Active commuting is associated with lower risk of cardiovascular events: Evidence from a prospective cohort study of 264,337 UK Biobank participants

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Active commuting is associated with lower risk of cardiovascular events: Evidence from a prospective cohort study of 264,337 UK Biobank participants

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Abstract

Objective – To investigate the association between active commuting and incident cardiovascular disease (CVD), cancer and all-cause mortality.

Design – This study included prospective data from the UK Biobank, a population-based study. Active commuting (walking or cycling to and from work versus using a car or public transport) was used as our exposure variable.

Setting - UK Biobank

Participants - 264,337 participants (52% women; mean age 52.6 years), recruited from 22 sites across the UK.

Main outcome measures – All-cause, CVD and cancer mortality, and incident CVD and cancer events.

Results– 2430 participants died (496 CVD deaths, 1,126 cancer deaths) over a median of 5.0 years [IQR 4.3 to 5.5] follow-up. There were 3,748 cancer and 1,110 CVD events. Active commuters were less likely to have a CVD event (HR: 0.61, [0.49-0.76], p<0.0001) or die from CVD (HR: 0.57, [0.41-0.79], p=0.001). Theses association was attenuated but remained significant after adjusting for potential other major lifestyle confounders (age, sex, deprivation, ethnicity, BMI, dietary intake, smoking, sedentary behaviour and comorbidities) (CVD events HR: 0.77, [0.66-0.97], p=0.028; CVD mortality HR: 0.69, [0.49-0.97], p=0.034). However, no association were found between active commuting and all-cause mortality (HR: 0.99, [0.86-1.14], p=0.889) or cancer events (HR: 0.92, [0.82-1.03], p=0.156) or cancer mortality (HR: 1.08, [0.89-1.32], p=0.429).

Conclusions - Active commuting was associated with lower hazard of CVD events and CVD mortality independent of major confounding factors. Initiatives to encourage and support active commuting may therefore reduce the burden of these important chronic conditions.

INTRODUCTION

The associations between low levels of physical activity and increased morbidity and mortality are well established;[1] however, it has been estimated that more than a third of the population worldwide is physically inactive.[2] There is a decreasing trend in overall physical activity worldwide, which is due, in part, to reductions in active commuting.[3 4] Evidence from ecological studies suggests that rising levels of obesity are more pronounced in settings with greater declines in active commuting.[3 4] The use of active forms of commuting such as walking or cycling to and from work has been recommended by the UK National Institute for Health and Care Excellence (NICE) as a feasible way of incorporating greater levels of physical activity into daily life.[5] Previous studies consistently suggest that adoption of active commuting translates into higher overall levels of physical activity.[6-8] A recent study found that whilst participants who walked to work were no different to those who drove in relation to sitting time and weekend physical activity, their overall physical activity was 45% higher.[6]

There is evidence that active commuters have lower BMIs [9 10], and more favourable cardiovascular disease risk profiles[11-13] than those who use non-active modes of commuting. A meta-analysis, including 173,146 participants in total, reported that active commuting was associated with lower risk of adverse cardiovascular outcomes, with the association being more robust in women than men.[14] However the work was limited by use of a heterogeneous range of cardiometabolic endpoints (including incident hypertension, diabetes, stroke, coronary heart disease (CHD) and cardiovascular disease (CVD)), and inconsistent adjustment for confounders between studies, with the authors recommending that further studies examining the association between active commuting and cardiovascular disease endpoints were needed. Evidence on the association of active commuting on risk of mortality[15-17] and cancer[18] are equivocal with the available studies limited by a relatively small numbers of participants, some studies only considering cycling (and not walking) as an active commuting mode, and lack of adjustment for some major confounder factors such as diet, comorbidities and sedentary behaviour.[14]

There is therefore a clear need for a robust, large-scale investigation of the association between active commuting and prospective health outcomes. The aim of this study was, therefore, to use UK Biobank, a very large, prospective, population-based cohort study, to investigate the association between active commuting and incident CVD, cancer all-cause mortality. Our secondary aim was to identify correlates of active commuting that could help to improve the design of future interventions aiming to increase overall physical activity levels in the population.

METHODS

Study design

Between April 2007 and December 2010, UK Biobank recruited 502,549 participants (5.5% response rate), aged 40-69 years from the general population.[19] Of these, 264,337 (52.6%) participants were recruited after commuting data were added to the baseline assessment and, therefore, were included in this study. Participants attended one of 22 assessment centres across England, Wales and Scotland[20 21] where they completed a touch-screen questionnaire, had physical measurements taken and provided biological samples, as described in detail elsewhere.[20 21] In this population-based study, all-cause, CVD and cancer mortality, and incident CVD and cancer events were the main outcomes; and active commuting (cycle or walk to work versus car or public transport) was the exposure of interest. Socio-demographic factors (age, sex, ethnicity and area socioeconomic deprivation index) smoking status, body mass index, sedentary behaviour and dietary intake were treated as potential confounders, as were prevalent depression, cancer and long-standing illness at baseline.

