**Associations between commute mode, cardiovascular disease, cancer and all-cause mortality in England and Wales: a cohort study using linked Census data over 25 years**

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**ABSTRACT** (250/250)

**Background**

Active travel is increasingly recognised as an important source of physical activity. We aimed to describe associations between commute mode and cardiovascular disease (CVD), cancer and all-cause mortality.

**Methods**

Cohort analyses were of 394,746 participants from the Office for National Statistics Longitudinal Study, which linked census data from 1991, 2001 and 2011 to mortality and cancer registrations. Commuting by private motorised transport, public transport, walking and cycling were compared in terms of these outcomes using Cox proportional hazards models with time-varying covariates. Models were additionally stratified by socio-economic group.

**Findings**

During the study period, 13,983 participants died, 3,172 from CVD, 6,509 from cancer and there were 20,980 incident cancer cases. In adjusted models, cycle commuting was associated with 20% lower all-cause mortality (Hazard Ratio = 0.80, 95% Confidence Interval = 0.73-0.89), 24% lower CVD mortality (0.76, 0.61-0.94), 16% lower cancer mortality (0.84, 0.73-0.98) and 11% lower cancer incidence (0.89, 0.82-0.97) than those commuting by private motorised vehicle. Rail commuters had a 10% lower all-cause (0.90, 0.83-0.97) and 20% lower CVD mortality (0.80, 0.67-0.95) in addition to 12% lower cancer incidence (0.88, 0.83-0.94), and walk commuting was associated with 7% lower cancer incidence (0.93 (0.89-0.97)). Stratified analyses did not reveal differences in associations between socio-economic groups.

**Interpretation**

This large cohort study adds to existing evidence for the beneficial health impacts of more physically active commute modes, especially cycling and train use, and suggests that all socio-economic groups could benefit.

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National Institute for Health Research Professorship award (Millett RP 2014-04-032)

Research in context panel

**Evidence before this study**

Evidence from meta-analyses have shown that cycle commuting is associated with reduced rate of all-cause mortality, cardiovascular disease (CVD) incidence and cancer mortality, while walk commuting is associated with reduced rate of CVD incidence. However, many of the included studies have short follow-ups and compared those accumulating high levels walking or cycling during commutes with those accumulating lower levels. These studies did not make comparisons with those who commuted using private motorised modes. Primary studies using comparisons with car commuters have found that cycling is associated with reduced all-cause mortality, CVD and cancer incidence and mortality, while walk commuting was associated with reduced CVD. A systematic review of health benefits of public transport use found that initiating public transport was associated with reduced adiposity but few cohort studies have investigated non-adiposity outcomes. Potential mechanisms for these associations include physical activity, atmospheric pollution and wellbeing.

**Added value of this study**

This study draws on a nationally representative data source with participants contributing up to 25 years of follow-up. The large dataset uniquely allows a longer-term investigation of public transport users stratified by train and bus use; it also allows the investigation of differences across socio-economic groups not previously studied. It found that cycling to work was associated with lower rates of all-cause mortality, CVD mortality, cancer mortality and cancer incidence. Rail commuters had a reduced rates of all-cause and CVD mortality in addition to incident cancer, and walk commuting was associated with a reduced rate of incident cancer. Stratified analyses did not reveal any differences in associations between socio-economic groups.

**Implications of all the available evidence**

Commuting is a potentially important source of physical activity and physically active commute modes, especially cycling and train use, are associated with a range of health benefits compared with car use. Policy makers in the health sector and beyond should consider the health impacts of policy decisions which affect people’s travel choices.

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Introduction**

The association between commute mode and health may act through several pathways, including physical activity and inhalation of air pollution, with physical activity suggested as the more important of the two [1](#_ENREF_1), [2](#_ENREF_2). Less well understood pathways include noise and stress, which may also play a role. Physical activity improves health in a range of ways including reducing rates of all-cause mortality, cardiovascular disease (CVD) and some cancers [3](#_ENREF_3). In addition to physical activity differences, car use is also reportedly associated with higher ambient levels of atmospheric pollutants than other modes, however, the increased ventilation rate of pedestrians and cyclists leads to greater inhaled doses with these modes [1](#_ENREF_1). To examine the impact of these exposures there has been increased research on links between travel mode and mortality [4](#_ENREF_4). For example, analyses of UK Biobank data showed that alternatives to car use were associated with reduced CVD mortality and cancer incidence [5](#_ENREF_5), [6](#_ENREF_6). However, UK Biobank is not nationally representative, with participants being healthier than the general population and in common with much previous work, comprised a relatively short follow up period with consequent low numbers of events [5](#_ENREF_5), [7](#_ENREF_7).

