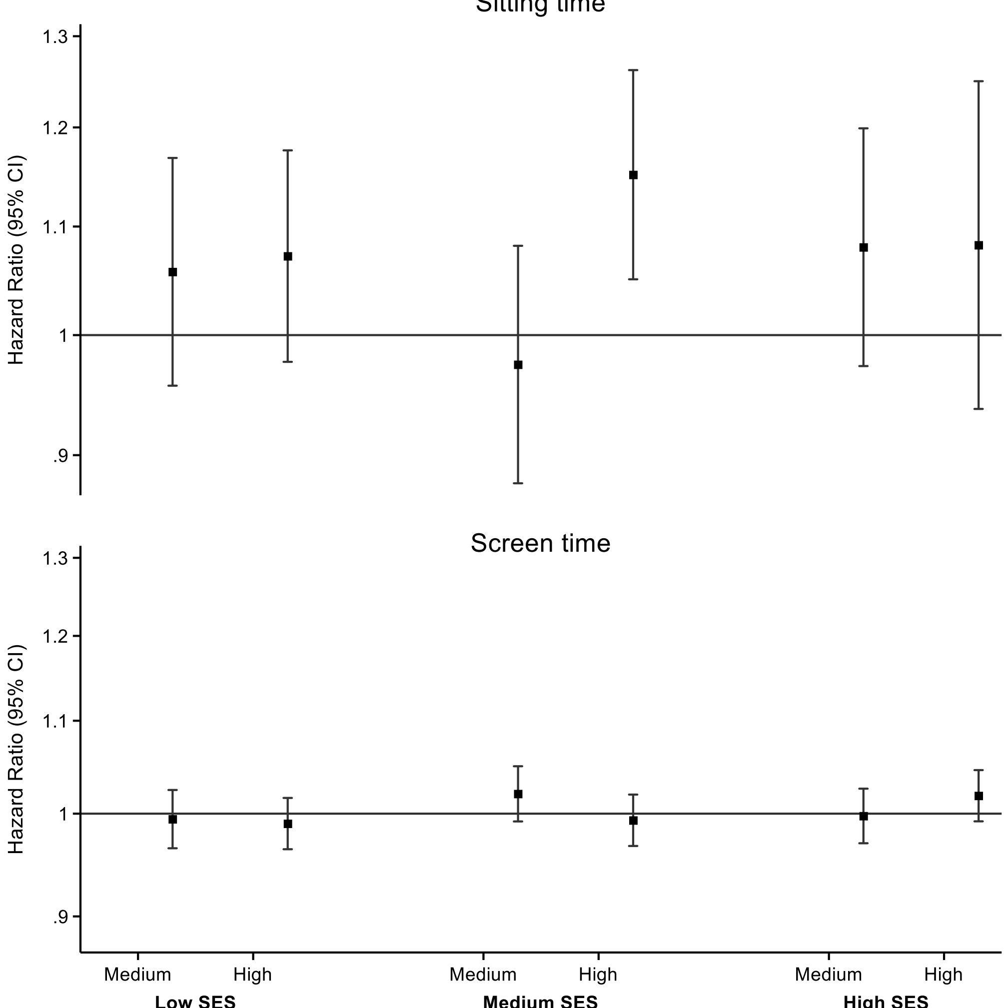
ACCEL_MVPA: Device-measured total physical activity was measured using the Axivity AX3 triaxial accelerometer worn on participant's dominant wrist for a 7-day period. Total minutes spent on MVPA (a sum of moderate and vigorous activities) was extracted and categorised into tertile-based thirds. 'Low' indicated the first tertile, 'Medium' indicated second tertile and 'High' indicated third tertile.
Low SES: High ACCEL_MVPA (1,044/ 5,778), Medium ACCEL_MVPA (1,269/5,734; 1.14(1.03-1.27)), Low ACCEL- MVPA (1,504/5,489; 1.20(1.09-1.32))
Medium SES: High (1,099/ 6,005), Medium (1,314/ 5,755; 1.10(1.00-1.20)), Low (1,533/5,507; 1.13(1.03-1.24))
High SES: High (1,160/ 6,065), Medium (1,336/5,837; 1.13(1.02-1.26)), Low (1,424/5,411; 1.14(0.98-1.32))

LTPA was calculated using the frequency and duration of walking for pleasure, other exercises, and strenuous sports in the last 4 weeks and categorised into tertile-based thirds.
Low SES: High LTPA (8,233/25,665), Medium LTPA (8,816/ 27,464; 1.00(0.97-1.03)), Low LTPA (9,549/29,984; 0.99(0.96- 1.02))
Medium SES: High (9,776/30,552), Medium (9,942/30,876; 1.00(0.98-1.03)), Low (9,310/29,585; 0.97(0.95-1.00))
High SES: High (10,537/33,185), Medium (10,310/32,417; 0.99(0.96-1.02)), Low (9,175/28,797; 0.99(0.96-1.02))

Household physical activity was assessed by asking participants the frequency and duration of light and heavy do-it-yourself activities in the last four weeks and categorised into tertile-based thirds.
Low SES: High household physical activity (5,178/16,437), Medium High household physical activity (6,287/19,567; 1.01(0.97-1.05)), Low High household physical activity (6,985/21,844; 1.01(0.97-1.06))
Medium SES: High (7,539/23,329), Medium (7,721/24,594; 0.96(0.93-0.99)), Low (7,461/23,235; 0.99(0.96-1.02))
High SES: High (8,103/25,571), Medium (8,413/26,391; 1.00(0.97-1.03)), Low (7,337/22,849; 1.01(0.98-1.05))

All analyses were adjusted for sex, ethnicity, sleep score, dietary pattern score, smoking and alcohol consumption. IPAQ_MVPA and LTPA analyses were additionally adjusted for screen time (derived using daily hours of TV viewing and non-occupational computer use), ACCEL_MVPA for device-measured sitting time and household physical activity analyses for LTPA and screen time. Deaths due to other causes were treated as competing risks.