Patient involvement

This study was conducted using the UK Biobank resource. Details of patient and public involvement in the UK Biobank are available online (www.ukbiobank.ac.uk/about-biobank-uk/ and https://www.ukbiobank.ac.uk/wp-content/uploads/2011/07/Summary-EGF-consultation.pdf?phpMyAdmin=trmKQlYdjjnQIgJ%2CfAzikMhEnx6). All authors confirm that the development of the research questions and outcome measures were not informed by patients' priorities, experience, and preferences. No patients were asked to advise on interpretation or writing up of results. The UK Biobank will disseminate all key findings from this study on its website, where participants can follow-up research conducted in the UK Biobank. Participants were thanked in the acknowledgements section.

Procedures

Date and cause of death were obtained from death certificates held by the National Health Service (NHS) Information Centre for participants from England and Wales and the NHS Central Register Scotland for participants from Scotland. Date and cause of hospital admissions were identified via record linkage to Health Episode Statistics (HES) records for England and Wales and to the Scottish Morbidity Records (SMR1) for Scotland. Detailed information about the record linkage procedure is available online.[20 21] At the time of analysis, mortality data were available up to 17 February 2014 for England and Wales and 31 December 2012 for Scotland. Therefore, for the analyses of mortality, follow-up was censored at these dates or at the date of

death if this occurred earlier. Hospital admission data were available for the Scottish and English/Welsh participants until 30 June 2012 and 1 March 2011, respectively. Therefore, for CVD events, end of follow up was classified as these dates unless preceded by death or admission. Incident CVD events were defined as an ICD 10 code of I21, I21.4 or I21.9 recorded on a death certificate or hospital admission; CVD mortality was defined as ICD 10 code I21, I21.4 or I21.9 recorded on the death certificate. Cancer events wwere defined as an ICD code of C0.0-C9.9, D3.7-9 or D4.0-8 recorded on the cancer registry, death certificate or hospital admission; cancer mortality was defined as ICD 10 code C0.0-C9.9, D3.7-9 or D4.0-8 recorded on the death certificate.

At baseline assessment, active commuting, TV-viewing and physical activity were recorded by participants recruited from August 2009 onwards using a touch-screen, self-completed questionnaire. Participants were asked "In a typical day, what types of transport do you use to get to and from work?". Four possible answers were provided: a) car/motor vehicle; b) walk; c) public transport; and d) cycle. For the purpose of this study car/motor vehicle and public transport were merged and considered not active commuting and cycle or walking were merged and considered as active commuting. In addition, participants were asked "In a typical day, how many hours do you spend watching TV?". Physical activity was based on the International Physical Activity Questionnaire (IPAQ) short form,[22] with participants reporting frequency and duration of walking, moderate and vigorous activity undertaken in a typical week.[22] Data were analysed in accordance with the IPAQ scoring protocol (http://www.ipaq.ki.se/scoring.pdf), and total physical activity was computed as the sum of walking, moderate and vigorous activity, measured as metabolic equivalents (MET-hours.week^{-1}). Participants were excluded from the analyses if they recorded implausible values; defined as the sum of their total physical activity, sleeping time and TV-viewing exceeding 24 hours. An objective, accelerometer-based measure of physical activity was obtained in a subset of participants using a tri-axial wrist-worn accelerometer (AX3, Logging Accelerometer). Mean daily accelerations calculated using Open Movement AX3 open-source software (Open Lab, Newcastle University, UK),[23 24] (which provides outputs equivalent to those generated by the GENEActiv accelerometer used in other large-scale population cohorts)[23 24] were used as the objective measure of total physical activity. Cardiorespiratory finesse was assessed in a subset of 76,519 participants recruited from August 2009. Participants underwent a 6-minute incremental ramp cycle ergometer test with workload calculated according to age, height, weight, resting heart rate and sex and then expressed in terms of maximal METs (where 1 MET ≡ 3.5 ml.kg^{-1}.min^{-1}) as described elsewhere.[25]

Dietary information was collected via a self-reported dietary frequency questionnaire (Oxford WebQ), with participants asked about usual consumption of a range of foods.[26] Area-based socioeconomic status was defined

from postcode of residence using the Townsend score, a deprivation index derived from census data on housing, employment, social class and car availability.[27] Age was calculated from dates of birth and baseline assessment. Medical history (physician diagnosis of depression, longstanding illness, diabetes, CVD, and cancer) was collected from the self-completed, baseline assessment questionnaire. Height and body weight were measured by trained nurses during the initial assessment centre visit. Body mass index (BMI) was calculated as (weight/height^2) and the WHO criteria[28] used to classify BMI into categories: underweight <18.5, normal weight 18.5-24.9, overweight 25.0-29.9 and obese ≥30.0 kg.m^{-2}. Further details of these measurements can be found in the UK Biobank online protocol (http://www.ukbiobank.ac.uk) and our supplementary material.