While travel by foot, bicycle and public transport in England and Wales has been declining for four decades, the commute is still a major potential source of physical activity for large numbers of working aged people [8](#_ENREF_8). In England and Wales, private motorised vehicles are the predominate commute mode at 67%; commuting by public transport is 18%, walking 11% and cycling 3%. However, variations in mode are seen, especially between urban areas, with efficient public transport systems and walkable distances between locations, and more rural areas which are more dependent on car use [8](#_ENREF_8), [9](#_ENREF_9).In England and Wales commute mode is patterned by socio-economic groups, with walking and public transport more common among the more deprived and car use more common among the less deprived [8](#_ENREF_8). Active travel may therefore have the potential to offset well-known health inequalities, such as differences in life expectancy and CVD rates [8](#_ENREF_8), [10](#_ENREF_10). However, the association between travel mode and health outcomes across socio-economic groups is unknown, differences might occur if the less affluent commute by foot or bicycle due to being unable to afford alternatives rather than making a positive choice, which might be more likely among the more affluent [8](#_ENREF_8), [10](#_ENREF_10). A recent systematic review identified few studies of active commuting and health; limited consideration of cancer outcomes; and very few studies which adequately considered measures of socio-economic group [4](#_ENREF_4). Finally, sample sizes have prevented many previous studies disaggregating commute modes to include cycling and specific public transport modes, despite differences in associated levels of physical activity between public transport modes[11](#_ENREF_11).

We aimed to extend previous research using data from a population-based linkage study over a longer period than many previous studies to examine impacts of commute mode on CVD, cancer and all-cause mortality and incident cancer. This large sample size and follow-up enabled the exploration of potentially differential impacts across socio-economic groups.

**Methods**

**Sample**

Data come from the Office for National Statistics – Longitudinal Study (ONS-LS), a dataset which links data from several sources, including the Census of England and Wales (henceforth the Census) and registrations of death and cancer diagnoses. Participant tracing and data linkage are coordinated by the UK Office for National Statistics to enable social and demographic research. Included participants contributed complete data for at least one eligible census (1991, 2001 and 2011) and were followed up through 2016 (2015 for cancer incidence). Census participation is a legal requirement in the UK leading to high response rates, e.g. 94% in 2011 [12](#_ENREF_12). The ONS-LS samples approximately 1% of the population from each census, based on four undisclosed birth dates in the calendar year (4 out of 365) and reports high linkage rates (98.8% of eligible participants in 2011) allowing census data from consecutive censuses to be linked together, in addition to enabling the linkage of events data, such as mortality and cancer registrations [13](#_ENREF_13). For example, ONS-LS personnel linked individuals to the National Cancer Registration and Analysis Service (England) and the Welsh Cancer Intelligence and Surveillance Unit (Wales), which are systematic collections of data on instances of cancer [14](#_ENREF_14), [15](#_ENREF_15). In addition to individual data on exposure and confounders from the Census, the ONS-LS also contains variables derived from census data about participant’s neighbourhood of residence, including population density and area-based measures of socio-economic group. In order to examine commute mode, the sample was restricted to the economically active, e.g. excluding those who were less than 16 years of age, full-time carers and retired participants.

**Variables**

*Exposure*

The primary exposure was usual commute mode in four categories: private motorised mode (e.g. car, motorbike), public transport (e.g. bus, rail), walk or cycle, with people working from home excluded. In order to investigate associations of different forms of public transport individually, we also conducted analyses with these disaggregated into bus and rail. Exposure data were derived from responses to the census question about usual commute mode, where participants selected one from a list of travel modes. The travel modes listed varied slightly from census to census with a full list of modes available in each census is given in **Appendix Table 1**.

