The Health Impacts of Public Transport Use

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Statement of contribution

This thesis is my own work and the work of others is referenced where appropriate.

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Abstract

Introduction

Public transport use is common and often involves short walks to and from public transport stops. Population impacts of physical activity accumulated as part of public transport journeys are potentially substantial but remain understudied compared with other transport modes. This thesis aims to examine the potential health effects of public transport use.

Methods

(1) A systematic review of the cardio-metabolic health effects of public transport. (2) Analyses of nationally representative data to examine predictors of public transport use and related physical activity. (3) Examine the association between the English free older person's bus pass and bus use and active travel levels, and establish whether these impacts differ across ethnic groups. (4) Analyses of census data to identify associations of public transport commuting with cancer and mortality.

Results

The systematic review found 10 studies and concluded that public transport was associated with reduced adiposity, with little research available on other outcomes. Public transport use in England is higher among: women, those of minority ethnicity and the socio-economically disadvantaged. Public transport users in England accumulated an average of 21 minutes a day of physical activity in the course of public transport journeys. The free bus pass had high uptake and was associated with higher bus use and active travel and these effects may be greater among ethnic minority groups. Public transport commuting in England and Wales was associated with reduced cancer incidence, with larger associations seen in rail commuters than bus commuters.

Discussion

Public transport use in England is common and is associated with reduced adiposity, higher physical activity and lower incidence of cancer. These findings suggest that increasing public transport use can improve population health through increased physical activity.

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Abbreviations

AOR – Adjusted odds ratio

BMI - Body Mass Index - weight (kg)/height $(m)^2$

CHD – Coronary Heart Disease

CI – Confidence interval

CVD – Cardiovascular Disease

DfT – UK Department for Transport

ELSA – The England Longitudinal Study of Aging

GIS – Global Information Systems

IHD – Ischaemic Heart Disease

IRR – Incident Rate Ratio

KM – Kilometre(s)

MET – Metabolic Equivalent Tasks

MVPA – Moderate to Vigorous Physical Activity

NSSEC – National Statistic Socio-economic classification

ONS – UK Office for National Statistics

ONS-LS – Office for National Statistics - Longitudinal Study

UKHLS – United Kingdom Household Longitudinal Survey

WHO – World Health Organization

Chapter 1 – Public Transport

Most people travel somewhere on most days, be that to work, to shop, to access leisure or simply travel for its own sake. Although the health effects of walking and cycling are well studied, there is much less research on health impacts of public transport. This is despite public transport being a common travel mode which is capable of covering long distances, unlike walking or cycling, and has the potential to be more environmentally sustainable than car use. Existing high levels of public transport use mean that the accumulation of health effects in all public transport users may lead to substantial population impacts, while the potential for many current car users to switch to public transport suggests the possibility of even greater population health effects.

In this thesis I have examined the health impacts of public transport, specifically those due to the physical activity accumulated in the course of public transport journeys. This included walking or cycling to access public transport and during transfers between public transport modes. This topic was of interest due to the large and growing burden of non-communicable disease globally. Physical activity is an important modifiable risk factor associated with non-communicable diseases and is therefore an important potential mechanism to influence population health. Incorporating physical activity into daily travel is appealing as it can build physical activity into the daily routine rather than requiring additional tasks such as visiting the gym. Other potential mechanisms through which public transport might influence health were not directly considered, these included wellbeing and pollution. This thesis primarily used data from England, however, it is situated within a global literature on the health effects of public transport and comparisons with evidence from other contexts are drawn where appropriate. England was chosen as it represents a mature public transport setting. Although future policy might alter the public transport offering in England substantially, the health implications of the existing situation will inform policy makers in England and other similar developed countries, in addition to providing some guidance to developing

countries as to what developments should and should not be considered. England also offers a rich source of routinely collected data, however, there is little research of this kind into public transport use and especially the health effects of public transport**.** The available routinely collect data are representative of the population of England and are sufficient to address the aims of this research. Nationally representative data ensure that findings are generalisable to the population as a whole and not the result of local transport conditions and also allows the investigation of subgroups. Primary data collection was therefore considered unnecessary for this project, despite its role in this field of study more generally.

Chapters 1-3 cover the background to this topic, including a summary of existing literature on public transport use in England and a discussion of the policy context in which decisions about public transport policy are taken. This section also reviews the existing evidence for a health benefit from transport. Chapter 4 contains the aims of objectives of this thesis. Chapter 5 is a systematic review of evidence for potential cardio-metabolic health benefits of public transport use, which concluded that initiating public transport use was associated with a small reduction in adiposity. Chapter 6 contains a description of public transport users and of those using specific public transport modes in England, this shows that public transport use is common and particularly so among the socio-economically disadvantaged and those of minority ethnicities. Chapter 7 is a quantification of the physical activity accumulated in the course of public transport journeys in England, which found this was an average of 21 minutes a day with greater amounts seen in train users than bus users. Chapter 8 is an examination of the associations between the free older person's bus pass and bus use and active travel, along with an investigation of possible ethnic variations in these associations. This found that the free bus pass was associated with increased use of more active travel modes and that this might be greater in ethnic minority groups. Chapter 9 is an analysis of the impact of commute mode on cancer and mortality risk, which found that public transport commuting was associated with reduced risk of incident cancer, while train commuting was associated with reduced risk of all-

cause and cardiovascular disease (CVD) mortality. Chapter 10 is a discussion of the findings and a comparison with the existing literature, in addition to considering potential future research themes. It considers the potential improvement to health which could be seen if public transport use were encouraged at the expense of car use and how these benefits may reduce inequality if bus use is encouraged but might increase inequality if only rail use is considered.

1.1 Public transport and its use in England

Public transport is passenger transport shared with other members of the general public [5], in England this usually involves bus or rail transport.[6] Other public transport modes in England include a relatively small amount of ferry travel and a growing use of domestic air travel, which were not considered directly in this work.[7] In England and Wales, rail public transport comprises trains (sometimes known as National Rail), in addition to light-rail systems which operate in some urban areas. Light-rail systems include London Underground, in addition to eight other networks in England and Wales, two of which are also in London, the Dockland Light Railway and the London Tramlink. The other networks are in Nottingham, the Midlands, Sheffield, Tyne and Wear, Manchester and Blackpool. Some sources have used different categorisations and the London Underground is not always considered along with the other light-rail systems, which might be because its construction predates the use of the term.[8-10]

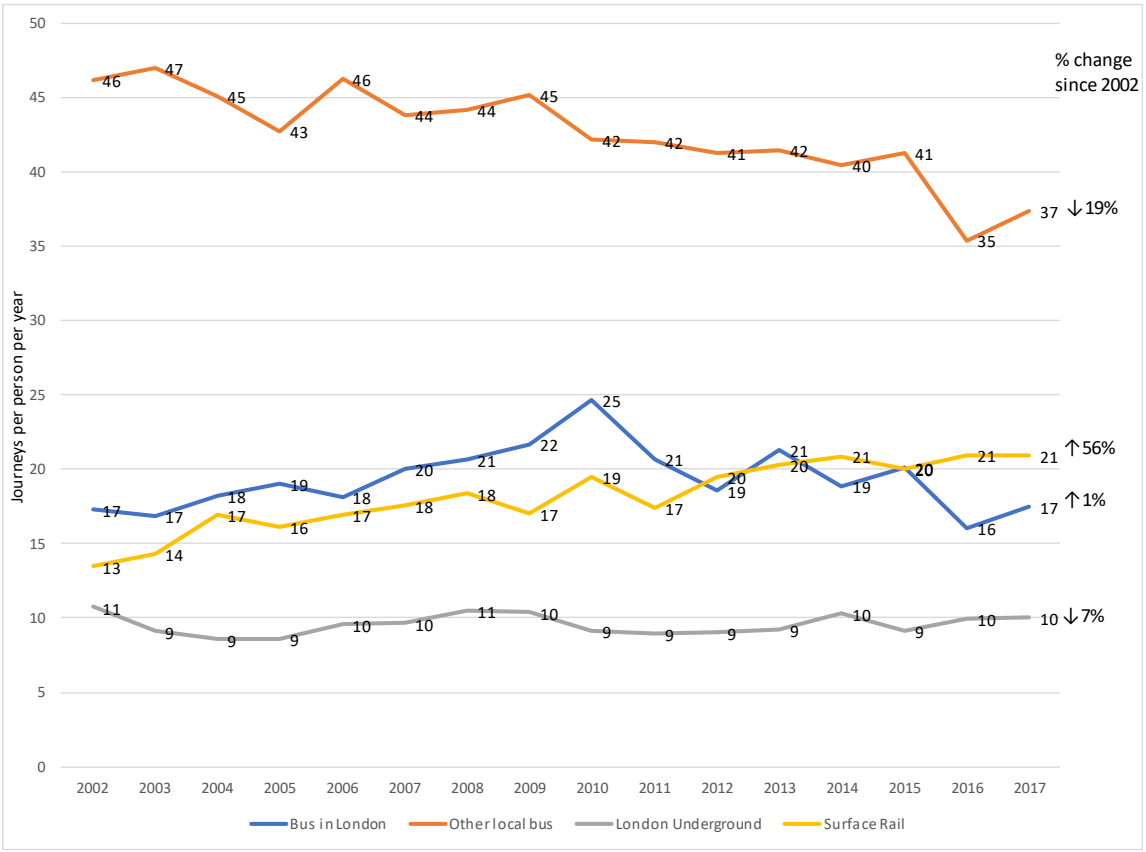
Travel statistics in England are provided by the Department for Transport (DfT) and are usually based on the National Travel Survey (NTS) [11], these show that in 2015, public transport use in England constituted 10% of all journeys, compared with 22% for walking and 64% for car use.[12] Bus was the most commonly used public transport mode, comprising 7% of all journeys, with 3% being by rail, including both train and light-rail.[12] Examination of distance travelled showed that rail use made up 10% of all distance, compared with 5% by bus, 78% by car and 3% by walking.[13]

However, the use of different travel modes varies considerably between different areas of England, 13% of all trips in London were by bus, compared with 3% of trips in the South East and East of England. In rural areas, 2% of trips were by bus compared with 9% of trips in urban areas.[14] In London, 14% of journeys were by train or London Underground, compared with 1% or less in the North East, Yorkshire and Humber, East and West Midlands and the South West .[14] Light-rail, other than London Underground, was combined with modes including domestic flights and ferries for this analysis, but comprised 1% of London journeys and less in other areas of England.[14]

1.1.1 Trends in public transport use

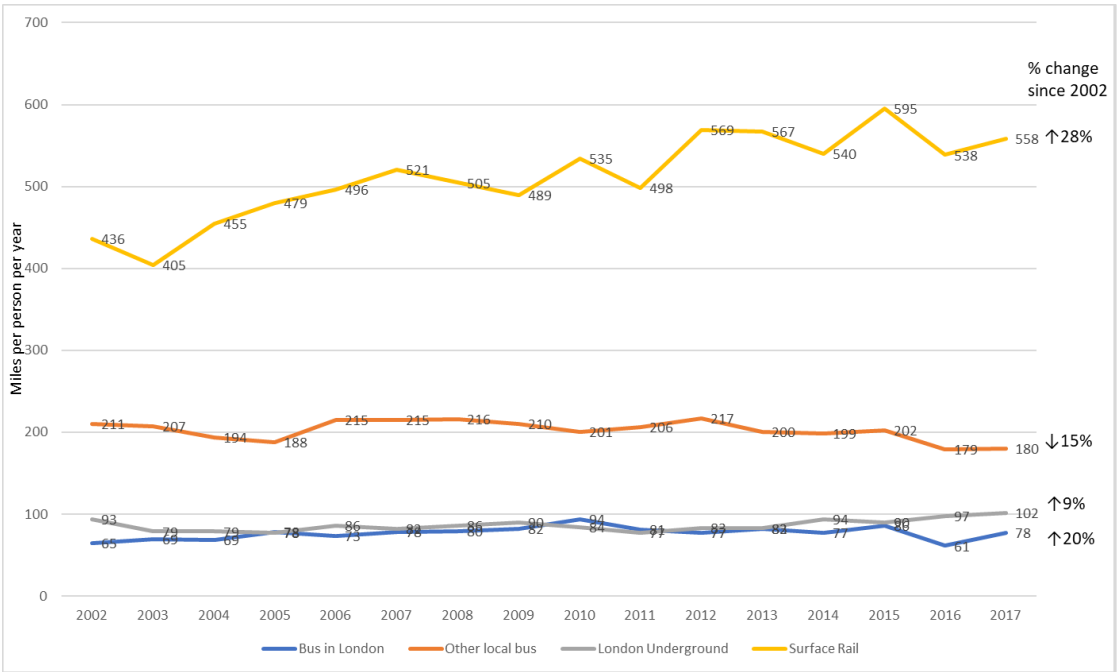
Trends in public transport are best understood alongside trends in overall travel and car use. Throughout the second half of the twentieth century, Great Britain experienced an increase in the number of journeys taken and the distance travelled, this occurred alongside a shift in preferences towards private vehicle use and away from public transport.[7, 15, 16] However, between 2002 and 2015, total travel fell in terms of journeys and distance, reflected by a fall in the number of car, bus and walking journeys, in the same period the number of train journeys increased.[6, 17] Overall public transport use appears to have been broadly stable in England since 2002. However, this masks differing trends in different modes, notably a reduction in bus use outside of London and an increase in surface rail use throughout England. Trends in public transport use among the population of England are presented in Figure 1-1 and Figure 1-2.