Statistical analyses

The association between active commuting and prospective health outcomes (all-cause, CVD, and cancer mortality; CVD and cancer events) was explored using Cox-proportional hazard models. The models for CVD events and CVD mortality were run excluding participants with a history of myocardial infarction, angina or stroke at baseline; similarly models for cancer were run excluding participants with a cancer diagnosed at baseline. The referent category for all analyses was no active commuting.

For each of the approaches described above, we ran four incremental models that included an increasing number of covariates: "model 0" included age, sex, ethnicity (white, black, South Asian, Chinese and other), and deprivation index as covariates; "model 1", was also adjusted for long-standing illness, depression, CVD and cancer (in analyses where these participants were not excluded); "model 2" also included type 2 diabetes, hypertension, BMI, smoking status (current, former, never), dietary intake (alcohol, fruit and vegetables, red meat, oily fish, poultry and processed meat intake) and total sedentary behaviour. The proportional hazard assumption was checked by tests based on Schoenfeld residuals. All analyses were performed using STATA 14 statistical software (StataCorp LP).

Ethical Approval

The UK Biobank study was approved by the North West Multi-Centre Research Ethics Committee and all participants provided written informed consent to participate in the UK Biobank study. The study protocol is available online (http://www.ukbiobank.ac.uk/).

RESULTS

Of the 502,549 participants recruited to UK Biobank, 264,337 (52.6%) provided data on mode of commuting. The median follow-up period was 5.0 years [IQR 4.3 to 5.5]) for all-cause, CVD and cancer mortality and 2.1 [IQR 1.4 to 2.8] years for CVD and cancer events. Over the follow-up period, a total of 2,430 participants died, with 496 deaths from CVD and 1,126 deaths from cancer; 1,110 and 3,748 participants had CVD and cancer events, respectively.

The main characteristics of the participants by active commuting are summarised in Table 1. In summary, individuals who actively commuted were more likely to have high levels of socio-economic deprivation, and had a lower prevalence of overweight, obesity and physical inactivity compared to the non-active commuting group. Active commuters had a lower BMI, waist circumference and percentage body fat, and had slightly higher levels of total physical activity and fitness in comparison to those using car or public transport (Table 1). No major differences were found in dietary intake patterns between active and non-active commuters.

[Insert Table 1]

Table 1. Baseline characteristics by active commuting

	Overall	Car/Public Transport to work	Walk/Cycle to work
Socio-demographics			
Total n	264,337	234,125	30,212
Women, n (%)	138,575 (52.4)	121,160 (51.8)	17,415 (57.6)
Age (years), mean (SD)	52.6 (7.0)	52.6 (7.0)	52.3 (7.1)
Deprivation index quintile, n (%)			
Lowest (Less deprived)	52,030 (19.7)	48,916 (20.9)	3,114 (10.3)
Lowest-Middle	51,892 (19.7)	48,117 (20.6)	3,775 (12.5)
Middle	53,496 (20.3)	48,440 (20.7)	5,056 (16.8)
Middle-highest	55,602 (21.1)	47,776 (20.4)	7,826 (25.9)
Highest (Most deprived)	50,943 (19.3)	40,540 (17.3)	10,403 (34.5)
Ethnicity, n (%)			
Whites	247,684 (94.0)	219,433 (94.0)	28,251 (93.9)
South Asians	5,501 (2.1)	4,990 (2.1)	511 (1.7)
Blacks	5,083 (1.9)	4,522 (1.9)	561 (1.9)
Chinese	960 (0.4)	829 (0.4)	131 (0.4)
Mixed background	1,857 (0.7)	1,585 (0.7)	272 (0.9)