*Outcomes*

Outcomes for these analyses were: (1) all-cause mortality, assessed by death registrations; (2) CVD mortality (International Classification of Diseases and Related Health Problems, 10th Revision code (ICD-10): I20-25 + I60-69); (3) cancer mortality (ICD-10: C00-C97 + D37-84) and (4) incident cancer. For those classified under the previous ICD9 coding system, equivalent codes were used; these are given in **Appendix Table 2.** Dates of death and cancer registrations were provided by the ONS-LS to the nearest month, more specific time of death is not available due to the risk of disclosure of identity. Analyses considered only participants’ first incidence of cancer registration, as subsequent diagnoses might be recurrences, metastases or another primary cancer, which are likely to have differing aetiological pathways [16](#_ENREF_16).

*Covariates and confounders*

Potentially confounding variables included in these analyses were measures of participant demographics: age; age2; sex; ethnicity (minority ethnic group, white). Household circumstances where assessed using housing tenure (homeowner, non-homeowner); marital status (married, non-married) and presence of a long-term illness (yes, no). Workplace and socio-economic variables were: university education (no degree, has a degree); National Statistics Socio-economic Classification of occupation (higher, intermediate, routine/manual) and individual level quintile of their ward’s Carstairs Index (a composite of male unemployment, lack of car ownership, overcrowding and social class of household head) [17-22](#_ENREF_17). Access to a car (yes, no) was included as a potential determinant of car use and population density of participant’s ward of residence (<2000 persons per km2, 2000+ persons per km2) as measure of neighbourhood built environment. Finally, year of cohort entry was included to account for changes over time. Neighbourhood measures (population density and Carstairs Index) were based on the participants’ ward of residence. The categorisation of ethnicity, education and marital status were dictated by the available data and comparability of variables over time, while population density was available as a categorical variable which was dichotomised as close as possible to the median in the absence of a strongly evidence-based alternative.

**Analyses**

The characteristics of participants were summarised by usual commute mode. For participants who contributed data from two or more censuses, the baseline data reflects that provided in their earliest included census data-point.

Participants were followed up from the date of their first eligible census until either they were no longer eligible (e.g. not employed at a subsequent census), they were absent from a subsequent census, their date of death registration, their emigration was registered or until the end of the study period (December 2016 for mortality or December 2015 for cancer incidence analyses). Cause specific mortality analyses additionally censored participants at the date of death from other causes. Incident cancer analyses excluded participants with a history of cancer and censored participants at death.

We used Cox proportional hazards regression models to estimate Hazard Ratios (HRs) with 95% confidence intervals for the associations between commute mode and study outcomes (all-cause, CVD and cancer mortality and cancer incidence) [23](#_ENREF_23), [24](#_ENREF_24). Commute mode was entered as a time-varying exposure in the models which allowed participants who reported different modes in different censuses to contribute data to all commute modes they reported. Time-varying covariates were all those listed under ‘covariates and confounders’ except for age, sex, ethnicity, limiting long-term illness and year of study entry, which were sourced from baseline and were judged to be time invariant for the purposes of these analysis. For participants contributing data to multiple censes, subjects’ socio-economic, household and workplace characteristics were allowed to vary over each-10-year period and were entered as time-varying covariates in the models.

The proportional hazards assumption was evaluated both graphically by plotting Schoenfeld residuals against survival time, and statistically by regressing the scaled Schoenfeld residuals on functions of time to test for a non-zero slope.

The main analyses were conducted using a four-category measure of commute mode (private motorised vehicle, public transport, walk, cycle) and examined all-cause mortality, CVD mortality, cancer incidence and cancer mortality. Analyses were then conducted with public transport users disaggregated into bus and rail users in order to examine any differences between these two modes. Potentially modifying factors were tested for an interaction and where appropriate analyses were stratified to explore potentially differential impacts across groups. These factors were three categories of NS-SEC, population density (<2000 persons per km2 versus 2000+), full versus part-time working (only available in 2001 and 2011) and sex (male versus female). To assess for a potential dose response, the subset of data from 2001 and 2011 which contained straight line commute distance was used. Commuters were dichotomised into short and long distance commuters, based on being above or below mode-specific median commute distances. All analyses used private motorised transport commuters as the reference category.

To explore the impact of changing commute mode, we compared those who continued using private motorised vehicle in 1991 and 2001 with those who switched from private motorised in 1991 to active commuting in 2001, we also compared those who continued active commuting in 1991 and 2001 with those who changed from active in 1991 to private motorised commuting in 2001. Participants were follow-up from 2001 to 2016 (2015 for incident cancer analyses).