Figure 1-1: Journeys per person per year by England resident by selected public transport modes from NTS 2002-2017



Made using NTS data from Department for Transport [6, 18]

Figure 1-2: Miles travelled per person per year by England resident by selected public transport modes from NTS 2002-2017



Made using NTS data from Department for Transport [6, 18]

Trends in the use of public transport differ by geographical location. Bus use in London residents increased considerably from 163 journeys per person per year in 1993/94 to 285 journeys per person per year in 2008/09, it then appeared to plateau before falling to 255 journeys per year in 2016/17.[19] Between 1991/92 and 2016/17, bus use in England outside of London fell from 68 journeys per person per year to 47 and in Wales from 46 journeys per person per year to 32 [19], this followed a long period of decline in bus use through the 1970s and 1980s.[19, 20] In recent years, the largest falls in bus use have been in regions with higher pre-existing levels of bus use, for example, local bus use in the North East of England fell from 81 journeys per person per year in 2004/05 to 67 journeys by 2016/17.[21] While the East of England had much lower levels in 2004/05 with 30 journeys per person per year but has maintained this level, with 31 journeys in 2016/17.[21]

Higher bus use in London compared with other areas of England is likely to be due to better availability of buses and shorter journey times in urban areas [22] and partially due to differences in the way London bus services are regulated.[23] In England outside of London, miles covered by buses have declined since 2010, this is the case for metropolitan areas and non-metropolitan areas.[24] Bus routes can be either supported by local authorities or run on a commercial basis, albeit with some subsidies from central government, which are discussed in greater detail in Section 2.1. Since 2010, local authority supported bus routes have fallen from 24% of the total to 17% [24, 25], which comes amidst a 25% fall in spending on supported buses in England from £299.6m in 2010/11 to £225.7m in 2015/16.[23] In Wales between 2010/11 and 2016/17, commercial bus route mileage has remained stable while local authority supported mileage fell by more than 50%.[24]

Train use in England increased substantially between 1995/97 and 2016, from 12 to 21 journeys per person per year.[6] Regional comparisons of train use can be problematic where journeys span multiple regions, with journeys often assigned to the travellers region of residence. This is more common with train than other public transport modes as train journeys are on average longer than

those of other modes.[26] That said, train journeys by London residents have increased from 37 per person per year in 2002/03 to 57 in 2016/17.[14] Other regions have also seen large growth in train use in this period, for example, the East of England saw an increase from 16 to 23 journeys per person per year.[14] Although no region has seen a decrease, the East Midlands, West Midland, South West and North East have seen no increase in train use.[14]

The London Travel Demand Survey of 8,000 Greater London residents showed that London Underground trip rates increased between 2005/06 and 2016/17, e.g., weekday rates increased by 20%.[27] However, a small decrease was seen between 2015/16 and 2016/17, which is consistent with other data from 2017/18 suggesting a dip in London Underground usage.[27, 28] The combined journey rate for all the other eight light-rail networks in England and Wales increased from 10 to 16 between 2004/05 and 2017/18.[29] Light-rail systems with the greatest increases were those which had expanded in this time period, for example, in Nottingham and Manchester.[30] The London Underground carried 1,395 million journeys in 2017/18 while the other eight English light-rail networks combined carried 267 million, which, if restricted to the six networks outside of London was 119 million.[9, 28]

1.2 Public transport globally

Global changes in patterns of travel are largely driven by similar trends, however, the impacts of these trends differ in different parts of the world. Increased urbanisation is one contributor to this: in 2016 there were 31 cities with a population of 10 million people or more, and by 2030 that is projected to increase to 41, with the 10 new megacities expected to be in developing countries.[31] Other global trends include the growth of technology in transport, this includes ride-hailing apps such as *Uber*, which in 5 years grew from a start-up to being established in 250 cities worldwide.[32] Technology which facilitates sharing, as opposed to owning, in transport and other sectors is

estimated to grow from revenues of $15billion in 2015 to $335billion in 2025.[32] Measuring the global impact of these trends on travel patterns can be problematic as data sources are often not comparable cross-nationally. Where this is the case, international surveys are useful to allow comparison, however, these often lack the detail which local surveys provide.

The use of public transport in the USA has increased in recent years, from 1.9% of journeys in 2009 to 2.5% in to 2017.[33] This increase came predominantly from public transport commuting, which increased from 3.7% to 5.5% of commutes in the same period. Travel in the USA differed across ethnic groups, for example, 93% of White Americans travelled to work by car compared with 87% of Hispanic Americans and 82% of African Americans.[34] Travelling to work by public transport was reported by 2% of White Americans, 6% of Hispanics and African Americans, with similar disparities seen with non-work travel.[34, 35] There was an approximately 11% reduction in total journeys between 2009 and 2017, with declines predominantly among journeys for shopping and for family errands, with little decrease seen in commuting.[33]

An analysis of European travel surveys compared modal share by distance and found that Latvia and Switzerland had the greatest proportion of travel by public transport, with 28.2% and 20.5% respectively, although the report gives little explanation of these results.[36] Other international comparisons suggest that Japan, Russia, India and China have the highest levels of rail use, with Australia, USA, Saudi Arabia and Mexico having the lowest levels.[37] Car ownership in these same countries were also compared, with Canada, Australia, Japan and the USA having the highest levels and China, India and Indonesia having the lowest, although China saw a six-fold increase in car ownership between 2005 and 2015.[37]

Many low- and middle-income counties lack the detailed travel data to allow comparisons with that from England. However, data is available for public transport systems in some cities, for example,

data about bus rapid transport (BRT) systems in several middle-income counties, in addition to high-income countries. BRT is a heterogeneous term to describe a public transport system using buses, which are usually segregated from regular road traffic for at least some of their route. Proponents argue that is has many of the benefits of rail transport but with greater flexibility, lower costs and shorter construction times.[38] Although the earliest examples of BRT systems opened in the 1970s, a review of 40 BRT systems in 2006 found that 27 of them were opened on or after 2000.[39] Examples of BRT systems are those of Curitiba, Brazil, which was built in 1974 and is therefore the oldest in the world; it is 10.1kilometres (km) in length with daily two-way ridership of 156,200 per day.[40] The system in Bogotá, Colombia, which at 84km in length is the largest in the world and has two-way daily ridership of 1.3 million people.[38, 40] Other cities with a BRT system include Lagos, Nigeria, which is 22 km in length and has daily ridership of 195,500 and Adelaide, Australia with is 3km and carries 30,000 passengers per day.[40]

1.3 Inequalities in public transport use

In addition to geographical differences, public transport use varies across the population, including by age, sex, ethnicity and socio-economic position. Official statistics calculated using NTS data for England show that total travel increases with age, from 806 journeys per person per year in 17-20 year olds to a peak of 1,139 in those aged 40-49, it then gradually reduces before falling sharply in those aged 70+ to 793 journeys per person per year.[41] Total distance travelled follows a similar pattern but peaks slightly later, among those aged 50-59.[42] Age trends in car use follow the same pattern as that for total travel, with a peak in those aged 40-49 and aged 50-59 for journeys and distance respectively, with gradually lower use in those aged younger and older.[41] Age trends in journeys travelled by bus and distance travelled by bus are similar, with bus travel most common among younger people, for example, those aged 17-20 report 107 journeys per person per year, falling to 38 in those aged 50-59, however, usage then rises to 67 journeys per person per year in

those aged 70+.[41, 42] Train use peaks at 62 journeys per person per year in those aged 21-29 before falling to 30 in those aged 50-59 and lower still in those older, with similar trends seen in distance travelled by train.[41, 42] DfT analyses suggests the peak in train use in this age group might be due to commuting.[43] Light-rail use (excluding London Underground) was greatest among those aged 21-29 in terms of both journey stages and distance, with diminishing use with increasing age.[44]

In 2017, women in England made more journeys than men [18, 41], although men travelled greater distances.[18] Men travelled more by train than women, while women travelled more by bus than men, in terms of journeys and distance.[18, 41, 42] Gender differences in trip purpose were also seen, with women making more journeys taking children to school and to shop and fewer commuting journeys than men.[45] Use of other public transport modes, which includes light-rail, ferries and domestic flights combined, were comparable between women and men.[41]

There is evidence that when compared with White people, those of minority ethnicity in England travel less [22, 46] but use public transport more.[47, 48] Analyses using NTS data from 2011 to 2015 found that Black residents of England reported 31% of journeys by public transport and 24% by bus, compared with 16% and 10% in Asian and 8% and 5% in White residents.[49] In addition to differences in the travel modes used, levels of total travel, of any mode, also varied between ethnic groups, with White people making an average of 955 journeys per person per year, while in Black and Asian people this was 779 and 775 respectively.[49] Data from 2011 showed that Black people were more likely to travel by bus than other groups and White people were more likely to travel by car, whilst rail transport had a more complex picture.[48] This might be explained by the higher proportion of Black people that live in inner London, where public transport is better and driving and parking are more difficult, whilst there are higher proportions of White and Asian people living in outer London.[50] Differences in access to private transport might also contribute to differing

patterns of public transport use, adults of minority ethnicity in England are more likely to live in a household without access to a car.[51] For example, in 2017 17% of White adults lived in households without a car, compared with 24% of Asian adults and 44% of Black adults.[51] While some of these differences might be driven by socio-economic factors, cultural factors may also play a role.[22]

NTS data from 2005 to 2015 in England showed that those with lower incomes were more likely to use the bus, with a gradient of decreasing use with increasing income quintiles, a similar pattern was seen for the number of journeys and the distance travelled by bus.[43] The opposite gradient was seen with train use, which increased as income increased.[43] The number of journeys and the distance travelled by train had less clear trends, with those in the middle and highest earning quintiles doing more journeys and the second lowest and highest earning quintile travelling a greater distance.[43] Light-rail use (excluding London Underground) was generally higher among those in higher income quintiles, in terms of journey stages and distance, although there is a suggestion that the lowest income quintile had higher use than some of the intermediate quintiles.[44] London Underground use was greater in those with higher incomes, in terms of both journeys and distance.[52]

Chapter 2 - Public Transport Policy in England

Investment in public transport has the potential to address numerous societal goals, including economic and health goals.[53, 54] For those without access to a car, public transport facilitates access to services and enables participation in society.[54] For this reason, public transport is specifically mentioned in the Sustainable Development Goals (SDGs), with goal 11 to make cities and human settlements inclusive, safe, resilient and sustainable.[55] Goal 11.2 states:

> *"By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons"[55]*

Public transport is subsequently a major beneficiary of government spending, with total transport spending in England in 2017/18 over £23 billion, of which £13.7 billion was rail transport spending, local public transport spending was £1.9 billion and roads received £4.3 billion.[56] The proportion of transport spending on rail has increased in recent years due to large capital expenditure on new rail infrastructure [56, 57], which is indicative of increasing recognition by local and national governments of the importance of public transport systems.

2.1 UK Bus policy context

In 1986 bus services in England outside of London were deregulated, which resulted in the system of governance which remains in place today. For the 50 years prior to 1986, almost all buses were publically owned either through local Passenger Transport Authorities or as one of 52 subsidiaries of the state owned National Bus Company, with services planned by local authorities.[20, 58]

Deregulation was partly driven by large declines in bus use, which occurred as access to cars and car use expanded across the UK [15, 59]; reduced bus use led to a shortfalls in passenger fare revenues and an increasing financial burden on local authorities, who were forced to subsidise services.[60] Deregulation allowed new providers to enter the market and compete for passengers, with the government's stated aim of allowing competition and the free market to drive up standards and reduce costs.[20, 60] In addition to deregulation, most public bus provision, including the 52 subsidiaries of the National Bus Company, was privatised in order to improve the management of bus services.[20] This deregulation of bus services forms the basis for current bus provision. By 2006, the 52 former public bus companies were all operated by seven companies and by 2011 69% of bus provision was by five private operators: Stagecoach; FirstGroup; Arriva; National Express; and Go-Ahead.[60, 61]

The current post de-regulation administrative framework allows for any company to set up and provide services they deem to be commercially viable, subject to certain criteria, for example, ensuring the safety of passengers.[60] Eligible bus companies then receive subsidies, which comprise about 45% of bus operators' revenue.[62] Subsidies come from three broad sources: the Bus Service Operators Grant (BSOG), direct service procurement by local authorities and remuneration for concessionary travel. The BSOG is a rebate of 70-80% of the fuel duty paid on fuel used to run eligible services.[62] Reform of BSOG is currently under consideration with criticisms that subsidising profitable bus routes is not the best use of government money, in addition, linking the rebate to fuel use is counter to the climate change agenda and disincentivises a shift away from fuels that are subject to fuel duty, which are predominantly fossil fuel based.[62, 63] Local authorities directly procure services which are deemed socially necessary, for example, services to isolated areas with no access to a commercially viable route.[60, 62] These contracts are awarded subject to open tender, with local authorities stipulating service regularity and fares.[60, 62] Finally, bus operators are reimbursed for providing services to those with concessions, for example, the free older person's

bus pass, the annual cost for these concession in 2016/17 was £1.17bn.[62, 64] Reimbursement follows the general principle of making the bus service providers no better or worse off as a result of concessionary fares, this is calculated to compensate operators for revenue forgone and for any net additional costs.[65]

London bus services were excluded from the deregulation in the 1980s due to pre-existing differences in local authority oversight.[58] Although the London municipal bus companies were sold in 1994-1995, their services continue to be regulated and planned by government through franchising, where the transport authority (now Transport for London) invites tenders from private firms to run certain planned routes under a set of conditions, such as environmental standards.[60] Routes are usually grouped together in tranches allowing more lucrative routes to be combined with those which are less lucrative, approximately 20% of London bus routes go out to tender each year.[58] This means that London buses are still privately operated, however, companies compete for the market rather than operate under market competition.

The success or otherwise of bus deregulation is contested. Critics point out that fares have risen since deregulation and that this has been greater in areas of England outside London, where buses were deregulated.[66] During this time, bus journeys in London have doubled while decreasing substantially in the rest of England.[58] However, a direct comparison of subsidies paid for bus services before and after deregulation is not possible due to incomparable data and although London was exempted from deregulation, it is a poor control for examining the impact of deregulation due to differences with other areas of England.[58] London has a larger population at a greater density than is seen in other areas of the England [67, 68], which might explain some of the differences in bus use between London and other areas of England.[69, 70] London also has a dense urban rail network that may facilitate greater bus use than in other areas.[71]

Attempts by subsequent governments to reform bus services indicate that they felt the post-1986 deregulated system could be improved upon. The Labour governments from 1997 to 2010 twice attempted to reform bus provision in 2000 and then again in 2008.[58] The reforms made provision for Quality Partnership Schemes (QPS) and Quality Contract Scheme (QCS), although neither were ever implemented in practice by any local authority. The QPS was a formal agreement with bus providers to improve facilities e.g. provide bus lanes, in exchange for particular standards, such as new greener vehicles.[58] QCSs allowed local authorities to take greater control of local bus services under certain conditions. The reasons these provisions were never implemented differed from authority to authority but the restrictive conditions required by the legislation may have led local authorities to fear legal action from the bus companies.[58]

The 2017 Bus Services Act enabled local transport authorities in England to have franchising powers, similar to those in London.[60] These powers were initially made available only to Mayoral Combined Authorities, these are areas that have secured devolution deals from Westminster since 2014.[60] When the Act came into law, the eligible authorities were: Greater Manchester, Liverpool City Region, West Midlands, West of England, Cornwall, North East, Tees Valley, Sheffield City Region, Greater Lincolnshire, East Anglia.[72] Other local transport authorities can apply for consent from the Secretary of State for Transport to initiate franchising, subject to conditions.[60] Short of the franchising powers, and available to all local transport authorities, the 2017 Act also contains another attempt to foster partnerships between bus operators and local authorities in the form of Advance Quality Partnerships (AQP). AQPs allow greater commitment from each side, e.g. bus operators can undertake certain ticket and price commitments, while local authorities can implement parking restrictions and traffic management policies.[60] Despite intent from some Metro-mayors, no changes have been implemented in the 18 month since the Act took effect in April 2017, with authorities still formulating their proposals.[60, 73]