Others	2,476 (0.9)	2,115 (0.9)	361 (1.2)
Smoking status, n (%)			
Never	151,954 (57.7)	134,410 (57.6)	17,544 (58.2)
Previous	83,158 (31.6)	73,880 (31.6)	9,278 (30.8)
Current	28,491 (10.8)	25,184 (10.8)	3,307 (11.0)
Obesity-related markers			
BMI ($kg.m^{-2}$), mean (SD)	27.3 (4.7)	27.4 (4.7)	26.2 (4.5)
BMI Categories, n (%)			
Underweight (<18.5)	1,228 (0.5)	965 (0.4)	263 (0.9)
Normal weight (18.5-24.9)	89,578 (34.0)	76,459 (32.8)	13,119 (43.6)
Overweight (25.0 to 29.9)	111,017 (42.2)	99,366 (42.6)	11,651 (38.7)
Obese (≥30.0)	61,522 (23.4)	56,431 (24.2)	5,091 (16.9)
Waist Circumference (cm), mean (SD)	89.6 (13.3)	90.0 (13.4)	86.7 (12.6)
Central Obesity, n(%)	80,333 (30.5)	72,927 (31.3)	7,361 (24.4)
% Body fat, mean (SD)	30.5 (8.4)	30.7 (8.4)	29.6 (8.8)
Fat free mass (kg), mean (SD)	24.3 (9.4)	24.5 (9.4)	22.5 (9.2)
Fitness and Physical activity			
Fitness (METs), mean (SD)*	9.4 (3.3)	9.4 (3.3)	9.9 (3.4)
Grip strength (kg), mean (SD)	32.5 (11.0)	32.7 (11.1)	31.1 (10.5)
Objective weekdays total PA ($milli\text{-}gravity.day^{-1}$), mean (SD)	29.0 (8.6)	28.8 (8.5)	30.7 (9.1)
Objective weekend total PA ($milli\text{-}gravity.day^{-1}$), mean (SD)	29.1 (10.4)	28.9 (10.2)	30.6 (11.1)
Total physical activity ($MET.h^{-1}.week^{-1}$), mean (SD)	46.7 (69.5)	45.4 (69.2)	56.19 (70.8)
Achieve physical activity guidelines, n (%)	141,430 (53.5)	122,963 (52.5)	18,467 (61.1)
TV viewing ($h.day^{-1}$), mean (SD)	2.4 (1.3)	2.4 (1.3)	2.3 (1.5)
Total Sedentary Behaviour ($h.day^{-1}$), mean (SD)	4.9 (2.3)	5.0 (2.3)	3.8 (2.1)
Dietary intakes			
Total energy intake ($Kcal.day^{-1}$), mean (SD)	2170.7 (679.4)	2167.2 (680.8)	2195.0 (669.2)
Alcohol intake (% of TE), mean (SD)	5.2 (6.6)	5.2 (6.7)	4.9 (6.3)
Fruit and Vegetable intake ($g.day^{-1}$), mean (SD)	322.4 (192.1)	319.7 (190.7)	343.2 (201.5)
Oily fish ($portion.week^{-1}$), mean (SD)	1.03 (1.0)	1.0 (0.9)	1.1 (1.0)
Red meat, ($portion.week^{-1}$), mean (SD)	1.9 (1.4)	1.9 (1.4)	1.8 (1.2)
Poultry meat, ($portion.week^{-1}$), mean (SD)	1.9 (1.2)	2.0 (1.3)	1.7 (1.4)

Processed meat intake (portion.week^{-1}), mean (SD)	1.9 (1.1)	1.9 (1.1)	1.8 (1.1)
Health status, n (%)			
Diabetes history	9,391 (3.6)	8,556 (3.7)	835 (2.8)
Hypertension	51,778 (19.6)	46,408 (19.9)	5,370 (17.8)
Cancer history	14,672 (5.6)	13,026 (5.6)	1,646 (5.5)
Long standing illness	64,706 (25.0)	57,756 (25.2)	6,950 (23.6)
CVD	59,864 (22.7)	53,724 (23.0)	6,140 (20.3)
Depression history	84,657 (32.2)	74,789 (32.2)	9,868 (32.9)

BMI body mass index; PA physical activity; MET basal metabolic-equivalent. SD standard deviation; n number. A greater Townsend index score implies a greater degree of deprivation.*Fitness data was available for a subset of 76,519 participants.

[End of Table 1]

Correlates of active commuting are presented in Figure 1. In summary, women, the most deprived fifth of the cohort, physically active and fit individuals, and those in the middle or higher tertile for physical activity were more likely to actively commute. Conversely, individuals from South Asian or Black ethnic backgrounds, previous and current smokers, individuals with middle or higher levels of TV-viewing or sedentary behaviours, and those who were overweight, obese or centrally obese, or had an existing medical diagnosis of CVD, diabetes, hypertension, cancer, long standing illness or depression, were less likely to active commute.

Overall, there was a significant association of active commuting with subsequent CVD mortality and CVD events (Fig 2). The association was slightly attenuated, but remained statistically significant, after adjustment for age, sex, deprivation and ethnicity (CVD mortality HR: 0.57 [0.41 to 0.79], p=0.001; CVD events HR: 0.61 [0.49 to 0.77], p<0.0001). The association persisted following adjustment for sedentary behaviour, BMI, past medical history and dietary variables (CVD mortality HR: 0.71 [0.52 to 0.97], p=0.031; CVD events HR: 0.77 [0.61 to 0.97], p=0.027) (Fig 2). However, no significant association were found between active commuting and all-cause mortality or cancer mortality or cancer events (Fig 2).