Sensitivity analyses added both self-reported health and presence of a limiting illness as covariates, which were first added to the Census in 2001. We also investigated potential reverse causality with analyses which excluded the first two years of follow-up subsequent to each census, for example, to minimise the impact of those in pre-existing poorer health selecting less active commute modes. All analyses were conducted with Stata 15, StataCorp, USA.

**Role of the funding source**

The study sponsors had no role in study design; the collection, analysis and interpretation of data; in the writing of the report and in the decision to submit the paper for publication. The corresponding author had full access to all the data in the study and had final responsibility for the decision to submit for publication.

**Results**

*Sample*

Of 784,677 individuals who contributed data for at least one census between 1991 and 2011 and were traced in the ONS-LS, 416,871 were economically active, e.g. ≥16 years, not retired and not a full time carer (**Appendix Figure 1**). The exclusion of 15,459 individuals who reported working from home or ‘other’ as their commute mode left 401,477 eligible participants. Additional exclusions were made of those with missing data for commute mode (N=5,038) or missing data for at least one covariate (N=1,693), leaving an analytical sample of 394,746 individuals (although samples differed slightly between analyses). This represents a sample of economically active working-age individuals. A comparison between those excluded due to missing data and those who were included shows that those excluded were less likely to use private motorised vehicle (53.1% versus 65.5%), to have a university degree (7.5% versus 20.6%) and more likely to be aged 60 years or more (15.4% versus 4.2%).(**Appendix Table 3**).

At baseline 65.6% of participants were private motor vehicle commuters, 18.8% were public transport commuters, 12.4% walk and 3.2% cycle commuters **(Table 1).** Participants aged between 30 and 59 were more likely to be private motor vehicle commuters than other groups, e.g. 68.1% of those aged 30-44 were private motor vehicle commuters compared with 62.0% of those aged ≤29 years. Those aged ≤29 years were most likely to be public transport commuters, 22.5%, compared with 15.7% of those aged 45-59. Men were more likely than women to be private motor vehicle commuters (71.6% vs. 58.7%) or cycle commuters (4.0% vs 2.3%) but were less likely to be public transport commuters (15.6% vs. 22.4%) or walk commuters (8.7% vs. 16.6%). White participants were more likely than minority ethnic groups to be private motor vehicle commuters (67.3% vs. 50.9%) or cycle commuters (3.4% vs. 1.4%) and were less likely to be public transport commuters (16.9% vs. 35.2%). Those living in areas of less than 2,000 persons per square kilometre were more likely to be private motor vehicle commuters than those with at least 2000 persons (75.3% vs. 58.0%) but were less likely to be public transport commuters (10.6% vs. 25.1%). Characteristics of those using different commute modes at 1991, 2001 and 2011 are also displayed in **Appendix Tables 4 – 6** with disaggregated public transport use in **Appendix Table 7**. These show that although some changes over time are seen, for example the proportion of participants with a university degree, the relationships between the variables and commute mode remain broadly similar.

*Associations between travel mode and outcomes*

Compared with those who commuted by with private motorised vehicle, cycle commuters had a 20% reduced rate of all-cause mortality (Hazard Ratio (HR) = 0.80 (0.73, 0.89)), 24% reduced rate of CVD mortality (HR = 0.76 (0.61, 0.93)), 11% reduced rate of incident cancer (HR = 0.89 (0.82, 0.97)) and 16% reduced rate of cancer mortality (HR = 0.84 (0.73, 0.98)) in adjusted models (**Figure 1 and Appendix Table 8**). Walk commuters had 7% lower rates of incident cancer (HR = 0.93 (0.89, 0.97)) and non-significant positive associations with other outcomes in adjusted models. In unadjusted analyses, walk commuters had 17% and 16% higher rates of all-cause (HR = 1.17 (1.11, 1.23)) and cancer mortality (HR = 1.16 (1.08, 1.25)) respectively, which attenuated to modest non-significant rate reductions in adjusted analyses. Public transport commuters had a 7% lower rate of incident cancer than private motorised vehicle commuters (HR = 0.93 (0.89, 0.97)) in adjusted models, with larger associations in unadjusted analyses (HR = 0.79 (0.76 to 0.82). For other outcomes there was suggestive evidence for a small non-significant positive association with public transport commuting in adjusted analyses.