2.2 English National Concessionary Travel Scheme (The Free Bus Pass)

The free bus pass for older people in England was introduced in 2006 by the Westminster government, it provided free off-peak local bus travel for England residents aged 60 years and over.[65] Prior to this, older people were entitled to half price bus travel. The policy was then expanded in 2008 to include local buses throughout England between 9.30am and 11pm on weekdays and all day at weekends.[65] The age of eligibility is linked to female state pension age and, as such, has been gradually increasing since May 2010 and is set to reach 66 in 2020.[74] The devolved administrations of Scotland, Wales and Northern Ireland each have separate provision of free bus travel for older residents, these vary slightly from the English policy having all maintained 60 as the age of eligibility.[75-77] Some local authorities in England offer more generous benefits than the statutory national minimum, e.g. London residents receive a Freedom Pass entitling them to free travel on almost all public transport in London, including the London Underground.[65] Following the introduction of the free bus pass in England, uptake increased from around 54% to approximately 76% of those eligible.[78] In addition to older people, a different scheme provides free bus travel to eligible disabled people, for example, those who are blind and those with difficulty walking.[65] In 2018, the government committed to retaining free bus travel for older and disabled people in England, removing the need for future governments to regularly renew the policy.[79]

There is evidence that holding a free bus pass is associated with better health outcomes. Analysis of 16,911 participants from a nationally representative survey of travel patterns found that bus pass holders were more likely to use active forms of travel and walk more frequently than non-holders.[80] A cross-sectional analysis of data from older adults in England found that public transport users and those eligible for a free older person's bus pass had a reduced odds of being obese.[81] Further analysis of this data demonstrated that female bus pass holders had faster gait

speed and reduced body mass index (BMI, weight(kg)/height $(m)^2$) and waist circumference when compared with non-pass holders, potentially through higher levels of physical activity.[82]

The bus pass was not introduced to improve the health of recipients, it was intended to guarantee financial security into older age and to alleviate social exclusion.[83, 84] Evidence suggests that the bus pass has been effective in reducing depressive symptoms, however, the mechanism is unclear as the researchers were unable to detect an effect on a measure of social isolation.[85] Free public transport has been shown to facilitate social activities, access to amenities and to prevent exclusion.[86] Other authors have concluded that the free bus pass improves quality of life and does this to a greater extent in those 'in high social need'.[87] However, it is likely that those who are most vulnerable to social isolation have higher likelihood of non-cost barriers to bus use, such as poor mobility or ill-health, and therefore may not benefit from this entitlement.[87]

The annual cost of providing bus passes to eligible older and disabled people in England was estimated at £1.17bn in 2014/15 [64], this cost has led to the provision of such universal benefits being called into question.[88, 89] Restricting the bus pass with financial means testing has been suggested as a way to reduce the cost of this policy, while ensuring that those in greatest need continue to be supported.[65] However, others claim that means testing would dramatically reduce uptake and fail to target those in greatest need, while significantly increasing the administrative burden.[90-92] Interviews and focus groups with bus pass holders have indicated that the wellbeing benefits of the free bus pass might be contingent on it being free. Free bus pass holders perceived it as a deserved entitlement as result of their having spent a lifetime paying taxes.[86] They therefore perceived their free bus pass as the conferment of a sense of belonging and of self-worth. If the bus pass is seen as a response to vulnerability, which is possible if it was restricted by financial means, these benefits may be foregone and bus pass use could become stigmatised.[86]

Bus use is more common among the socio-economically disadvantaged, with 75 journeys per person per year by bus in the lowest income quintile, compared with 40 journeys per person per year in the highest earning quintile.[52] Researchers have used NTS data from 2005-2008 to examine whether the benefits of the free bus pass differ across socio-economic groups, with one study finding similar associations between the free bus pass and active travel in those who owned their own home and those living in rented accommodation.[80] This was despite higher bus pass uptake among those living in rented accommodation than was seen in home owners.[80] Another study found that wealthy participants and those in paid employment had lower bus pass uptake when compared with less wealthy and retired participants.[82] The impact of these differences on bus use is unknown, as participants in this survey who did not have a bus pass were not asked about bus use.[82] Although there are known associations between socio-economic position and ethnicity and those of some minority ethnicities have greater bus use than other ethnic groups, ethnic differences in the associations of the free bus pass have not been examined, which represents a gap in knowledge.[48, 93]

2.3 Rail policy context

Current train regulation in England is the result of the privatisation of British Rail in 1994, when passenger rail services were organised into 26 subunits which were then separately offered for sale as franchises.[8] Although there have been changes since the initial privatisation, the system is broadly similar, private companies compete on the basis of price and service improvements to run a franchise for a specified length of time with a predefined timetable.[94] Service improvement might include new rolling stock, better reliability and increased frequency of service.[94] Franchises operate with differing profitability, most receive a government subsidy but some return a share of profits to government.[94] Successful franchisees are required to pay a fee to access the track and station infrastructure from Network Rail, a public body which owns and manages the rail network in

Great Britain.[8, 94] Although franchisees are responsible for the majority of train services in England, some services operate under different terms, such as the London Overground.[94]

Between 2004 and 2015 average rail fares grew by 17.9% over and above inflation, despite which rail use continued to grow.[6, 95] However, it is worth noting these rises were predominantly prior to 2011, from 2011/12 to 2016/17, ticket revenue increased from £8.0bn to £9.5bn, but this was due to increased passenger numbers with the cost of individual journeys unchanged, after adjustment for inflation.[96, 97] In this time period the UK government's net contribution to rail has reduced from £4.3bn to £3.4bn.[97, 98]

The current Conservative government has expressed an intention to change the way that passenger rail services operate in England. Secretary of State for Transport, Chris Grayling, has called for a more vertically integrated operation, with track and trains being operated by a partnership of public and private entities.[8] Details of how these arrangements will work are not yet available and are likely to differ across the network, however, following the collapse of the east coast mainline franchise for the third time in 12 years, other have called for more radical reform of the network.[94] This varies from taking the franchises back into public ownership, favoured by The Labour Party in their 2017 General Election manifesto, to the abolition of franchises and a transition to greater competition on the track.[8, 99, 100]

Devolution of train control has been another area of recent policy interest. Prior to 2016, under the London mayoralty of Boris Johnson, control of some train services were transferred from the DfT to Transport for London, to form part of the London Overground network. However, a change in Mayor of London, Chancellor of the Exchequer and Secretary of State for Transport in 2016 appears to have put an end to future devolution of train control to London.[101, 102] It has also been suggested that greater devolution of train control should be extended to other parts of England, including by a

report for the DfT.[103, 104] However, the DfT has brought forward no concrete proposal as of the end of 2018.

In addition to changes to the existing train network, there are ongoing efforts to expand the system. This includes proposals to re-open previously abandoned routes, e.g. Newcastle upon Tyne to Ashington, and new large-scale infrastructure as part of High Speed 2-Phase 1 and Crossrail (The Elizabeth Line) which are already approved and in differing stages of construction. Proposed future projects also include High Speed North, High Speed 2-Phase 2 and Crossrail 2.[105-108] The reorganisation of the existing train network along with new projects, approved and pending, mean that decision makers both locally and nationally face important decisions that will affect public transport provision in England for years to come.

2.4 Technological disruption of the transport sector

Alongside changes to existing public transport systems, disruptive technological developments have the potential to radically change transport behaviours in England and globally and to impact on any associations between transport and health. The impact of technology on health has been seen with the emergence of app based ride-hailing platforms such as *Uber* and *Lyft*,[109] which have been associated with large increases in the number of private hire vehicles. For example, between 2015 and 2017 the number of registered private hire vehicles in London increased by 50% and outside of London increased by 16%.[110] In addition, there has been a blurring of the line between app based ride-hailing services and public transport with the development of demand responsive buses.[111] These have been offered by apps such as *Citymapper* in addition to traditional bus companies.[112, 113] They are usually small buses which are shared with other users and offer street corner to street corner transport.[111-113] This type of demand responsive bus has been proposed for areas on the fringes of cities where current bus use is not as frequent as in inner city areas.[111]

Autonomous vehicles also have substantial potential to disrupt transport policy. Modern vehicles incorporate several autonomous features, for example, parking assistance, whereas fully autonomous vehicles, or self-driving cars, are currently under development but are not yet approved for the public highway.[114] Among the proposed benefits of autonomous vehicles is a reduction in accidents, with human error a causal factor in an estimated 75%-95% of road traffic collisions.[115] Improved mobility among those unable to drive, including vulnerable groups such as the elderly and the disabled, might contribute to improved quality of life for these individuals.[114] However, although this might meet individual's utilitarian travel needs, it might not fulfil their desire for autonomy.[116] Efficiency benefits from autonomous vehicles result from them communicating directly with each other and traffic signals, and could lead to reduced journey times.[117] However, the magnitude these benefits are disputed, especially where autonomous vehicles interact with conventional vehicles.[114, 117] Some estimates suggest that journey times might increase where autonomous vehicles make up less than 25% of the vehicle fleet.[117] Many of the predicted benefits are dependent on a transition to 100% autonomous vehicles, however, it is far from clear that there is an appetite for people to entirely relinquish their ability to drive.

Linked to autonomous vehicles is the potential for a transition away from a car-ownership model to a transport-on-demand model, where a vehicle is summoned only when required. With cars currently spending an estimated 95% of their time parked, a transition away from car ownership could potentially yield large amounts of space in the built environment which is currently used for car storage.[118] Additional road space could be used for designated public transport lanes or alternatively be adapted to create more walkable neighbourhoods, encouraging people to travel on foot and bike. A transport-on-demand model, if combined with cost-per-mile pricing, could mean individuals paying a higher marginal price per journey.[119] Cost per mile pricing is where the price of driving more closely linked with the distance travelled, for example, with the use of Global Positioning System (GPS) tracking. This compares with the current situation where the large sunk

cost associated with car purchase is combined with a small marginal cost of each journey, which is likely to encourage car use.[119] The higher marginal cost associated with cost-per-mile pricing could disincentivise car use for short journeys, encouraging active travel.[119] This would be dependent of the pricing model of the mobility service provider and possibly a reformed tax system for transport.

Technological disruption in non-transport sectors could also have an effect on transport. Home entertainment streaming services, such as *Netflix*, might reduce the demand for travel to access entertainment. In addition, apps which allow people easy access to food delivery from restaurants and takeaways, such as *Deliveroo*, might reduce travel demand to eat out, while the continued growth in online retail could lead to reduced travel for shopping. Recent figures from London show a 16% reduction in leisure trips between 2013 and 2016 while shopping trips have been declining since 2007, dropping by 35% by 2016.[53] In addition, London has seen a reduction in travel for work purposes, possibly as a result of working from home on at least some days of the week.[53, 120]

The impacts of these technological changes on transport are uncertain therefore their potential health implications are not known. Health effects might derive from increased use of ride-hailing apps such as *Uber*, for example, if door-to-door travel displaces journeys using more active modes, the resultant reduction in physical activity could lead to an increased disease burden. However, a transition from a car-owner model to a greater use of transport-on-demand could disincentivise short car journeys and potentially free up large areas of urban space, currently occupied by parked cars. If this space were re-purposed to create shared public space, this might encourage greater active travel and other beneficial behaviours. The potential implications of reduced travel for shopping, eating out and entertainment purposes would appear to lead to reduced active travel to access these services but much would depend on how the time saved is used. This is in addition to

the potential dietary impacts of food delivery apps, which might plausibly increase consumption of unhealthy foods.

Chapter 3 - Public Transport and Health

Public transport use affects health through multiple potential mechanisms, including physical activity accumulated in the course of public transport journeys. This thesis will investigate the potential physical activity benefits of public transport use, including the walking and cycling to access public transport and several important physical activity related outcomes, e.g. adiposity, CVD, cancer and mortality. Other potential mechanisms include: 1) Exposure to atmospheric pollutants, which is greater for car users than users of other modes (pollutants here include particulate matter of size less than 2.5µm and ultrafine particles of size less than 0.1µm).[121] In addition, reduced congestion as a result of greater public transport use could lead to improved air quality.[122-126] 2) Reduced CO_2 and other greenhouse gas emissions associated with switching from private motor vehicles to public transport, with climate change estimated to cause 250,000 deaths per year between 2030 and 2050.[125, 127-129] 3) Road traffic collisions, which are a significant global cause of death, with over 1.3 million deaths in 2015.[130] for example, a study comparing modes in the USA showed that fatalities per billion miles 2000-2009 were 7.28 for drivers or passengers of a car or light truck.[131] This compared with 0.43 fatalities per billion passenger miles on a train, 0.24 on a light-rail system and 0.11 as a passenger on a bus.[131] 4) There is some evidence that public transport use might have benefits for wellbeing more widely [132-135], while free bus travel has been associated with a range of outcomes, including reduced loneliness.[85, 86, 136, 137]

3.1 Physical activity

Physical activity is defined as bodily movement which requires energy expenditure.[138] It is quantified using metabolic equivalent tasks (METS), a weight adjusted measure of energy expenditure, with 1 MET being equivalent to the resting metabolic rate for a typical individual (4.18kJ/kg/hr).[139] Moderate activity is defined as 3-5.9 METs, i.e. 3-5.9 times resting energy

expenditure, with vigorous activity defined as ≥6 METs.[139] UK and global guidelines for physical activity in adults recommend 150 minutes of moderate intensity physical activity or 75 minutes of vigorous physical activity per week.[140, 141] Although, in an attempt to broaden recommendations to encourage activity across the day, rather than in a small proportion of it, Canada has created the first 24-hour movement guidelines for children, which encourages children to sweat, step, sleep and sit for sufficient amounts of time each day.[142, 143]

The 2016 Health Survey for England found that 66% of men and 58% of women met physical activity recommendations, meaning that more than a third of the population were insufficiently physically active.[144] Global estimates in 2016 put the prevalence of physical inactivity at 28% (25%-32%), which would place 1.4 billion people at risk of physical inactivity sequelae.[145] Total physical activity is an overall measure made up of a number of constituent domains which is can be conceptualised using the SLOTH model: S characterises sleep, L time spent in leisure, O time in paid work (or occupation), T time in transportation and H time in home based work (unpaid work).[146] Inconsistent physical activity measurement tools over time make definitive conclusions about physical activity trends difficult.[147] However, levels of occupational and transport related physical activity appear to be in decline globally.[148-150] Although there is some evidence that leisure-time physical activity increasing and this might contribute to more people meeting physical activity guidelines, there are no good data from England which is consistent over time, therefore trends in overall total physical activity are uncertain.[147, 148] Data from a range of high-income countries show that there has been a decline in those meeting physical activity guidelines from 69.1% in 2001 to 63.2% in 2016.[145] There is also evidence that despite leisure physical activity increases, because the physically active time might be expected to constitute only 5% of a person's waking time, it cannot compensate for the reduced energy expenditure in those domains which make up the remaining 95% of daily activities.[147, 150, 151]

Physical inactivity has known associations with several important health outcomes, including all-cause mortality, CVD and cancer, in addition to other important CVD risk factors, such as obesity and hypertension.[152] The dose-response relationship for physical activity and several health outcomes demonstrates that the greatest benefits are seen among those moving from little or no physical activity to doing some.[153, 154]