When the analyses were repeated following exclusion of all participants with a history of diabetes, hypertension, cancer, depression and long standing illness from the analysis, the findings were broadly similar (Fig 2, "Model 2"). Similarly, landmark analysis, excluding events that occurred during the first year of follow-up did not alter our results (Supplementary Table S1).

DISCUSSION

The main finding of this study was that there were significant independent associations of active commuting with CVD mortality and CVD events. However, no associations were found for all-cause mortality, or cancer mortality or events. Our results revealed that the associations of active commuting with CVD mortality and events were independent of age, sex, deprivation, ethnicity, sedentary behaviour, dietary patterns and other confounding factors including BMI and comorbidities. Further analysis revealed that individuals with higher fitness, as well as those from the most deprived quintiles, were more likely to be active commuters, and commuters had higher levels of total physical activity. Individuals with higher levels of sedentary behaviours, or those who were overweight or obese, and with chronic illness or health conditions, were more likely to use car or public transport. These results are important, because daily active commuting could be an important contributor to total physical activity and, for walking commuters, it can be implemented virtually everywhere, and is inexpensive. For people with longer commutes, it may be possible to make part of their commute active, for example by parking some distance away from work. Therefore, promoting active commuting may be an effective and easy way of increasing the overall level of physical activity in the population.

The strong evidence of an association with health for both overall and leisure-related physical activity,[29 30] contrasts with few studies of non-leisure forms of physical activity, such as active commuting. There is limited and conflicting evidence on the association of active commuting and prospective health outcomes including all-cause mortality, CVD and cancer events. Evidence for the association between all-cause mortality and active commuting has been inconclusive with some studies suggesting that cycling to and from work reduced the hazard for all-cause mortality by 30% (RR:0.72 [95%CI 0.57 to 0.91])[15] whereas other studies reported that this association was abolished after adjustment for confounding factors.[16 17] This contrasts withpresent data, using the largest data set to date, revealed no association between all-cause mortality and active commuting in either minimally adjusted or fully adjusted models. There is also limited prospective evidence for the association between cancer and active commuting; one study conducted in 67,143 Chinese women found that increasing time spent in cycling but not walking was associated with a lower hazard for cancer mortality.[18] However, these findings are in disagreement with our result, where we show no association of active commuting with cancer mortality or cancer fatal and non-fatal events. This may be a consequence of the shorter follow-up to date in the present study, which at ~5 years may not have been long enough to detect an effect of active commuting on cancer outcomes. For CVD outcomes, a meta-analysis published in 2008 and conducted in 173,146 participants from 15 studies found that active commuting has a protective effect on cardiovascular outcomes (RR: 0.89

[95%CI: 0.81 to 0.98],p=0.016).[14] These results should however be viewed in light of a heterogeneous range of CVD outcome measures – ranging from incident hypertension to CVD mortality – variable levels of adjustment for confounding factors, and a relatively limited number of available studies which were mainly drawn from cohorts in Finland [14]. Indeed,the authors acknowledged that further studies were needed in order to confirm the association between active commuting and hard CVD outcomes in other populations.[14] The present study, which is larger in size than all previous studies combined, and includes participants recruited across the UK across a wide spectrum socio-economic status, provides the most robust assessment of the association between active commuting and CVD outcomes to date. The size of UK Biobank allows prospective analysis of transport method as a predictor of future disease and death within a very short follow-up time.[31] This feature is advantageous, because for most prospective cohort studies, outcome data are collected over periods of about 10–15 years, during which time many participants can change exposure level, leading to misclassification and underestimation of health benefit.[31]

The inclusion of a wide range of health, demographic and behavioural variables in the dataset allowed for comprehensive adjustment for the effect of confounding factors. Moreover, we also conducted more robust sensitivity analysis by excluding all participants with comorbidities that were diagnosed at baseline. As we show in our results, participants with comorbidities including hypertension, diabetes, cancer, depression and long-standing illness were all less likely to active commute. Therefore, their exclusion provides more robust and convincing evidence of the true association between active commuting and incident events. Furthermore we undertook landmark analyses, excluding all participants with an event in the year after baseline measurements were made to reduces the potenital effects of reverse causality. This did not alter any of the study findings.