Analyses disaggregating public transport commuters showed that rail commuters had a 10% lower rate of all-cause (HR = 0.90 (0.83, 0.97)) and 21% lower rate of CVD mortality (0.79 (0.67, 0.94)) in addition to 12% lower rate of incident cancer (HR = 0.88 (0.83, 0.94)), while bus commuters showed no statistically significant difference from the private vehicle reference category (**Figure 2 and Appendix Table 8).** In unadjusted analyses bus commuters had poorer outcomes than rail commuters. For example, the unadjusted HR for all-cause mortality among bus commuters was 1.19 (1.13, 1.26) and in rail commuters was 0.73 (0.68, 0.79).

Tests for interaction showed that population density and part-time working had no impact on associations (**Appendix Table 9**). Analyses stratified by NS-SEC social classification suggested that associations were of similar magnitude and direction across occupation based socio-economic group (**Figure 3 and Appendix Table 10**). Although there was no consistent evidence for differences by NS-SEC group, bus, rail and cycle commuters who were of managerial social class had lower point estimates for all-cause mortality but when examining cancer incidence bus, rail and cycle commuters of intermediate social class exhibited the lowest point estimates. In sex stratified analyses, wide confidence intervals mean that even where point estimates diverge there is no evidence for differences between men and women (**Appendix Table 11**).

Median commute distances varied from 0.8km for walk commuters to 13.1km for rail commuters (**Appendix Table 12**). Comparison of outcomes between commuters above and below the median distance for their commute mode was inconclusive but suggests in many cases that longer commutes were associated with better outcomes, although this was not the case for cycling (**Appendix Table 13**). Analyses of changing commute mode resulted in estimates with wide and overlapping confidence intervals, which in all adjusted analyses were consistent with no effect (**Appendix Tables 14-15**).

Sensitivity analyses additionally adjusting for self-reported health produced similar results as did those excluding the first 2 years of follow-up subsequent to each census (**Appendix Table 16 and Appendix Table 17).**

**Discussion**

This analysis of data from a large cohort study found that cycling to work was associated with a reduced rate of all-cause, CVD and cancer mortality, and incident cancer compared with private motorised commuting. Rail commuting was associated with a reduced rate of all-cause and CVD mortality and incident cancer while walk commuting was associated with a reduced rate of incident cancer. These associations were found to be similar across socio-economic groups.

**Strengths and limitations**

These analyses make use of large representative population-based data with high levels of linkage to mortality and cancer data. Participants contributing up to 25 years of follow-up and the large sample size allowed granularity in assessing commute modes, including both specific analyses of cycling, as well as separating public transport into bus and rail. Nonetheless, this large and long-term dataset has some limitations due to the lack of granularity in some variables of interest and the absence of others. This includes the use of usual commute mode as the exposure, which is a simplification and fails to capture travel for other purposes, use of different modes during the same day, use of different modes on different days and those who only commute on certain days (including part-time working). This may drive some of the difference between these findings and those of researchers using more detailed measures of commute mode, which are discussed in the next section. There were ten years between assessments of commute mode and if individuals changed their commute mode, it is uncertain exactly when that happened, which introduces some measurement error. Comparing commute mode in consecutive censuses shows that those who change mode are more likely to change to private motorised mode than any other, the impact of which is likely to bias towards the null (**Appendix Table 18**). We additionally did not have data on some potentially important confounding variables such as air quality, dietary intake, adiposity, smoking, non-commuting physical activity, medications and comorbidities. The potential impacts of some of these missing variables are uncertain as there are conflicting findings on the association of active commuting with leisure time physical activity and on the impacts of adiposity on transport mode choice [25](#_ENREF_25), [26](#_ENREF_26). Additionally, adiposity is potentially on the causal pathway between commute mode and our outcomes, so while it would have been interesting to evaluate the importance of this factor, the impacts of this on our results remain uncertain. However, we did adjust for a range of covariates and sensitivity analyses which included self-reported health and excluded the first two years of follow-up produced similar findings. Nonetheless, it is plausible that more detailed medical history and lifestyle data would have allowed for more complete adjustment for potentially confounding factors.