Physical inactivity is an important risk factor for cardio-metabolic health. There are established associations between physical activity and CVD mortality, ischaemic heart disease, stroke, obesity, type 2 diabetes and hypertension.[152, 155] CVD, stroke and type 2 diabetes are among the outcomes which demonstrate a non-linear dose response relationship with physical activity.[152, 154] These relationships confer the greatest benefits on the most inactive as they moved from little or no physical activity to some. For example, the risk of type 2 diabetes reduced by 26% with the accumulation of 11.25MET-hrs per week, which equates to meeting the global physical activity recommendation of 150 minutes of moderate physical activity per week.[154] Whereas the accumulation of double that amount of physical activity was associated with a total risk reduction of 36%, further physical activity was associated additional, but diminishing, benefits.[152, 154] The evidence base for an association between physical activity and obesity is equivocal, this might be due to the relatively high levels of physical activity required to cause weight loss in the absence of dietary changes.[156] Alternative explanations include reverse causality, with heavier individuals being less physically active than lighter individuals, and measurement error preventing accurate measures of physical activity exposure.[157]

Mortality from CVD, stroke and coronary heart disease (CHD) in the UK all reduced by approximately 70% between 1980 and 2013.[158] This occurred alongside substantial reductions in smoking and hypertension, in addition to changes in the management of CVD, for example, a large increase in prescriptions for statins and use of percutaneous coronary interventions.[158-160] However, there

remains a considerable burden from CVD, with prevalence having increased slightly in this period.[158] In contrast to smoking and hypertension, other cardio-metabolic risk factors have seen substantial increases in recent years. Obesity (BMI > 30kg/m^2) prevalence in England increased from 14.9% to 25.6% between 1993 and 2014.[161] UK prevalence of diagnosed type 2 diabetes doubled between 2000 and 2013, from 2.4% to 5.3%.[162] Estimates suggest that the costs attributable to diabetes in 2010/11 constituted 10% of NHS expenditure, and that this could rise to 17% (over £22bn) by 2035/36.[163]

Evidence reviews, including the Global Burden of Disease Study, have found that physical activity is also associated with some cancers, with the strongest associations seen with breast cancer and colon cancer, weaker evidence was seen for endometrial and prostate cancers.[152, 164] Some evidence indicated that the dose-response relationship between physical activity and colon cancer was non-linear with greater benefits seen with increased physical activity among the most inactive.[152] This was less clear than for cardiovascular outcomes and for breast cancer was less certain still.[152]

Breast and colon cancer were two of the top three most common cancer sites in England in 2016.[165] In the 10 years from 2006 to 2016, the age-standardised incidence of breast cancer increased slightly from 162 per 100,000 females to 168.[166] Between 2000/01 and 2010/11 one- and five-year breast cancer survival rates improved, for example, one-year survival was 93% for those diagnosed in 2000/01, compared with 96% for those diagnosed in 2010/11.[166] Between 2006 and 2016, bowel cancer (which includes cancers of the colon, rectum and rectosigmoid junction) incidence was relatively stable, it decreased from 91 to 85 cases per 100,000 males and from 58 to 57 cases per 100,000 females.[166] Bowel cancer survival over one- and five-years have both improved in recent years, for example, men diagnosed in 2000/01 had one-year survival of 71% which improved to 77% in 2010/11.[166]

As a risk factor for some of the largest causes of mortality, it is unsurprising that physical activity is associated with all-cause mortality.[130] Estimates attribute up to 9% of global mortality, or between 3.2 and 5.3 million deaths annually, to physical inactivity.[167, 168] Again, the dose-response relationship appears to be non-linear with greatest benefits seen among the inactive as they move from little or no physical activity to some.[152, 153, 169] Mortality rates in England have declined for males and females between 2001 and 2016, however, since 2011 the rate of decline appears to have slowed with some evidence for a plateau.[170]

3.2 Active Travel

Active travel is that which involves physical activity, this includes walking and cycling but also the use of scooters and roller-skates. Research into the benefits of active travel has focused on walking and cycling, often aggregated into a single measure for research purposes.[132, 171-173] Walking can be greater or less than the 3.5MET threshold for moderate physical activity.[139] This means that walking can be light or moderate activity, depending on the pace and the physical condition of the walker.[139] Cycling would usually be considered moderate activity but similar caveats apply.[139] However, research has also looked specifically at the effect of walking and cycling measured by volume (distance or time) irrespective of intensity.

A systematic review and meta-analyses of walking and cycling for any purpose estimated the benefits associated with accumulating 11.25 MET-hours per week of walking or cycling, equivalent to meeting global physical activity guideline of 150 minutes of MVPA.[174] This study found that walking and cycling were associated with an 11% and 10% reduction in risk of all-cause mortality respectively, although it is uncertain whether those who walked or cycled actually accumulated the assumed 11.25MET-hours per week.[174] Another meta-analysis found that those reporting high walking levels had a 31% reduced risk of CVD compared with those in reporting low levels of walking

[175], with other evidence suggesting cycling is associated with reduced adiposity, diabetes and elevated high-density lipoprotein cholesterol.[176, 177] Meta-analyses of commuting have shown that walk commuting was associated with risk reductions of 27% for CVD incidence but no association was seen with incident cancer, cancer mortality, CVD mortality or all-cause mortality [178], with some evidence for an association with lower systolic blood pressure.[177] While cycle commuting was associated with risk reductions of 46% for CVD incidence, 25% for cancer mortality and 24% for all-cause mortality, no associations were seen with CVD mortality or breast cancer incidence.[178] Other research has found an association between cycle commuting and reduced risk of cancer incidence and elevated adiposity.[172, 179, 180]

Meta-analyses of a combined measure of walk and cycle commutes have also been conducted, including studies which examined walking and cycling separately, in addition to those studies which examined only a combined measure. Walk/cycle commuting was associated with a 9% reduction in CVD incidence risk and an 8% reduction in all-cause mortality risk with no association seen with breast cancer incidence, cancer mortality and CVD morality.[178] Another meta-analysis by Hamer et al. examined commute mode, finding that a combined measure of walking and cycling was associated with an 11% reduced risk of CVD (fatal and non-fatal), with these finding stronger among women than men.[171] It is unclear whether these reviews pooled walking and cycling because they believed that the health association of walking and cycling were equivalent or due to reasons of pragmatism. Physical activity more generally has well established associations with improved health, including a reduced risk of all-cause mortality, CVD, colon cancer, breast cancer and type 2 diabetes, in addition to other conditions, such as osteoporosis.[152] Other modes, including public transport, have often been grouped together in research of this kind, which has prevented the specific effects of public transport on health outcomes such as CVD, cancer and mortality from being established.[181, 182] Given the importance of public transport of a transport mode, the lack of

research into the association of its use and these outcomes represents a substantial gap in knowledge.

3.3 Physical activity in public transport use

In order to access public transport, it is usual to walk or cycle in order to get from the journey's start to the public transport stop. This is usually repeated at the far end in order to reach the journey's final destination and sometimes to transfer between different public transport modes, for this reason, some consider public transport to be an active travel mode.[183]

A 2012 review found that public transport use was associated with between 8 and 33 minutes per day of physical activity, however, most of the included studies used small and highly selective populations.[184] This range spans from a relatively small amount of physical activity to a substantial contribution to daily physical activity. The review included two studies of UK public transport users, one of which concluded that surface rail users walked an average of 0.9km per journey, which the authors converted to 10-12 minutes to allow comparison.[184, 185] The second UK study measured steps per day with an accelerometer in those aged 70+.[186] This study found that each additional public transport journey per week was associated with 412.7 more steps per day (converted to 8 minutes of walking per day).[184, 186]

Subsequent research, which used GPS in conjunction with objective accelerometer data, also found public transport to be associated with physical activity. These studies were generally small, with up to 540 participants and found between 4.2 and 14.6 minutes per day of physical activity in association with public transport use.[187-193] Among 234 participants in Paris, public transport use was associated with 10.2 (9.6- 10.9) minutes of moderate to vigorous physical activity (MVPA) per journey.[189] This was greater among train users and lower among bus and coach users.[189] A

study of 274 residents of Seattle, USA found that public transport users accumulated 14.6 (13.1, 16.1) minutes of transit related physical activity on the days they used transit.[192] Researchers using data from 540 commuters in South West England and Wales showed that public transport commuters accumulated 25.7 minutes per day of physical activity during the commute, compared with 7.3 minutes for car commuters and 34.3 minutes for walk commuters.[187] An evaluation of new light-rail infrastructure in Salt Lake City, USA found that new users of public transport saw an increase of 4.2 minutes (0.9, 7.4) of daily MVPA and that public transport users accumulated 11.9 minutes (8.5, 15.3) more total MVPA on days they used public transport compared with days they did not.[188, 191]

Recent meta-analyses have suggested that new public transport infrastructure was associated with an increase in transport related physical activity.[194-196] One meta-analysis took the intensity of physical activity into consideration and found that new light rail infrastructure was associated with an approximately 30 minutes per week an increase in transport-related light-to-moderate intensity physical activity (1.76MET hours/week (0.19, 3.32)).[195] Another meta-analysis found that transport physical activity increased by 6.7 minutes per week (-10.1, 23.5) following the construction of new light-rail infrastructure, however, this was accompanied by a reduction in total physical activity of 67.2 minutes per week (-91.2, 16.8).[194, 196] It is possible that increases in physical activity associated with public transport use were more than compensated for by reductions to other physical activity, this is potentially important for any expected health benefits. However, there were relatively few studies included in this meta-analysis and they had diverse findings so further research in necessary to explore potential substitution effects.

Although some of the evidence discussed above is from England, there is no large representative study which quantifies the physical activity carried out as part of public transport journeys among public transport users in England, which therefore represents a gap in knowledge on this subject.

There is also no comparison of the volume of physical activity associated with different public transport modes, or associated with individual and neighbourhood characteristics of users, such as socio-economic position.

Some research has found an association between public transport use and reduced adiposity. For example, a cross-sectional analysis of 7,534 UK commuters using the UK Household Longitudinal Study (UKHLS), a representative survey of UK households, found that public transport commuters had lower average objectively measured BMI and percentage body fat than those who commuted by car.[172] Another cross-sectional study, this one of 13,102 residents of New York, USA showed that higher bus stop density and subway stop density were associated with lower objectively measured BMI, after adjustment for individual and neighbourhood level characteristics.[197] However, a separate report from the same study concluded that these associations with BMI were only present among those with more education, higher income and those of non-Hispanic White ethnicity.[198] There is also evidence that switching to public transport use from other modes is associated with a reduction in BMI, an additional day per month of public transport use being associated with a change in BMI of -0.005 kg/m^2 (-0.012 to 0.002).[176]

3.4 Measuring physical activity

Traditional methods of measuring physical activity, including physical activity in transport, use questionnaires, for example, to ask participants how much walking they have done in the last year. The International Physical Activity Questionnaire (IPAQ) is a commonly used validated short questionnaire, which aims to quantify physical activity levels.[173, 199] It asks about walking and cycling, including that which takes place as part of a larger journey. However, it is not possible to disaggregate which walking and cycling is associated with which modes, for example, which is associated with public transport. Questionnaires of this sort are also subject to recall biases, to

reduce these biases travel diaries can be used, these ask participants to recorded travel as close as possible to when it occurred.[200] Travel diaries ask participants to record the details of all travel carried out for a set period for time, e.g. a week, this includes information about each journey, the distance travelled, the time taken and the mode used, including where more than one mode is used.[200-202] However, travel diaries have also been criticized for self-report bias and underreporting trips.[203, 204] They have been shown to underestimate walking journeys and the length of journeys when compared with objective measures.[203]

Objective measures of travel often involve a GPS device, which uses satellites to measure location and can track movements over time.[203] GPS is sometimes used alongside an accelerometer, which is a small electronic device worn on the participant's body, which records the volume, intensity, frequency and pattern of movements, along with time and date information.[205-207] Accelerometers are often used for the objective measurement of physical activity.[205] Although these methods overcome many of the limitations of more traditional methods, they are not without their own limitations. GPS devices suffer from a loss of signal when entering a tunnel or where high-rise buildings or tree canopy block the satellite signal.[201] Participants might forget to take a device with them or may have technological problems which lead to the loss of data, they may also fail to charge them sufficiently.[201, 204] However, many of these limitation are surmountable, for example, by using mobile phone masts to augment GPS signal.[201] Similarly, the use of postural monitors which judge position relative to gravity can overcome problems with traditional accelerometers, which would fail to register cycling as activity.[208, 209] Problems persist processing raw objectively measured physical activity data due to a lack of accepted thresholds for different intensities of physical activity, which is important because the thresholds selected can lead to large differences in the outcome.[210] Current estimates of objectively measured physical activity are also substantially different from equivalent self-reported estimates.[211, 212] For example, when the 2008 Health Survey for England measured with both methods, of those who met physical activity

recommendations based on self-reported data, only 10% of men and 8% of women also met the recommendations when measured using accelerometry.[211] It also means that comparing objectively measured physical activity with thresholds developed for use with self-reported physical activity may not be valid.