Our study also provides novel evidence regarding correlates of active commuting. These findings could be relevant for targeting public health policies aiming to increase overall physical activity in the sub-groups of the population who are less likely to be active commuters. In contrast to the majority of health-related lifestyle factors, individuals who lived in the most deprived areas, who had lower educational attainment and lower incomes were more likely to actively commute.[32] However, 80% of participants from the most deprived quintile still did not actively commute, suggesting considerable room for improvement. The higher prevalence of active commuting in deprived communities may be related to their lower access to cars and the lower costs associated with active commuting. This finding agrees with previous finding where individuals with lower education level were more likely to actively commuting compared to those with higher education levels.[15]

Active commuters were more active overall and were more likely to meet the 150 minutes of physical activity recommended in guidelines;[30] they were also fitter and had lower levels of sedentary behaviour. Active commuting was less prevalent among South Asian and black participants; groups known to be at higher risk of

diabetes and CVD. Therefore, targeting interventions to encourage active commuting at these groups may be especially beneficial at reducing ethnic inequalities in health and overall health burden.

Implications of findings

Data from the 2011 census showed that, in England and Wales, 23.7 million individuals regularly commute to a workplace – more than half of the 41.1 million adults of working age covered by the census.[33] Two-thirds use private motorised transport with far fewer commuting by public transport (18%), walking (11%), and cycling (3%).[33] Policies designed to affect a population-level modal shift to more active modes of commuting therefore present major opportunities for public health improvement. Moreover, identification of correlates of active commuting could be useful in identifying individuals for whom future interventions aiming to increase physical activity levels are designed.

Strengths and limitations of the study

UK Biobank provided an opportunity to test our research question in a very large, prospective cohort in which we could evaluate all-cause, CVD and cancer mortality, as well as CVD and cancer events. UK Biobank is representative of the general population with respect to age, sex, ethnicity and deprivation within the age range recruited but is not representative in other regards.[19] Whilst this limits the ability to generalize prevalence rates, estimates of the magnitude of associations regarding disease or mortality and disease risk in the current study will not be affected by this and will therefore be generalizable.[19 34] As is the case for any observational study, causality cannot be confirmed. However, in our analyses we examined incident events and excluded those with prevalent disease at baseline therefore a temporal relationship could be demonstrated. Moreover, when all events that occurred within the first year of follow-up were excluded the findings of the study were not altered – therefore we have minimised the possibility of reverse causality due to undiagnosed disease at baseline. Although existing disease and comorbidities before the UK Biobank measurement day were self-reported, these self-reported records were based on diseases that have been medically diagnosed. Thus, our findings were robust to procedures designed to limit reverse causality. Furthermore, UK biobank is a prospective cohort study in its early follow-up stage, therefore it is possible that the lack of association between active commuting and health outcomes such as all-cause mortality and cancer was a consequence of the relative short period of follow up; thus this needs to be revised in the future once longer-term follow-up data from the UK Biobank becomes available. A further key limitation of this study, in common with much of the literature on active commuting

and health, is the somewhat crudely quantified exposure. UK Biobank participants were asked to give their main commuting mode, meaning mixed-mode journeys were not captured. It is therefore likely that the people who reported using a form of public transport as their main mode were highly heterogeneous in terms of the levels of physical activity their commutes entailed. Such an effect would bias the findings of the study to the null (i.e. individuals with an active portion of their commute would have been designated as inactive commuters), thus the real association between active commuting and outcomes is likely to be as least as strong as the present data suggest.

In conclusion, the present data shows a clear association between active commuting and lower risk CVD events and CVD mortality, independent of major potential confounding factors. Moreover, we have identified correlates of active commuting that could help to maximise potential public health gains from interventions aiming to increase overall physical activity at the population level. Thus, interventions to increase active commuting in the journey to and from work should be considered as part of strategies to reduce the population burden of CVD.

WHAT IS ALREADY KNOWN ON THIS TOPIC

Active commuting, such as walking or cycling, has been recommended as a feasible way of incorporating greater levels of physical activity into daily life. A meta-analysis, including 173,146 participants in total, reported that active commuting was associated with lower risk of adverse cardiovascular outcomes. However the work was limited by use of a heterogeneous range of cardiometabolic endpoints (including incident hypertension, diabetes, stroke, coronary heart disease (CHD) and cardiovascular disease (CVD)), and inconsistent adjustment for confounders between studies, with the authors recommending that further studies examining the association between active commuting and disease endpoints were needed.

WHAT THIS STUDY ADDS

The main finding of this study was that there were significant independent associations between active commuting and incident CVD events and CVD but for not all-cause mortality and cancer events or cancer mortality. Our results revealed that these associations were independent of socio-demographic factors, sedentary behaviour, dietary patterns and other confounding factors including obesity and comorbidities. Moreover, we have identified correlates of active commuting that could help to maximise potential public health gains from interventions aiming to increase overall physical activity at the population level. These results are important,

because daily active commuting could be an important contributor to total physical activity and, for walking commuters, it can be implemented virtually everywhere, and is inexpensive. Even for people living further away, it may be possible to make part of their commute active. Therefore, promoting active commuting may be an effective and easy way of increasing the overall level of physical activity and reducing CVD risk in the population.