We were unable to explore the direct or indirect mechanisms that were responsible for our findings. Studies comparing the relative importance of physical activity and atmospheric pollutants in the health effects of transport suggest that physical activity is likely to predominate [1](#_ENREF_1), [2](#_ENREF_2). Other mechanisms such as the stress during journeys may also explain some of our findings, although these appear complex and context dependant [27](#_ENREF_27). Our findings represent the health associations of using different commute modes and are likely to encompass multiple pathways. Further research is required to better elucidate which mechanisms might predominate and in which contexts. Many of our supplemental analyses suffered from wide confidence intervals leading to inconclusive findings. A low number of events in subgroups may also have been responsible for our inability to detect interactions with hypothesized modifiers such as population density and part-time working. Other potential causes of these issues include the measures available in the data, for example, the use of straight-line commute distance, which is likely to be an imprecise proxy for commute dose and the use of population density as a measure of the built environment. Measurement error associated with only having commute mode recorded every 10 years possibly contributed the lack of findings in the analyses of changing mode.

**Comparison with other research**

Our results broadly concur with other research on the health impacts of travel modes, although differing follow-up times and exposure classifications make exact comparisons difficult. We identified smaller associations for walk and cycle commuting than a 2018 systematic review and meta-analyses [4](#_ENREF_4). For example, the review found that cycle commuting was associated with rate reductions of 24% for all-cause mortality and 25% for cancer mortality, compared with 20% and 16% respectively in this analysis. These differences could be due to the review comparing the most active commuters with the least active, which is likely to yield larger differences than the analyses in this study, which were not restricted to commuters on these extremes [4](#_ENREF_4), [28](#_ENREF_28), [29](#_ENREF_29). A separate systematic review which examined only cycle commuting found that it was associated with reduced rate of incident and fatal cancer, although meta-analyses were not conducted.[30](#_ENREF_30)

Associations identified in a 2018 study using UK Biobank data with 5 years of follow-up were also larger than those here [5](#_ENREF_5) . For example, rate reductions for cycle commuting and all-cause and CVD mortality were 41% and 52% respectively, compared with 20% and 24% in this study. Another study using UK Biobank investigated commuting and non-commuting travel with modes dichotomised into those who exclusively travelled by car and those who used any other mode or combination of modes [6](#_ENREF_6). Those findings were broadly consistent with ours in that more physically active travel modes were associated with lower all-cause mortality [6](#_ENREF_6). Differences between the findings of UK Biobank and these analyses could be due to differences in the exposures, with UK Biobank participants being able to select multiple travel modes; differences in sample demographic characteristics, with UK Biobank recruited from volunteers and only those aged ≥40 years; and differences in available covariates, with UK Biobank collecting more detailed data on comorbidities, diet, non-commuting physical activity and smoking. Importantly, the UK Biobank sample, although large is not representative of the UK population unlike our sample, which increases the potential generalizability of our results[7](#_ENREF_7).

The health impacts of public transport use are less well understood than those of walking and cycling. However, public transport users accumulate physical activity in the course of their public transport journeys, often through walking to connect journeys from their origins or to their ultimate destinations [11](#_ENREF_11), [31](#_ENREF_31), [32](#_ENREF_32). A systematic review of longitudinal studies additionally found that initiating public transport use was associated with an 0.30kg/m2 reduction in body mass index (BMI), although there remains a paucity of high quality studies in this area[33](#_ENREF_33). However, this is one of the first studies to examine whether public transport use is associated with incident mortality. The positive associations seen were primarily among rail rather than bus commuters. This may be due to rail users accumulating more physical activity in the course of their journeys than bus users, which is consistent with bus stops being more densely located than train stations and therefore more likely to be closer to journeys’ origins or ultimate destinations[11](#_ENREF_11), [34](#_ENREF_34). Other possible explanations are differences in reliability, speed and levels of crowding which may affect stress levels of those using buses and trains differently. Evidence also suggests that bus users have greater exposure to atmospheric pollutants than rail transport [1](#_ENREF_1). Train commutes are on average longer than bus commutes, therefore some of the differences might be due to people taking on longer (train) commutes in order to get access to an increased salary and/or better housing and neighbourhood of residence, which themselves might lead to improved outcomes.[27](#_ENREF_27) Train users are also likely to be more socio-economically advantaged than bus users, in this sample and elsewhere [34](#_ENREF_34), meaning that residual confounding could explain some differences between these modes. The NS-SEC stratified results provide no evidence for differences across groups, which is consistent with other research and indicates that benefits may be available across socio-economic groups.[6](#_ENREF_6) Alternately, it could be that alternative conceptualisations of socio-economic group such as education, absolute income or wealth would find differing results or that the relatively low numbers of events in these stratified analyses may have led to a lack of power to detect differences.