3.5 Inequalities in physical activity and cardio-metabolic outcomes

There are large variations in cardiovascular outcomes across the population, in the UK and globally.[213] This is partially attributable to gradients in several important CVD risk factors, such as physical activity, diet, smoking and obesity with variations seen between the sexes, across socio-economic groups and in different ethnicities.[213]

3.5.1 Age and sex

In England in 2015, 67% of men were overweight (BMI ≥ 25kg/m^2) compared with 58% of women.[214] Obesity (BMI ≥ 30kg/m^2) is very similar in men and women, both 26%, although it is only in recent years that men have reached the same levels as women, historically having had a lower prevalence.[214] Overweight and obesity is England increases with age peaking in men aged 45-74 (78%-79% in these age categories) and women aged 65-84 (70%-72%) before dropping slightly in older adults.[215] Although the association between adiposity and adverse health outcomes weakens with age, there remains an association between obesity and all-cause mortality.[216]

Increases in diabetes between 1994 and 2016 have been predominantly seen among older adults, for example, among those aged 25-34 diabetes remained between 1% and 2%, while in men aged 75+ this increased from 7.5% to 19.3% and in women from 5.2% to 17.2%.[217] CHD is responsible

for almost twice as many deaths in men as women, however, women appear to have worse outcomes than men when they present with CHD, possible explanations are a genetic predisposition to CVD and poorer CHD care for women.[218]

In the 2016 Health Survey for England, 66% of men and 58% of women met the physical activity recommendation.[144] Physical activity levels peak in those aged 25-34, both in terms of meeting the recommended levels and in doing any physical activity. Among those aged 35 and above, with increasing age there is a gradual reduction in the proportion meeting physical activity recommendations.[144, 215, 216] In addition to the associations of physical activity with health outcomes such as mortality and morbidity, which have been discussed above, older people also benefit from physical activity effects on functional ability and independence.[219] A systematic review found that older people reaching 150-180 minutes per week of moderate physical activity could see a 50% reduction in functional limitations and disability.[219] There is also some evidence that a relatively high level of physical activity in older people is associated with decreased risk of dementia and Alzheimer's disease.[219]

3.5.2 Ethnicity

Some minority ethnic groups in England have a higher prevalence of overweight and obesity than White people, e.g. Black men and Black and Asian women.[220] Diabetes and CVD risk is also higher among South Asian and Black groups when compared with White people.[221] A study in Scotland found that when compared with White residents, males of Pakistani and African ethnicity had an 18% and 39% increased risk of stroke respectively.[222]

Some disparities in these health outcomes may be due to differences in levels of physical activity.[223] In England women of all minority ethnicities and men of South Asian ethnicity are less

likely to be physical active, physical activity measures here included leisure-time exercise, domestic tasks and walking.[223, 224] Participation in sport, games or physical activity has also been shown to be lower in many minority ethnic groups, including Black African, Black Caribbean, Indian and Pakistani participants in the General Household Survey.[225] Although often less physically active, research using data from the UKHLS 2009/11 suggested that minority ethnic groups in England are more likely to use active forms of transport in their commute, including public transport and walking.[47] It may be that active travel is a particularly important contributor to overall physical activity in groups which do less leisure physical activity.[223, 226]

3.5.3 Socio-economic position

There is a large established evidence base on inequalities in health patterns by socio-economic position, summarised by The Commission on Social Determinants of Health as "the higher one's social position, the better one's health is likely to be."[227-229] Echoing previous analyses and reports, the Commission concluded that the socio-economic characteristics of where a person lives affects their life expectancy and disability-free life expectancy.[227] In addition to neighbourhood level income-based deprivation, this gradient was seen with education, occupation and living conditions.[227] In England, those with lower educational attainment and those working in manual occupations were more likely to be obese than their more educated and non-manual occupation counterparts.[230] Findings across high-income countries show that education level was associated with CVD risk in men, and to a lesser extent in women.[231] Studies in the UK and elsewhere have also found an inverse association between socio-economic position and prevalence of diabetes.[232, 233] Those in more deprived groups were more likely to be diagnosed with most cancers than less deprived groups, they also had shorter survival following diagnosis.[166]

Transport is an important social determinant of health as it facilitates opportunities through access to work, education and social networks.[227] Public transport is therefore essential for those without a car to access many important services, the absence of which would be detrimental to their health. For this reason, Dahlgren and Whitehead advocated for government spending on public transport to enable those who would otherwise be in transport poverty to participate in society.[54] Similarly, the Commission on the Social Determinants of Health found evidence that the relationship between transport and health is socio-economically patterned, with greater amounts of travel seen among those with greater incomes.[227] Poor access to transport has been identified as an important barrier to inclusion and a driver of health inequalities.[227] Having access to public transport is particularly important for those who cannot access other forms of transport, whether due to financial barriers, medical conditions or age.

Data from the 2012 Health Survey for England show that the proportion of adults in England meeting physical activity guidelines is lower in households with lower income, it falls from 76% of men and 63% of women in the highest income quintile, to 55% of men and 47% of women in the lowest income quintile.[234]

3.6 Interventions to increase physical activity

The interventions to increase walking for which there is evidence of effectiveness are those targeted towards individuals or households identified as being motived to change their behaviour.[235] The most effective interventions are those which are tailored to the needs of the individual, including a group walking intervention in post-menopausal women which led to an increase in walking of 150 minutes per week.[235, 236] However, the authors acknowledge potential for bias from this study as participants were volunteers and were ‘predominantly white and middle class’.[236] In a systematic review of interventions to increase walking for transport, the most effective intervention led to an

increase of 70 minutes a week.[235, 237] This involved a workplace intervention which provided a booklet of tailored advice.[237] However, interventions which require individual level changes in behaviour such as health promotion campaigns can contribute to widening inequalities.[238] This is attributed to a greater ability to respond to these interventions among those with higher levels of material or psychological resources, which has been described as having greater agency.[238] Agency is a concept which encompasses the ability or capacity to exert power and control one's own actions and life and choices.[239] Interventions to improve diet and reduce obesity that require individuals to use lower levels of agency are more likely to be effective and are more equitable.[240]

In comparison with an individual level approach, a population approach aims to shift the whole population risk distribution and avoids having to identify susceptible populations.[241] This approach to tackling ill-health has been shown to disproportionately benefit deprived groups who most suffer the effects of health inequalities.[238] A review which looked at population level interventions found that walking could be increased by 9-75 minutes per week.[242] Effective interventions were those incorporating some aspect of mass media, community initiative or environmental change.[242] The evidence base for population interventions to increasing walking is currently small, but it is growing with an increased use of natural experiment study designs.[242]

A health in all policies approach states that all policies, regardless of sector, should have their impact on health inequalities evaluated and has been advocated by several influential policy documents, globally and in the UK.[227, 243, 244] As a transport policy conceived to ensure the financial security of recipients, evaluation of the free bus pass exemplifies a health in all policies approach to policy intervention. The free bus pass for older people can be considered as a population intervention, as it has not been targeted at any risk groups, except that defined by age. The free bus pass has been shown to increase bus and active travel immediately following its implementation and has been associated with lower adiposity and higher gait speed.[80, 82]

Summary

Public transport use in England is relatively common, although much less common than car use, and is a particularly important travel mode of some groups, including older and younger people, ethnic minorities and the socio-economically disadvantaged. This means that any health associations of public transport are likely to have substantial population impact and also effect health inequalities. This thesis will focus on the physical activity benefits of public transport, other potential mechanisms which will not be studied include: atmospheric pollution, climate change impacts, noise pollution, road traffic collisions and wellbeing

Recent largescale rail infrastructure projects, such as Crossrail and High-Speed 2, have led to a large increase in government spending on rail transport in England. Although neither of these projects are yet operational, train use has been increasing for over 20 years. Government support of bus services has reduced substantially since 2010, which has occurred alongside a decline in bus provision and use. However, the free bus pass for older people in England represents a large government commitment to bus subsidies. The free bus pass was found to be associated with bus and active travel immediately following its implementation, however, there is no longer term research or any assessment of whether the associations differ across ethnic groups.

Physical activity has known health benefits, in addition walking and cycling have established associations with improved health. Most public transport journeys contain some walking to access public transport or transfer between modes, however, the amount of walking and cycling as part of public transport journeys in England is unknown. Public transport journeys which contain walking or cycling might be expected to confer health benefits but there is uncertainty about the associations between public transport and cardio-metabolic outcomes such as adiposity, diabetes, CVD and also mortality.

Chapter 4 – Aims and Objectives

4.1 Aim of the thesis

The aims of this thesis are:

- To examine associations between public transport use and physical activity, cardio-metabolic health, cancer and mortality in England and Wales and to investigate potential inequality impacts
- To examine the associations between the free bus pass for older people in England and bus and active travel levels and to establish whether this differs across ethnic groups

4.2 Objectives and research questions

4.2.1 Associations of public transport use with cardio-metabolic health

Existing research into the health effects of transport have focused on the impact of walking and cycling, often in comparison with car use. There is good evidence that walking and cycling are associated with reduced diabetes, CVD and mortality. Public transport might affect population levels of physical activity due to walking and cycling to public transport stops and at interchanges, this walking and cycling might be expected to have cardio-metabolic health benefits.

Research questions addressed in Chapter 5

- What evidence exists for an association between public transport and cardio-metabolic health?

- What gaps exist in the literature for an association between cardio-metabolic health and public transport?

4.2.2 Public transport users in England

Transport statistics based on the number of journeys and distance travelled differ, depending on the relative speeds of different travel modes. However, because many people use more than one travel mode, these measures are not always the most appropriate way to quantify the users of specific transport modes. Available data on the characteristics of public transport users, and users of specific public transport modes, in England are primarily descriptive and have not been adjusted for potentially confounding factors.

Research questions addressed in Chapter 6

- How common is public transport use and the use of specific public transport modes (bus, train and light-rail) in England?
- Which individual and neighbourhood characteristics are associated with public transport use and the use of specific public transport modes in England?

4.2.3 Physical activity accrued as part of public transport use in England

In England, a large proportion of the population is insufficiently physical active. The use of active travel modes could be one way to address high levels of physical inactivity, this could include public transport, which often involves some walking or cycling as part of journeys. No large studies have quantified the physical activity associated with public transport use using representative data on public transport users in England.

Research questions addressed in Chapter 7

- How much physical activity do public transport users in England accrue in the course of public transport journeys?
- Does the level of physical activity accrued differ between users of different public transport modes?
- Does the level of physical activity accrued vary according to individual or neighbourhood characteristics?

4.2.4 Associations between the free older person's bus pass and active travel and ethnic differences in bus pass use

The free older person's bus pass was introduced in 2006 and entitled older adults in England to free bus travel. Some evidence has found that holding a bus pass was associated with increased use of active travel modes immediately following implementation, it is not known whether these associations persist or have changed. People of minority ethnicity in England have higher bus use than White people and those in some ethnic minorities groups have lower physical activity levels. However, it is unknown whether the free bus pass has differential associations across ethnic groups.

Research questions addressed in Chapter 8

- How has bus pass possession changed between 2006 and 2014?
- Which individual and neighbourhood characteristic are associated with holding a free older person's bus pass in England?
- Among those with a bus pass what are bus and active travel levels?

- Is the possession of a free bus pass for older people in England associated with higher bus and active travel levels?
- Does the association between the free bus pass and active travel differ across ethnic groups?

4.2.5 Commute mode and mortality and cancer

Research into the health effects of commute mode has primarily focused on walking and cycling to work, with public transport commuters combined with users of other modes, making the specific effects of public transport commuting unknown. As public transport commutes are likely to contain some walking or cycling in order to access public transport, it is possible that the accumulation of this physical activity is sufficient to lead to a measurable health benefit among public transport users, when compared with car commuters.

Research questions addressed in Chapter 9

- Which individual and neighbourhood characteristics are associated with commute mode in England and Wales?
- Is commute mode associated with cancer incidence, cancer mortality, CVD mortality or all-cause mortality?
- Does commute distance effect the association between commute mode and cancer and mortality outcomes?
- Does the socio-economic position of commuters effect the association between commute mode and cancer and mortality outcomes?

Chapter 5 – Associations of public transport use with cardio-metabolic health: a systematic review and meta-analysis

The health burden of cardio-metabolic diseases is considerable, ischaemic heart disease and stroke were the first and third largest causes of years lost to life globally in 2017.[245] Although the UK has seen declines in CVD, stroke and ischaemic heart disease in recent decades, alongside reductions in smoking and better control of hypertension; prevalence of obesity and type 2 diabetes have increased substantially in the last 20 years. [158-160] Some estimates put the costs associated with diabetes at over 10% of NHS expenditure and project that this is set to rise to 17% (over £22bn) by 2035/36.[163] Physical activity is associated with reduced risk of many cardio-metabolic health outcomes, including: CVD mortality, ischaemic heart disease, stroke, obesity, type 2 diabetes and hypertension.[152, 155]

Existing research into the health effects of transport have primarily centred on the impact of walking and cycling. Meta-analyses have found that walking and cycling for any purpose were associated with an 11% and 10% reduction in risk of all-cause mortality respectively.[174] Systematic reviews and meta-analyses have found that walking was associated with a lower body weight, BMI, diastolic blood pressure and cardiovascular risk [175, 246, 247], while cycling was associated with lower all-cause mortality, cancer risk, overweight and obesity.[176, 179] Another meta-analysis found that walk commuting was associated with a risk reduction of 27% for CVD incidence, with no associations found with incident cancer, cancer mortality, CVD mortality and all-cause mortality.[178] Cycle commuting was associated with 24% reduced risk of all-cause mortality and risk reductions of 46%

for CVD incidence and 25% for cancer mortality, although no associations were been with CVD mortality or breast cancer incidence.[178] A combined measure of walk and cycle commuting was found by a meta-analyses to be associated with an 8% reduced risk of all-cause mortality and a 9% reduced risk of CVD incidence.[178] Commuting by walking and cycling have both been associated with lower adiposity, measured using BMI and percentage body fat.[172, 180]

Public transport might affect population levels of physical activity due to walking and cycling to transport stops and at interchanges.[184] A 2012 review found that public transport use was associated with between 8 and 33 minutes per day of physical activity [184], spanning from a small contribution to daily physical activity to a substantial one. This review included data from 27 studies from North America, Europe and Asia with one contributing study finding that US public transport users accumulated a median of 19 minutes of physical activity per day associated with public transport.[248] Nine of these 27 studies used objective measures of physical activity, for example, GPS or pedometers. Studies that use GPS and accelerometers to measure physical activity objectively, generally find lower levels of physical activity than studies of self-reported physical activity.[207, 249] Studies of this kind have found that public transport use was associated with 15 minutes a day of walking [192] and 10 minutes per trip of moderate-to-vigorous physical activity.[189]

This is the first systematic review to examine the association between public transport and cardio-metabolic health. Public transport will be measured either by its use or through an indirect exposure, such as living in proximity to public transport. Constituent public transport modes such as buses, trains and light-rail will be included, in addition to an overall measure. Therefore, the research questions addressed in this chapter are:

- What evidence exists for an association between public transport and cardio-metabolic health?
- What gaps exist in the literature for an association between cardio-metabolic health and public transport?

5.1 Methods

A protocol for this systematic review was registered with the PROSPERO International Prospective Register of Systematic Reviews on 30th September 2016: (http://www.crd.york.ac.uk/PROSPERO/display_record.asp?ID=CRD42016048427).

Relevant research was located through electronic database searches (published and grey literature), internet searches using Google, and from the reference lists of included studies. The electronic databases searched were: Medline (Ovid), Embase (Ovid), Transport Database (Ovid), Scopus, The Cochrane Library, and opengrey.eu. Database searches were carried out in December 2017 with no restrictions on the date of publication. An example search strategy is presented in Appendix Table A-1 from the search of Medline (Ovid). Due to the constraints of the search engines, a simplified search strategy was employed with Google and opengrey.eu. Examples of terms used to identify public transport included 'public transport', 'bus', 'train', 'transit', 'subway' and 'commute', and those for cardio-metabolic health were 'cardiovascular', 'diabetes', 'hypertension', 'mortality', 'obesity', 'adiposity', body fat' and 'BMI'.

Following the literature search and deletion of duplicates, my supervisor (AL) and I independently conducted initial screening of titles and abstracts. For articles retained for inclusion by either assessor, we carried out independent screening of full texts, any disagreements were resolved through discussion.