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AUTHOR CONTRIBUTIONS

CCM, JPP, NS, JMRG contributed to the conception and design of the study, advised on all statistical aspects and interpreted the data. CCM perform the statistical analysis. CCM, JPP, NS and JMRG drafted the manuscript. CCM, DML, PW, JA, YG, RM, LS, DFM, JPP, NS and JMRG reviewed the manuscript and approved the final version to be published. CCM, JPP, NS and JMRG had full access to all the data in the study and take responsibility for the integrity of the data and the accuracy of the data analysis.

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TRANSPARENCY

The lead author, (the manuscript's guarantor), affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned (and, if relevant, registered) have been explained.

ETHICAL APPROVAL

UK Biobank received ethical approval from the North West Multi-centre Research Ethics Committee (REC reference: 11/NW/03820). All participants gave written informed consent before enrolment in the study, which was conducted in accord with the principles of the Declaration of Helsinki.

DATA SHARING

No additional data available

CONFLICT OF INTEREST

All authors have completed the Unified Competing Interest form at www.icmje.org/coi_disclosure.pdf (available on request from the corresponding author) and declare: no support from companies for the submitted work; no relationships with companies that might have an interest in the submitted work in the previous 3 years; no spouses, partners, or children have no financial relationships that may be relevant to the submitted work; no non-financial interests that may be relevant to the submitted work.

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FIGURE LEGENDS

Fig 1. Correlates of active commuting

Data presented as adjusted odds ratio (95%CI) (Referent group was set up as those who use car/public transport to work). Models were adjusted for age, gender, ethnicity and deprivation index. A greater quintile for Townsend index score implies a greater degree of deprivation.

Fig 2. Cox proportional hazard model of the association of active commuting with all-cause mortality, CVD and cancer events.

Data presented as adjusted Hazard Ratio (95%CI) by active commuting (Referent group was set up as those who use car/public transport to work). Main outcomes were defined CVD fatal and non-fatal events

Model 0 was adjusted for sex, age, ethnicity, and deprivation index

Model 1 was adjusted for model 0 plus long standing illness and depression and cancer

Model 2 was adjusted for model 1 plus HTA, diabetes, BMI, dietary intake (alcohol, fruit and vegetable, red meat, oily fish, poultry and processed meat intake), sedentary behaviour and smoking.

Model 3 was adjusted for model 2 but cases with baseline medical diagnose of long standing illness and depression and cancer, HTA and diabetes were excluded from the analysis.

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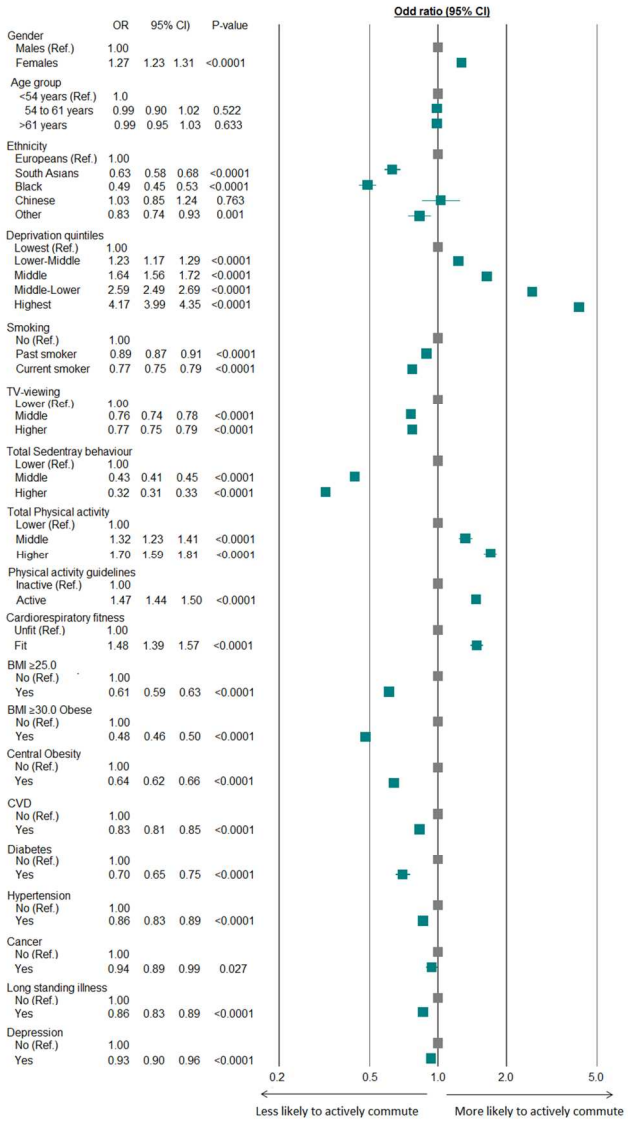