Figure S11: Association of sedentary behaviour with incident CVD across area-level socioeconomic status



Small squares denote point estimates of the sub-hazard ratio, and the bars indicate 95% confidence interval. Y axis is in log-scale. 'Low' indicated the first tertile, 'Medium' indicated second tertile and 'High' indicated third tertile. Reference: Lowest/first tertile. SES= Socioeconomic status. Townsend index, derived from respondent's postcode, was used as an indicator of area-level SES and categorised into tertiles with the lowest score indicating highest SES.

Sitting time: Device-measured sitting time was measured using the Axivity AX3 triaxial accelerometer worn on participant's dominant wrist for a 7-day period. Total minutes of sitting time was extracted and categorised into tertile-based thirds.

Low SES: Low sitting time (965/5,471), Medium sitting time (1,204/5,498; 1.06(0.96-1.17)), High sitting time (1,648/ 6,032; 1.07 (0.98-1.18))

Medium SES: Low (1,112/5,989), Medium (1,276/5,846; 0.97 (0.88-1.08)), High (1,558/5,432; 1.15(1.05-1.26))

High SES: Low (1,143/6,081), Medium (1,355/5,972; 1.08(0.98-1.20)), High (1,422/5,260; 1.08(0.94-1.25))

Screen time: Screen time was derived using daily hours spent watching TV and non-occupational and categorised into tertile-based thirds.

Low SES: Low screen time (15,286/47,591), Medium screen time (6,542/20,448; 0.99(0.96-1.02)), High screen time

(10,357/ 32,372; 0.99(0.96-1.02))
Medium SES: Low (16,168/50,815), Medium (7,359/22,822; 1.02(0.99-1.05)), High (9,673/30,657; 0.99(0.97-1.02)) High SES: Low (16,543/ 52,300), Medium (7,428/23,495; 1.00(0.97-1.02)), High (9,531/29,567; 1.02 (0.99-1.04))

All analyses were adjusted for sex, ethnicity, sleep score, dietary pattern score, smoking and alcohol consumption. Sitting time analyses were additionally adjusted for device-measured MVPA and screen time analyses for self-reported MVPA. Deaths due to other causes were treated as competing risks.

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Supplementary Table S6: E-values [point estimate (CI)]

Association of physical activity with all-cause mortality across individual-level SES*

	Low SES	Medium SES	High SES
Self-reported MVPA (IPAQ_MVPA)			
Low	1.74 (1.51)	1.56 (1.31)	1.54 (1.28)
Device-measured MVPA (ACCEL_MVPA)			
Low	3.00 (1.99)	2.30 (1.51)	2.64 (1.86)
Leisure time physical activity (LTPA)			
Medium	1.37 (1.11)	1.49 (1.24)	1.34 (1.00)
Low	1.54 (1.34)	1.62 (1.40)	1.51 (1.28)

Association of sedentary behaviour with all-cause mortality across individual-level SES*

	Low SES	Medium SES	High SES
Screen time			
High	1.43 (1.24)		1.67 (1.46)

Association of physical activity with all-cause mortality across area-level SES*

	Low SES	Medium SES	High SES
Self-reported MVPA (IPAQ_MVPA)			
Low	1.46 (1.16)	1.64 (1.40)	1.46 (1.16)
Device-measured MVPA (ACCEL_MVPA)			
Low	2.96 (2.06)	2.81 (1.95)	2.17 (1.37)
Leisure time physical activity (LTPA)			
Low	1.43 (1.21)	1.59 (1.37)	1.59 (1.37)
Household physical activity			
Low	1.51 (1.21)		

Association of sedentary behaviour with all-cause mortality across area-level SES*

	Low SES	Medium SES	High SES
Screen time			
High	1.74 (1.56)	1.51 (1.31)	1.34 (1.11)

Association of physical activity with incident CVD across individual-level SES*

	Low SES	Medium SES	High SES
Self-reported MVPA (IPAQ_MVPA)			
Medium			1.17 (1.09)
Low			1.17 (1.00)
Device-measured MVPA (ACCEL_MVPA)			
Medium			1.40 (1.20)
Low		1.42 (1.20)	1.44 (1.25)
Leisure time physical activity (LTPA)			
Low	1.20 (1.09)		

Association of sedentary behaviour with incident CVD across individual-level SES*

	Low SES	Medium SES	High SES
Sitting time			
High			1.40 (1.17)

Association of physical activity with incident CVD across area-level SES*

	Low SES	Medium SES	High SES
Device-measured MVPA (ACCEL_MVPA)			
Medium	1.42 (1.17)		1.40 (1.13)
Low	1.53 (1.32)	1.40 (1.17)	

Association of sedentary behaviour with incident CVD across area-level SES*

	Low SES	Medium SES	High SES
Sitting time			
High		1.44 (1.22)	

*E-values are provided only for statistically significant associations in main analysis.

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