Eligible study designs were randomised-controlled trials, quasi-experimental and longitudinal observational studies. On order to reduce the risk of reverse causality and unobserved confounding, cross-sectional studies were excluded.[250] This was because research into the association between physical activity related exposures and health is susceptible to reverse causality, especially where cross sectional methods are used. Reverse causality occurs where poor health leads to participants achieving lower levels of physical activity rather than low physical activity leading to poor health, this could happen where ill health makes physical activity more difficult. In addition to minimising the risk of reverse causality, studies which capture multiple measures over time may allow the investigation of intra-individual changes, this additionally reduces the risk of bias caused by unobserved confound at the individual level, further enhancing the potential for causal inference.

Eligible public transport exposures measures included public transport use and access to public transport, e.g., distance to bus stops. A relevant comparator was required, e.g. users of other transport modes or those with greater distance to a bus stop. Cardio-metabolic outcomes were: CVD mortality, diagnosis of CVD, type 2 diabetes, dysglycaemia (e.g. elevated blood glucose, insulin resistance, glucose intolerance), dyslipidaemia (e.g. elevated triglycerides or LDL, depressed HDL, hypertension/blood pressure), and adiposity (e.g. BMI, percentage body fat, waist circumference, waist to hip ratio and height-weight ratio). Self-reported and objectively measured data for exposure and outcome measures were eligible. Studies with adult populations or those of children aged 5 years or more were included. Only English language studies were included.

I carried out the data extraction using a customised Microsoft Excel spreadsheet, which was then checked by my supervisor (AL). Extracted data included the study name, year of publication, number of participants, length of follow-up, sampling strategy and details of participants; this included their age, location and the proportion male. In addition, measures of exposure, covariates, analytical

approach and effect estimates were extracted. Where the same study was used in multiple publications, that with the most recent data was included.

The risk of bias of included studies was assessed using criteria adapted from the Newcastle-Ottawa scale for cohort studies.[251] The Cochrane Collaboration recommends the Newcastle-Ottawa scale for use with non-randomised studies and this was suitable for use with all of the included studies.[251, 252] No overall risk of bias score was calculated due to debate about the validity of such measures. Using different risk of bias scoring tools with the same group of studies can yield substantially different outcomes, both in terms of the studies that score highly and also the pooled risk estimates among high-scoring studies.[253] To prevent the choice of risk of bias tool itself becoming a source of bias, the domains of the Newcastle-Ottawa scale were considered separately to assess whether studies with high risk of bias in a particular domain had systematically different findings from those that did not.[253] The domains of the Newcastle-Ottawa scale were: sample representativeness, selection of comparator, exposure measure, demonstration that outcome was not present at baseline, suitability of covariates (particularly physical activity in the case of this study), assessment of outcome, length of follow-up and levels of loss to follow-up.

For each outcome, the association with public transport was evaluated. For outcomes where different exposure measures were available, for example, public transport use and distance to bus stops, the associations were compared. Harmonisation was required to facilitate some comparisons, for example, studies measuring distances in miles were converted to kilometres. A random-effects meta-analysis was used, as described by DerSimonian and Laird, this weights each study proportionate to the inverse of its variance giving more weight to larger studies and less weight to smaller studies. Studies which used comparable exposure and outcome measures were meta-analysed, meaning this was carried out on five studies investigating change in transport mode and change in BMI.[254] To assess heterogeneity between studies included in the meta-analysis, an I^2

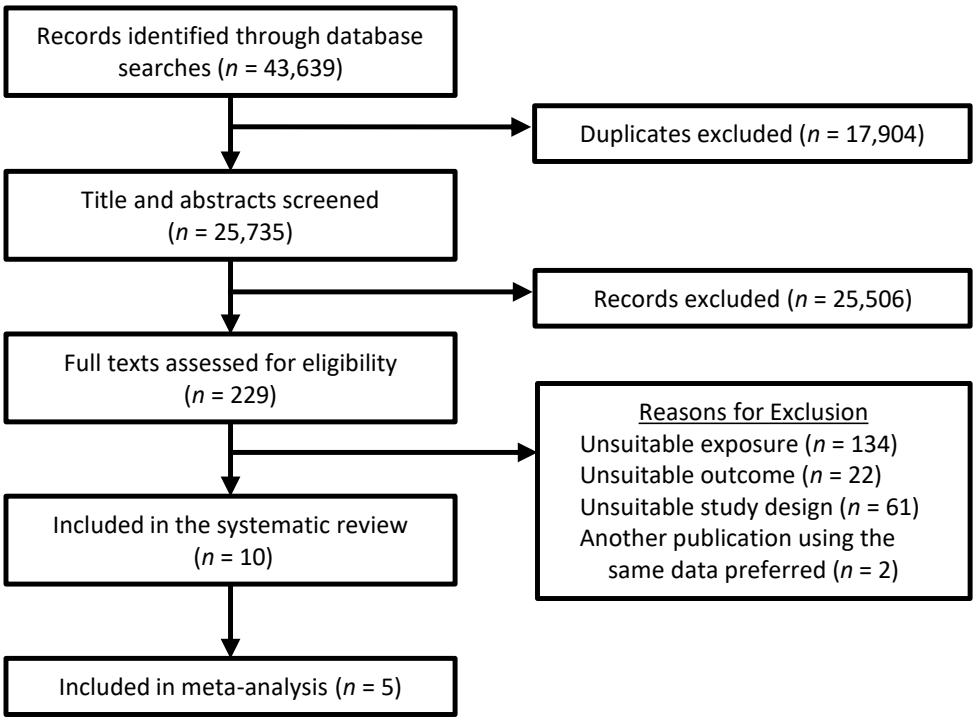
statistic was calculated; this estimates the percentage of the total variation in estimates which results from heterogeneity between studies as opposed to being by a result of chance.[255] To assess the potential for publication bias or other study size related heterogeneity, funnel plots were used to plot each study's effect estimate against its standard error.[256] An asymmetrical funnel plot indicates systematic differences between the findings of smaller and larger studies, this might be explained by publication bias or other small study effects.[256] In order to test the impact of including those ceasing public transport in addition to those initiating, and the impact of this on the relative weighting given to each included study, a sensitivity analysis was carried out with only data on initiating public transport use.

5.2 Results

5.2.1 Description of included studies

Literature searches identified 43,639 studies, which were reduced to 25,735 by the removal of duplicates (Figure 5-1). Following screening of titles and abstracts, 229 full texts were assessed for eligibility. Of these, 134 were excluded for ineligible exposure (e.g. an inability to separate public transport use from other transport modes), 22 were excluded for ineligible outcome (e.g. physical activity), 61 were excluded for ineligible study design (29 of which were cross-sectional) and two studies were excluded with another publication using the same data preferred. This left 10 eligible studies, which were included in the review, five of which were meta-analysed.

Figure 5-1: Flow chart of study inclusion



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Included studies were all of adult populations with mean baseline age between 41 and 62. Six studies were from the USA [122, 188, 257-260], three were from the UK [81, 261, 262], and one study was from China (Table 5-1).[263] All studies were published after 2008 with five being published after 2015.[122, 188, 258, 261, 263] Public transport users were compared with non-users in seven studies [81, 188, 257, 258, 260-262], with public transport measured by usual commute mode [258, 261, 262] or any public transport use.[81, 188, 257, 260] Proximity to public transport was examined by the remaining three studies, two used a measure of distance from home address to the nearest bus stop [259, 263], and the final study assessed the impact of new light-rail infrastructure.[122]

Changes in individual level BMI measures were the primary outcome in seven included studies [81, 188, 259-263], whereas two studies compared the proportion obese in exposed and unexposed groups.[257, 258] The odds ratio for obesity among public transport users and non-users was compared in one study.[81] Two studies examined waist circumferences, alongside BMI, as an adiposity measure.[81, 259] There was only one study which investigated a non-adiposity outcome, this was an ecological comparison of stroke mortality among those living close to new light-rail infrastructure and those living at greater distance.[122] Individual level measures of outcome were used in eight of the ten studies,[81, 188, 257, 259-263] with two ecological analyses, using data from US states [258] and city neighbourhoods.[122]

Table 5-1: Characteristics of included studies

First author, year [ref] & study characteristics	***N***	***average follow-up (years)***	***Exposure***	***Outcome***	***Covariates***	***Main findings***
Brown, 2008 [257] USA Evaluation of TRAX light rail line	n=47	1	Use of light rail	Proportion obese based on BMI	Income and employment	0.26 (95%CI = 0.01, 0.51) of those initiating public transport use were obese. Compared with 0.65 (95%CI = 0.41, 0.89) of non-public transport users and 0.15 (95%CI = -0.05, 0.35) of continuing public transport users
Brown, 2017 [188] USA Moving Across Places Study	n=536	1	Use of public transport	Change in BMI	Gender, age, education, t1 accelerometer wear time, t1 outcome values, changes in employment, temperature, self-reported health, participation interval, automotive time, and accelerometer wear time	The change in BMI was -0.56kg/m^2 (95%CI = -0.97, -0.14) in those initiating public transport use, 0.66kg/m^2 (95%CI = 0.21, 1.11) in those ceasing public transport use and 0.01kg/m^2 (95%CI = -0.44, 0.42) in continuing public transport users
Chen, 2017 [258] USA US government data	Ecological	10	Proportion of the population commuting by public transport	% of the population who were obese based on BMI	Per capita state income; State unemployment (% of labour force), % of state white population, Log of population density, % of state population with a bachelor's degree or higher, % of state population that consumed fruit 2+ times/day, and vegetables 3+ times/day, % of state population that engaged in daily physical exercise as recommended, per capita state healthcare expenditure (2010)	Higher levels of public transport commuting was associated with lower rates of overweight (-0.32 (95%CI = -0.05, -0.59)) and obesity (-0.21 (95%CI = -0.03, -0.39)) a year later. A 1% increase in public transport commuting was associated with a 0.21% reduction in obesity prevalence

First author, year [ref] & study characteristics	*N*	*average follow-up (years)*	*Exposure*	*Outcome*	*Covariates*	*Main findings*
Flint, 2016 [261] UK UK Biobank	n=5861	4.4	Commute mode	Change in BMI	Baseline BMI, age, sex, ethnicity, baseline household income, household income change, educational attainment, self-rated general health transitions, manual occupation transitions, days/week of leisure moderate physical activity, and changes between baseline and follow-up, occupational physical activity transitions	Initiating public transport use was associated with a -0.30kg/m^2 (95%CI = -0.47, -0.13) change in BMI compared with 0.32kg/m^2 (95%CI = 0.13, 0.50) among those ceasing public transport use
Hirsch, 2014 [259] USA Multi-Ethnic Study of Atherosclerosis (MESA)	n=5506	9.1	Distance from home to closest bus stop (objectively measure)	Change in BMI and waist circumference	Time-varying working status, current marital status, car ownership, cancer diagnosis, self-rated health compared with others, income, moved house between waves, a time trend and interactions of time trends with selected covariates (baseline age and race/ethnicity) allowing time trends to vary by these characteristics. Model 2 also includes potential mediators: time varying transport walking minutes/week, time varying smoking status, time varying alcohol consumption status, and an interaction allowing time trends to vary by baseline calorie consumption	An increase of 1km to the closest bus stop was associated with no change in BMI (0.01kg/m^2 (95%CI = -0.01, 0.02)) or waist circumference (0.02kg/m^2 (95%CI = -0.03, 0.07))
MacDonald, 2010 [260] USA New light rail line evaluation	n=301	1+	Light rail use after new rail line built	Change in BMI	Gender, race, age, employed, miles to work, education, rent, social and physical environment, plan to use LRT	Initiating new light rail use was associated with a change in BMI of -1.18kg/m^2 (95%CI = -2.22, -1.13) and a reduced odds of becoming obese OR= 0.19 (95%CI = 0.04, 0.92)

First author, year [ref] & study characteristics	*N*	*average follow-up (years)*	*Exposure*	*Outcome*	*Covariates*	*Main findings*
Martin, 2015 [262] UK British Household Panel Survey (BHPS)	n=4056	2	Commute mode	Change in BMI	Age, gender and BMI at t0, occupational status, working hours, household income, education, children, health status, car access at t0. home location, income, health, car access and pregnancy	Initiating public transport use was associated with a change in BMI of -0.12kg/m^2 (95%CI = -0.55, -0.30). Ceasing public transport use was associated with a BMI change of 0.46kg/m^2 (95%CI = 0.16, 0.86)
Park, 2017 [122] USA Texas Department of State Health Services Center for Health Statistics for 2002–2005	Ecological	2	Distance from home to a new light rail line	% change in stroke mortality	Seasonal and long-term trends, day of the week (weekday versus weekend), and the effects of meteorology	There was a reduction in the daily total stroke mortality rate of 39.3% (6.8, 60.4) within 5 miles and 33.3% (10.0, 50.6) within 10 miles of the light rail line but not in control areas; > 10 miles -4.1% (-31.9, 35.1)
Sun, 2017 [263] China China Family Panel Study (CFPS)	n=8028	2	Distance from home to closest bus stop (self-reported)	Change in BMI	Facilities access, private motor mode, age, age-squared, male, married, employed, family income, family income-squared, meat, junk food, eating out, sedentary time, exercise time, commute time, sleep time, eating time	An increase of 1km to the closest bus stop was associated with -0.10kg/m^2 (95%CI = -0.20, -0.01)

First author, year [ref] & study characteristics	*N*	*average follow-up (years)*	*Exposure*	*Outcome*	*Covariates*	*Main findings*
Webb, 2012 [81] UK English Longitudinal Study of Aging (ELSA)	n=4686	4	Use of public transport	Change in BMI Odds of being obese, using BMI and waist circumference	Age, a quadratic term for age, sex and use of public transport in 2006, having a difficulty with one or more activities of daily living (ADLs), car ownership and financial circumstances	Initiating public transport use was not associated with a change in BMI (0.08kg/m^2 (95%CI = -0.10, 0.27)), while ceasing public transport use was associated with an increase in BMI of 0.23kg/m^2 (95%CI = 0.01, 0.46). An association was found between use of public transport and BMI measured obesity, adjusted odds ratio (AOR) of 0.79 (95%CI = 0.63 to 0.98). This was not seen with waist circumference measured obesity (AOR=0.96 (95%CI = 0.80 to 1.16))

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5.2.2 Study Quality

The included studies each contributed between 47 and 8,028 participants, giving a total of 29,021 participants, in addition to two ecological studies (Table 5-1 and Table 5-2 with additional details in Appendix Table A-2 & **Error! Reference source not found.**). Nationally representative data from large population surveys were used by the three studies by Martin et al, Chen et al and Webb et al; this should lead to a reduced risk of bias.[81, 258, 262] The distance between home address and public transport infrastructure was used to identify participants in four studies by Brown and Werner, Brown et al, MacDonald et al and Park et al. [122, 188, 257, 260], with the study by Sun et al including only urban residents.[263] Only one of the included studies (Park et al) did not select control participants from the same population as the exposed group, which compared those near to a new light-rail line with those further away.[122] Self-reported exposure data, which is susceptible to recall bias, was used in eight of the included studies.[81, 188, 257, 258, 260-263] Objective exposure measures were used in two studies: Park et al to compare those near to new infrastructure with those at greater distance [122] and Hirsch et al, which used geographical information systems (GIS) to measure distance to the nearest bus stop.[259]

Objective measures of adiposity were used by five studies (Brown and Werner, Brown et al, Flint et al, Webb et al and Hirsch et al) [81, 188, 257, 259, 261], for example, as part of a large survey. Objective measures are less susceptible to misclassification bias when compared with self-reported adiposity measures [264], which were used by Chen et al, MacDonald et al, Martin et al and Sun et al.[258, 260, 262, 263] The study by Park et al examining stroke mortality used death registrations and the International Classification of Disease, 10th revision (ICD10) codes I60-I69.[122, 265] The study by Brown and Werner collected adiposity data at two time points, pooled these adiposity measures, increasing the risk of reverse causality and selection bias e.g. those who are more active or generally healthier choosing to live close to public transport.[257] Although the analytical

approach of this paper was cross-sectional, in line with the inclusion criteria set out in the review protocol, this study was included as the data collection was longitudinal.