Correlates of active commuting

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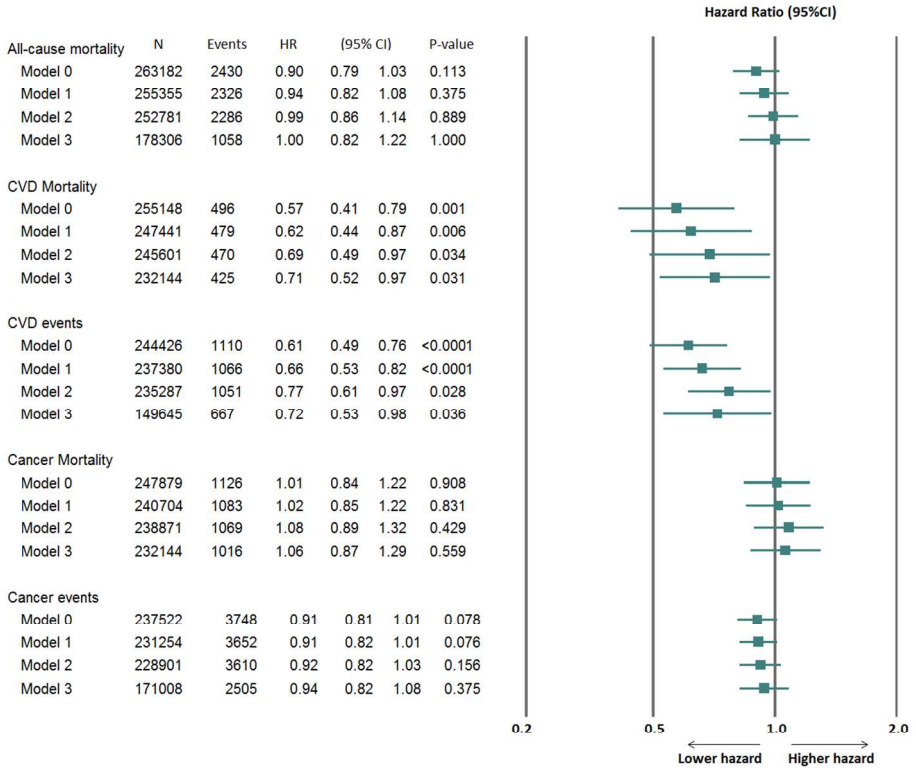

Cox proportional hazard model of the association of active commuting with all-cause mortality, CVD and cancer events.

SUPPLEMENTARY MATERIAL

Table S1. Landmark Cox proportional hazard model of the association of active commuting with all-cause mortality, CVD and cancer events occurring at least one year from baseline measurement.

		Overall		
	Total N	**Events**	**HR (95% CI)**	**p-value**
All-cause mortality				
Model 0	237,762	2,294	0.91 (0.80 to 1.05)	0.201
Model 1	230,684	2,196	0.95 (0.83 to 1.09)	0.484
Model 2	228,490	2,157	1.01 (0.87 to 1.15)	0.982
Model 3	161,399	1,007	1.02 (0.84 to 1.25)	0.777
CVD events				
Model 0	219,749	1,064	0.62 (0.49 to 0.78)	<0.0001
Model 1	213,120	1,019	0.67 (0.53 to 0.84)	0.001
Model 2	211,641	1,006	0.77 (0.61 to 0.97)	0.026
Model 3	108,762	449	0.71 (0.56 to 0.98)	0.045
Cancer events				
Model 0	213,693	3,597	0.92 (0.83 to 1.02)	0.149
Model 1	208,054	3,502	0.93 (0.83 to 1.04)	0.198
Model 2	206,061	3,462	0.94 (0.84 o 1.05)	0.284
Model 3	154,101	2,415	0.97 (0.84 to 1.09)	0.598

Data presented as adjusted Hazard Ratio (95%CI) by active commuting (Referent group was set up as those who use car/public transport to work). Main outcomes were defined all-cause mortality, CVD and cancer fatal and non-fatal events. Cases that occurred during the first year follow up were excluded from the analysis.
Model 0 was adjusted for sex, age, ethnicity, and deprivation index
Model 1 was adjusted for model 0 plus long standing illness and depression and cancer
Model 2 was adjusted for model 1 plus HTA, diabetes, BMI, dietary intake (alcohol, fruit and vegetable, red meat, oily fish, poultry and processed meat intake), sedentary behaviour and smoking.