The mixed findings for analyses of commute distance might results from lack of statistical precision as commute distance was not available for all participants. Straight line distance between residential and workplace addresses is unlikely to be an accurate measure of commute distance and the degree to which this is the case could vary between modes, for example, it seems plausible that walking is more closely aligned with straight line distance than train travel. Commute time data were not available, but this might provide a more valid measure of exposure to relevant pathways across modes. This might be especially the case for effects through a wellbeing mechanism as a result of long or stressful commutes. The suggestive finding that longer distance commutes were associated with better outcomes, even for train users, is consistent with research that people trade off long commutes for compensations in other areas, such as better housing or higher salaries [27](#_ENREF_27). This could drive some of the findings seen in these analyses.

**Policy implications**

The findings of this study of commuters in England and Wales are in line with existing evidence that switching to alternatives to car use is associated with health benefits [4-6](#_ENREF_4). However, a systematic review found potential differences in the relationship between studies in northern Europe and those from elsewhere so the generalizability of our findings are uncertain [4](#_ENREF_4). Differences in the built environment, public transport availability and social norms might lead to these differences. While more research is required into the importance of contextual factors and the relative importance of the differing mechanisms at play, there is sufficient evidence to support the policy aim of discouraging car use and encouraging alternatives.

There is considerable scope to increase the levels of active travel in England and Wales with 61% of trips and 77% of distance travelled by car in 2018 [35](#_ENREF_35). This study provides additional evidence for the health benefits associated with increased use of physically active travel modes, including public transport. Potential health benefits of public transport have received limited attention previously and this study identified public transport use to be associated with a reduced rate of incident cancer, while a recent systematic review linked public transport use to reduced adiposity[33](#_ENREF_33). These findings should inform policy decisions on future spending priorities, especially those in transport and other non-health sectors. This is especially the case given that increased walking, cycling and public transport use would contribute to improved air quality and subsequent health benefits for all. Our findings also indicate that the associations between commute mode and health were consistent across occupation based socio-economic groups. If the relative health benefits of active travel apply to all then the greater underlying risk experienced by those of lower socio-economic groups would result in greater absolute benefits for these groups [36](#_ENREF_36).

**Conclusions**

By using up to 25 years of follow up, this study adds to existing evidence for the beneficial health impacts of physically active commute modes, including cycling and train use. These associations were similar across socio-economic groups, strengthening calls for investment to encourage more physically active forms of travel. Further research on specific mechanisms behind these findings would be useful but should not detract from the large body of evidence that private car use will need to be reduced to meet future health and environmental goals.

**Author contributions**

CM, AAL, SC and RP designed the analyses in collaboration with EV and JP. RP conducted the data analyses and wrote the first draft of the manuscript. All other authors revised it for important intellectual content and approved the final version of this manuscript.

Declaration of Interests

We declare no competing interests.

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**Figure 1: Mortality and cancer outcomes by commute mode from the ONS Longitudinal Study 1991-2016. Hazard ratios are for usual commute modes compared with a reference category of private motorised vehicle commuting.**

Adjusted for age, sex, housing tenure, marital status, ethnicity, university education, car access, population density, National Statistics Socio-economic classification (NSSEC), Carstairs quintile, long term illness, year entered study



**Figure 2: Mortality and cancer outcomes by commute mode with disaggregated public transport users from the ONS Longitudinal Study 1991-2016. Hazard ratios are for usual commute modes compared with a reference category of private motorised vehicle commuting.**

Adjusted for age, sex, housing tenure, marital status, ethnicity, university education, car access, population density, National Statistics Socio-economic classification (NSSEC), Carstairs quintile, long term illness, year entered study



**Figure 3: Mortality and cancer outcomes by commute mode stratified by NS-SEC social classification from the ONS Longitudinal Study 1991-2016. Hazard ratios are for usual commute modes compared with a reference category of private motorised vehicle commuting.**

Adjusted for age, sex, housing tenure, marital status, ethnicity, university education, car access, population density, Carstairs quintile, long term illness, year entered study