Three of the included studies adjusted for non-transport physical activity, which was considered a likely confounding factor as transport physical activity was a hypothesised mechanism for the association under investigation, these were the studies by Flint et al, Chen et al and Sun et al.[258, 261, 263] Additionally, Hirsch et al adjusted for transport walking, using a measure which captured time spent walking, for example, to the store.[259] Another potentially important confounder was general health, which was accounted for by four studies by Flint et al, Martin et al, Hirsch et al and Brown et al, in most cases a self-report health measure was used.[188, 259, 261, 262] In addition to this, Webb et al adjusted for Activities of Daily Living (ADLs), which is a measure of a person's ability to person to complete certain tasks, e.g., to get dressed independently.[81] The by Hirsch et al and Sun et al adjusted for a measure of the quality of participant's diet [259, 263], while one ecological study by Chen et al included a measure of health expenditure at the state level.[258]

Table 5-2: Scores for domains of Newcastle-Ottawa scale

First author, year [ref]	Representativeness of the exposed cohort[6]	Selection of the non-exposed cohort	Ascertainment of exposure	Demonstration that outcome of interest was not present at start of study	Comparability of cohorts on the basis of the design or analysis (adjustment variables)	Assessment of outcome	Was follow-up long enough for outcomes to occur	Adequacy of follow-up of cohorts
Brown, 2009 [257]	C	A	B	B	B	A	A	47%
Brown, 2017 [188]	C	A	B	A	B	A	A	65%
Chen, 2017 [258]	A	A	B	A	A	C	A	n/a
Flint, 2016 [261]	B	A	B	A	A	A	A	21%
Hirsch, 2014 [259]	B	A	A	A	B[a]	A	A	68%
MacDonald, 2010 [260]	C	A	B	A	B	C	A	60%
Martin, 2015 [262]	A	A	B	A	B	C	A	88%
Park, 2017 [122]	C	B	A	B	B	B	A	n/a
Sun, 2017 [263]	C	A	B	A	A	C	A	?
Webb, 2012 [81]	A	A	B	A	B	A	A	?

See Appendix Table A-3 for adapted Newcastle-Ottawa scale criteria

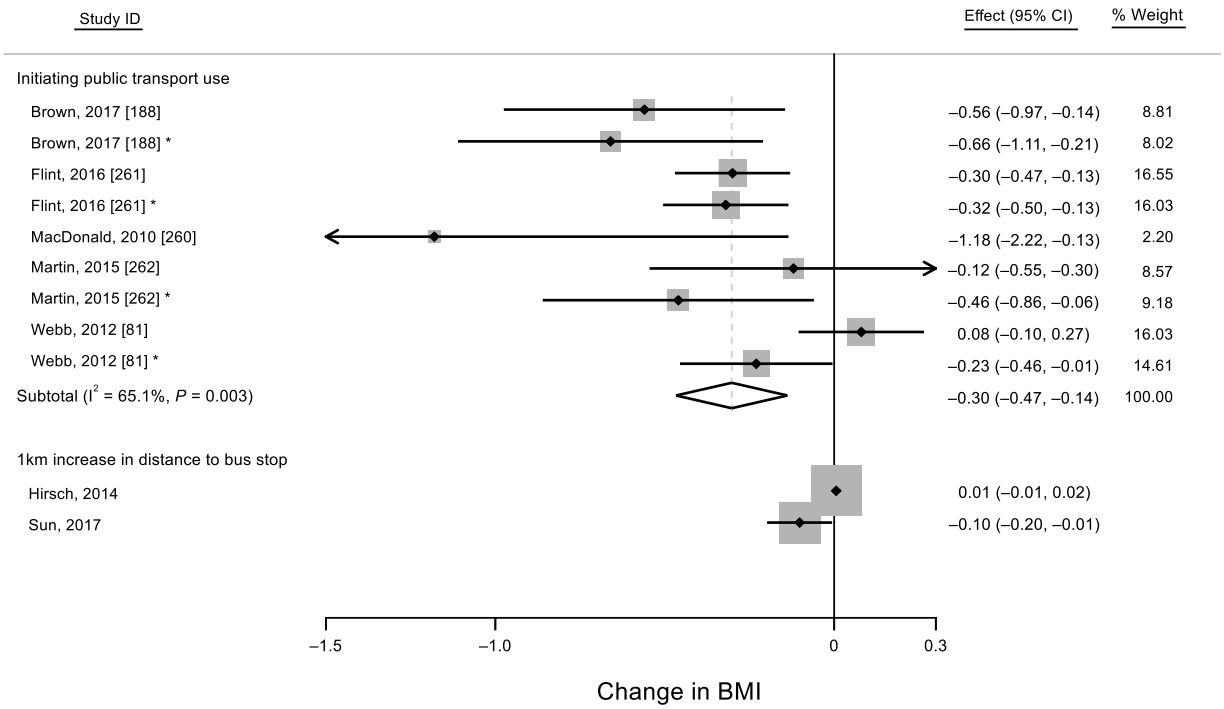
a – adjusts for transport walking

5.2.3 Public transport and adiposity

Public transport use studies

Of the 10 included studies, seven investigated the association between public transport use and adiposity. Of these studies, public transport use was assessed by self-reported usual commute mode by three studies and any use of public transport by four. Public transport use was consistently associated with lower adiposity when compared with no public transport use. Five studies examined change in BMI (kg/m^2) associated with initiating public transport use and were included in a meta-analysis (Figure 5-2).[81, 188, 260-262] As four studies examined ceasing public transport use, in addition to initiating, they provided two data points to the meta-analysis.[81, 188, 261, 262] The meta-analysis found that initiating public transport use was associated with a reduction in BMI of 0.30 kg/m^2 (95% CI=0.14, 0.47). An I^2 of 65.1% was associated with this meta-analysis, suggesting a moderate amount of between study heterogeneity.[266] The contributing study by MacDonald et al showed the largest change in BMI and was also the study with fewest participants and the only one of the five not to adjust for a measure of general health, this may have led to a greater risk of bias in this study.[260] The exclusion of this study from the meta-analysis led to an estimated reduction in BMI of 0.28 (0.12, 0.44) with an I^2 of 64.6% (Appendix Figure A-1).

Figure 5-2: Forest plot showing change in BMI (kg/m^2) associated with initiating public transport



The square surrounding the point estimates represent the weighting given within each analysis
** Indicates those who ceased public transport use - the direction of BMI change was reversed to allow comparison with those initiating*
Weights are from random effects meta-analysis

The two American studies by Brown et al and MacDonald et al included in the meta-analysis were evaluations of new light-rail infrastructure.[188, 260] They both had relatively small sample sizes (n=536 and 301) which were selected on the basis of their proximity to the new infrastructure.[188, 260] The studies by Flint et al, Martin et al and Webb et all were from the UK and had relatively large sample sizes (n=5861, 4056 and 4686) and used data from large surveys of the general population.[81, 261, 262] The low number of studies included in this analysis meant that formal testing for small-study biases, such as publication bias, was not possible while the funnel plot was inconclusive (Appendix Figure A-3). The disparity in findings between these studies might be explained by differences in the location of the studies or due to differences in study design, with the

two US studies being evaluations of new infrastructure, such as the length of follow-up. All four studies which examined both initiating and ceasing public transport use found a smaller a change in BMI among those initiating public transport use, compared with ceasing public transport use (marked in Figure 5-2 with a *), however, in each case the confidence intervals overlapped.[81, 188, 261, 262] Sensitivity analyses to evaluate the impact of restricting to data from those initiating public transport (excluding data from those ceasing public transport) has a slightly smaller effect estimate, albeit with reduced precision, -0.26mg/m^2 (-0.55, 0.02) (Appendix Figure A-2). Four of the five studies provided two data points, with only one study providing a single data point, this study saw its weighting to increase from 2.2% in the main analysis to 6.0% in this sensitivity analysis. The other four studies saw their relative weighting change little, e.g. Martin et al went from 26.2% in the main analysis (combining the weight of the two data points) to 28% in the sensitivity analysis. These minor changes to the weighting likely explain why this sensitivity analysis found only a small difference from the main analysis. Only one study in the meta-analysis included adjustment for non-transport physical activity (Flint et al).[261] However, the findings from this study were consistent with those of the other studies and were not substantially altered by non-transport physical activity adjustment, e.g. -0.30kg/m^2 (-0.47, -0.13) with physical activity adjustment and -0.32kg/m^2 (-0.49, -0.15) without.[261]

There were three studies of individual level data which provided findings which could not be included in the meta-analysis because they were not directly comparable. A study of older people in England by Webb et al which found that public transport users were less likely to be obese (BMI > 30kg/m^2) when compared with non-users (adjusted odds ratio (AOR) = 0.79 (0.63 to 0.98)).[81] However, this study did not find the same association using waist circumference as a measure of obesity.[81] A study in the USA by Brown and Werner found that 65% (95% CI=41, 89) of public transport users were obese, whereas among those who initiated or continued using public transport this was 26% (1, 51) and 15% (-5, 35) respectively.[257] This study used a cross-sectional analysis and

pooled individual level BMI measures from the two time points, which increases the potential impact of reverse causality and selection bias. The final study of public transport use and adiposity by Chen et al used ecological data over 10 years from the 50 states of the USA.[258] This study found that greater levels of public transport commuting were associated with lower rates of overweight (-0.32 (-0.05, -0.59)) and obesity (-0.21 (-0.03, -0.39)) 12 months later.[258] These finding indicate that a 1% increase in public transport commuting was associated with a 0.21% reduction in obesity prevalence at the state level.[258]

Proximity to public transport studies

The association between distance from home address to the nearest bus stop was examined by two studies.[259, 263] Their results have been harmonised to allow for comparison, presenting the change in BMI per 1km change in distance to the nearest bus stop (Figure 5-2). These studies present discordant results, with one study by Hirsch et al from the USA finding no association (0.01kg/m^2 (-0.01, 0.02)), this study additionally found no association with waist circumference. [259] The other study by Sun et al, from China, found a negative association with an increase in 1 km to the nearest bus stop associated with a BMI change of -0.10kg/m^2 (-0.20, -0.01).[263] These difference could be due to the availability of alternatives to public transport between the USA and China, such as the lower car ownership levels seen in China compared with the USA.[37, 267] This could mean that increased distance to bus stops leads bus users in China to walk further but in the USA people chose to travel by car rather than walk the greater distances. Indeed evidence from the UK, which has car ownership closer to that of the US than China, supports this by suggesting that reduced distance to bus stops were associated with increased walking.[268] These studies also differed on several characteristics, in addition to location, for example, the USA study objectively measured distance from home address to the nearest bus stop, whereas the study in China asked participants to self-report this distance, which might be susceptible to reporting bias. This could happen if participants

with higher BMI overestimated the distance walked to reach a bus stop. The Chinese study adjusted for participant's physical exercise whereas the study of US participants accounted for only transport walking.

5.2.4 Public transport and stroke mortality

One identified study by Park et al evaluated changes in stroke mortality associated with the opening of a new light-rail line.[122] Using data from two years before the line opened to two years after, this study compared stroke mortality in residents of all ages living within a 3-, 5- and 10-mile radius of the new line, with those at greater than 10 miles. The study used an interrupted time series analysis to compare total daily incidence of stroke, adjusting for seasonal and long-term trends, day of the week (weekday versus weekend), and the effects of traffic pollution (as measured by acetylene concentration). The study found a percentage change in stroke mortality in the 3-, 5- and 10-mile areas of -46.9 (-72.0, 0.6), -39.3 (-60.4, -6.8) and -33.3 (-50.6, -10.0) respectively.[122] The reductions in mortality show an apparent gradient of increasing magnitude of association with shorter distance to the new infrastructure, although reduced precision was seen in the smaller areas .[122] Those living greater than 10 miles from the new line saw no change in stroke mortality, -4.1% (-31.9, 35.1). This study used the same interrupted time series approach to find a decline in average levels of the atmospheric pollutant acetylene, which the study suggests as a possible causal mechanism for the changes in stroke mortality.[122]

5.3 Discussion

5.3.1 Main finding

This systematic review found 10 studies investigating the associations between public transport and cardio-metabolic outcomes. There were accordant findings that initiating public transport use was

associated with reduced adiposity, while proximity to public transport had mixed associations with adiposity. Few studies were located which examined associations between public transport and cardio-metabolic outcomes, other than adiposity.

5.3.2 Strength and limitations

This is the first systematic review examining the association between public transport and cardio-metabolic health. The exclusion of cross-sectional studies and the identification of studies with repeated measures allowed the investigation of intra-individual changes in outcome, which should reduce the risk of bias caused by unmeasured confounding.[250] Only one individual level study adjusted for non-transport physical activity, however, this study by Flint et al had findings that were comparable with other included studies and similar effect estimates with and without physical activity adjustment.[261] The search strategy employed for this review was comprehensive and covered transport, in addition to health, literature databases in order to minimise the possibility of overlooking relevant studies. The breadth of the search was augmented by the inclusion of grey literature, from grey.eu, Google and the Transport Database. Meta-analysis was possible using five studies, with those studies not included in the meta-analysis having broadly consistent findings with those that were.

Limitations of this review include the use of usual commute mode as the exposure measure in three of the included studies. This measure fails to capture any use of additional modes, either as part of the same journey or on different days of the week. The effect of this misclassification is unknown but there is there is no reason to assume it was differential, i.e. that some modes were more likely to be misclassified than others. If this were the case and the misclassification was non-differential, it would lead to a bias towards the null.[269] There was also substantial heterogeneity in the methods of exposure ascertainment, for example, one study by Flint et al combined public transport

commuters with walking and cycling when examining the effects of switching to, and from, car use.[261] Assuming that walking and cycling were associated with greater adiposity changes than public transport, this might lead to an overestimate of the association. All studies of adiposity used BMI as a measure, although two additionally used waist circumference. Although the validity of BMI as an adiposity measure is been criticised, especially with respect to its stability across age and ethnic groups, it remains a commonly used measure of adiposity in population studies.[234, 270]

Nine studies of adiposity and one examining stroke mortality constitutes a small evidence base, especially given the many other cardio-metabolic outcomes which remain unstudied. The included studies varied in terms of methodological quality and analytical approach, for example, several studies investigated intra-individual changes in outcomes, but this was not the case for all studies. Indeed, one study by Brown and Werner measured BMI at two time points but pooled the measures from both and examined the association between this pooled measure and change in transport mode.[257] This led to an increased risk of bias from reverse causality and self-selection. Many of the included studies were limited in their selection of covariates, leading to a failure to adjust for several potentially important confounding factors. For example, just three studies adjusted for non-transport physical activity [258, 261, 263], and two adjusted for diet quality [259, 263], which were considered likely confounders of the association being examined. Bias might result from unobserved confounding due to selection effects among public transport users and those that initiate its use. The insufficient number of included studies means that tests for publication bias and other small study effects were not possible. Nine of the 10 studies were from the USA or UK, which despite many similarities also differ substantially with respect to car dependence, population density in urban areas and public transport provision.[271-273] A greater number of studies from a wider range of contexts are required to examine how these factors influence the relationship between public transport use and cardio-metabolic health, therefore, at present the generalisability of these

findings is not known.[197, 274, 275] It is possible that given the recent publication dates of all the included studies, additional studies are currently being conducted which will address this.

5.3.3 Comparisons with other research

Research on the cardio-metabolic effects of transport has largely centred on walking and cycling, which are associated with greater benefits than seen with public transport in this chapter.[181] A 2015 systematic review and meta-analysis of the impact of walking interventions found that they resulted in a change in BMI of -0.53 kg/m^2 (-0.72, -0.35).[276] That walking is associated with a greater change in BMI than is seen in the finding is this chapter (-0.30kg/m^2 (-0.47, -0.14)) is compatible with those walking entire journeys accumulating more physical activity than those walking to access public transport. However, this might not always be the case, as many walking journeys are relatively short in distance.[277, 278] The literature search identified only one study that assessed a non-adiposity outcome, which investigated stoke mortality. This means that conclusions about public transport and cardio-metabolic health more generally are not possible. In comparison, a meta-analysis examining commute mode found that a combined measure of walking and cycling was associated with an 11% reduced risk of CVD.[171] Further research is required into the associations of public transport with non-adiposity cardio-metabolic health outcomes, especially given that an association was seen with adiposity.

5.3.4 Implications

Although the magnitude of the changes in adiposity associated with initiating public transport might appear modest, a reduction in BMI of 0.30kg/m^2 translates to a mean weight loss of 0.9kg in men and 0.8kg in women in the population of England.[279] This would be a clinically significant reduction in adiposity and is comparable with, or greater than, that is seen with many individually focused interventions.[280, 281]

The literature search in this chapter identified very little research into the associations between public transport and non-adiposity cardio-metabolic health outcomes. For this reason, it is important that the association between public transport use and cardiovascular disease be investigated. High levels of adiposity are merely a risk factor for disease, although it has been strongly linked with serious ill-health, for example, type 2 diabetes, CVD and mortality.[282-284] There were very few studies, even at an ecological level which investigated an association between public transport and cardio-metabolic health other than adiposity [122, 285], and there was not a single individual level study investigating this. Further research is required to investigate the health effects of public transport use, which is essential if policy in this area is to be evidence-based. Future research should investigate the impact of public transport on incident type 2 diabetes and CVD, using methods that account for selection bias and unobserved confounding.

5.4 Conclusion

Initiating public transport use was associated with a modest but clinically significant reduction in adiposity, while proximity to public transport had mixed associations with adiposity. There is little available evidence investigating public transport and any other cardio-metabolic outcomes. More research into public transport and cardio-metabolic health is required, especially into more clinically relevant outcomes, such as CVD mortality, with greater control for potentially confounding factors, for instance diet quality and non-transport physical activity.

Chapter 6 – Public Transport users in England

Transport use statistics can be presented in several different ways, including journey rates and distance travelled, or the percentages thereof, which can each give a different picture, when speed of travel varies by mode. For example, slower transport modes make up a much smaller proportion of distance than of journeys. The DfT gathers detailed travel data and publishes routine statistics by both journey rates and distance.[11] Usual commute mode is also often measured, because it is relatively easy to measure and commuting is an important contributor to total travel. However, many people use multiple modes, including more than one type of public transport, therefore these categorisations are not always the most useful.

Available data on the characteristics of public transport users in England are primarily descriptive and therefore not adjusted for other factors, such as socio-economic position. For example, a comparison of the percentage of journeys per person per year, by mode, and socio-economic position would be influenced by geospatial characteristics, such as a greater proportion of socio-economically advantaged people living in London, which has a dense public transport network.[18, 286, 287] Data on the characteristics of the users of specific public transport modes, where it is available at all, is also descriptive and therefore unadjusted.

There is currently no detailed characterisation of public transport users in England, which examines individual and neighbourhood attributes of public transport users. In addition, the use of separate public transport modes, including light-rail, has also not previously been well quantified. This chapter used detailed travel data from a sample of England residents that was nationally representative in terms of age, sex and region of residence to examine frequency of public transport use. Research questions addressed in this chapter are:

- How common is public transport use and the use of specific public transport modes (bus, train and light-rail) in England?
- Which individual and neighbourhood characteristics are associated with public transport use and the use of specific public transport modes in England?

6.1 Methods

6.1.1 Data

The data used in this chapter come from the National Travel Survey (NTS), which is a survey of the travel patterns of England residents, commissioned by the DfT.[288] NTS used two-stage random probability sampling and weighting to arrive at a representative sample of households in England.[202] The first stage of sampling involved a random draw of postcode sectors, stratified by geographical region, car ownership and population density (of postcode sector). Postcode sectors were the primary sampling unit in NTS, they have an average population of approximately 7,000 people. Some additional oversampling was used to take account of lower response rates in London. In the second stage, a household address was selected from the Postcode Address File, which is a list about 22.9 million addresses in the UK. In 2014, 12,852 addresses in England were selected from 756 postcode sectors. NTS employed what they call a quasi-panel design, whereby half of the postcode sectors were retained for the subsequent year's sample. Household addresses included in the previous three years were excluded, although this would not prevent those who moved address from being invited to participate in multiple years. Full details of the survey design can be found in study documentation.[202, 289]

All residents of selected households were asked to participate in the survey, this involved a face-to-face computer assisted personal interview and the completion of a 7-day travel diary. The interview included questions about socio-demographic characteristics, which will be described in greater detail

below, in addition to questions about travel, such as cycling frequency and public transport use. Households were assigned a reference person, usually the member with the highest income, who answered questions about the household, such as tenure and length of residence. Data provided by participants were combined with data derived from the household postcode sector, including population density, size of their conurbation of residence and a rural/urban categorisation. NTS annual response rates between 2006 and 2014 were between 59% and 63%, which is broadly comparable with other nationally representative surveys.[202, 290]

Participants used the travel diary to record all journeys carried out in a 7-day period, along with details of start and end locations, mode, distance, time taken and vehicles used. A journey was defined as "one-way course of travel from one place to another with a single main purpose".[202] For journeys which comprised more than one stage, details of each stage should have been recorded separately, with a new journey stage designated when the mode changed or where there was a change in vehicle which required a separate ticket. NTS therefore contains data about all journeys and also all individual journeys stages, giving granular data about travel patterns. NTS assigned a main mode to all journeys, journeys containing stages of differing modes were assigned a main mode based on that used for the longest stage, by distance. Participants began completing their travel diary on a specified day of the week to ensure an even spread across the sample.

Outcomes examined in this chapter were frequency of bus and train use from the interview questions, in addition to a binary measure of each of: public transport use, bus use, light-rail use and train use, which were based on any use during the 7-day diary period. Frequency of use data were from responses to the interview question: "How frequently do you use local buses? Please count each single trip as one journey and each return trip as two" and an equivalent question about frequency of train use. The question about frequency of train use specifically excludes underground, tram or light-rail and no separate question is asked about frequency of light-rail use. Respondents to

these questions selected from seven potential frequencies (three or more times a week; once or twice a week; less than that but more than twice a month; once or twice a month; less than that but more than twice a year; once or twice a year; less than that or never).

In addition to data from the interview about bus and train use frequency, data from the travel diary were used to identify participants who were public transport users. Each journey stage was categorised as being public transport or not. Stages were also categorised by specific public transport mode: bus, train or light-rail. Train use refers to surface rail (sometimes known as National Rail), while light-rail includes London Underground, in addition to eight other urban rail networks (Dockland Light Railway and Tramlink in London, alongside networks in Nottingham, the Midlands, Sheffield, Tyne and Wear, Manchester and Blackpool). A binary variable was then created for each participant based on whether they reported any stage using a public transport mode in the diary week. Binary variables were then created for any use of each of bus, light-rail and train in the diary week, allowing participants to be a user of more than one public transport mode. The interview questions looked at travel frequency of less than once a week and so allowed some understanding of those using public transport modes less frequently, while the diary data allowed a more detailed understanding of the different modes used by participants.

NTS participants provide details of their: age, sex, ethnicity (White, South Asian, Black, Other), household access to a car (yes, no). Size of their conurbation of residence (categorised as: London, metropolitan built-up areas/large urban >250k population, small/medium urban 50k-250k population and <50k population) and the population density of the household's postcode sector (<10, 10-24.99, 25-39.99, 40-74.99, 75+ persons/hectare) were also used.[288] The socio-economic position of participants was derived using household income (less than £25,000, £25,000-£49,999, £50,000 and over), housing tenure (owns, rents) and a measure of occupation related socio-economic position. This was calculated using the highest National Statistics Socio-economic

Classification (NS-SEC) of any resident of the participant's household (Managerial, Intermediate, Routine/manual, Not Classified – this group includes students, in addition to the long term unemployed).[288]

The analyses in this chapter used data from the 2010-2014 waves of NTS, which were pooled to increase the sample size and increase statistical power. Although addresses were excluded from the sampling frame for the three years following participation, by pooling five years' worth of data it is possible that the same participants were sampled twice. However, it was not possible to know whether this was the case from the data and it was considered unlikely. The sample was restricted to those participants aged 17 years and above from households in which all members participated in the interview and completed the 7-day travel diary, giving an analytical sample of 61,612.

6.1.2 Analyses

Frequency of bus and train use from the interview were examined descriptively. Data from the NTS diary were then used to assess whether reporting using a bus, light-rail or a train in the diary week were associated using any other public transport mode, this was done using cross-tabulation and Pearson's Chi squared tests. Diary data were then used to descriptively examine combinations of public transport modes used by public transport users. Data from the diary were then used to summarise the characteristics of public transport users with differences in public transport use across levels of each characteristic assessed using a Pearson's chi squared test. Associations between participant characteristics and public transport use were examined using logistic regression. This was carried out univariate for each characteristic and was carried out maximally-adjusted with all variables included in the model simultaneously. Logistic regression was then also used to examine the characteristics associated with bus use, light-rail use and train use in the same way. The amount of public transport accumulated by those characterised as users of each mode was

then calculated using the median and interquartile range (IQR), along with the mean and 95% CIs for the number of stages reported.

The complex survey design employed by NTS meant that individuals were not sampled independently, i.e. they were clustered within postcode sectors and households. If this were not accounted for, it could lead to increased variability between different years of NTS, therefore regression analyses took account of clustering within primary sampling units, which in NTS was the postcode sector.[291]. Accounting for variance between primary sampling units automatically incorporates additional levels of clustering, in a process known as ultimate clusters, it was therefore not necessary to account for further levels of clustering, for example, at the household level.[292, 293]. Although this assumption is based on replacing sampling units after selection (allowing them to be selected again), which was not the case in NTS, where sampling fractions are small this is understood to have little impact.[292, 293] As regression took place at the individual level, with stages used simply to identify individuals who used public transport, further clustering of stages within journeys was therefore not relevant to this analysis.

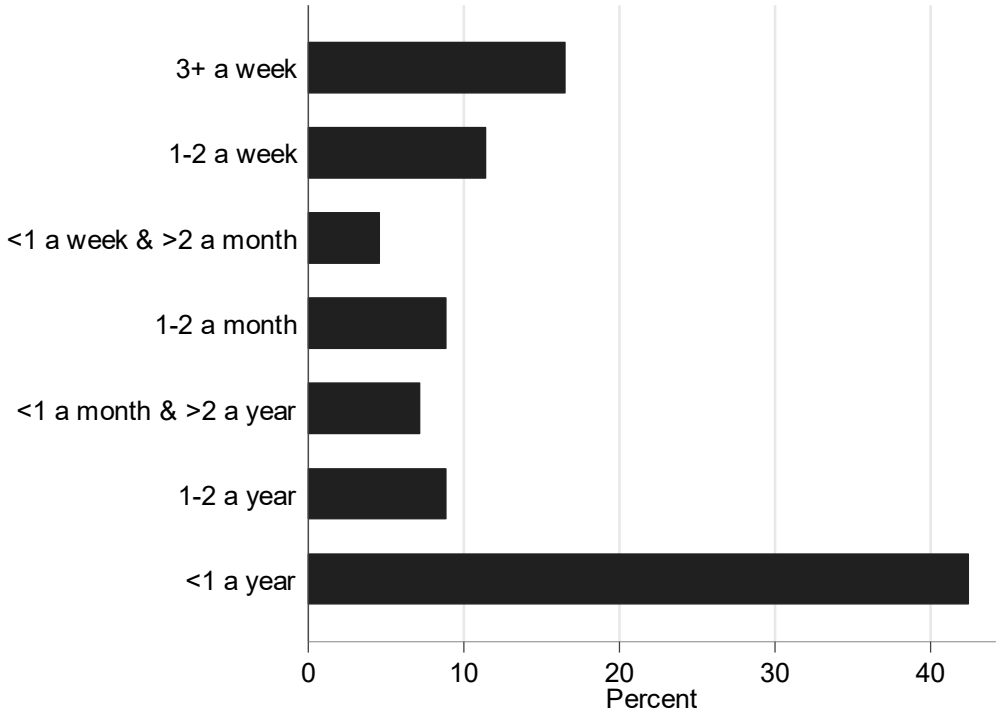
NTS provides weights for use in analyses, which aim to correct for biases in different levels of data, caused by differing probabilities of being sampled.[291] At the household level, these biases include non-response bias and selection bias, for example, due to multiple households sharing an address.[202] Non-responders and those with shared addresses are known to differ from the general population in terms of age and socio-economic position.[202] Weights were also used to ensure that the sample was representative in terms of age, sex and geographical region, based on mid-year population estimates calculated using census data. Participants started completing their diaries on different days of the week therefore weights at the level of the journey are required to account for differences in journey reporting across the days of the diary week (1-7).

6.2 Results

6.2.1 Interview questions on frequency of bus and train use

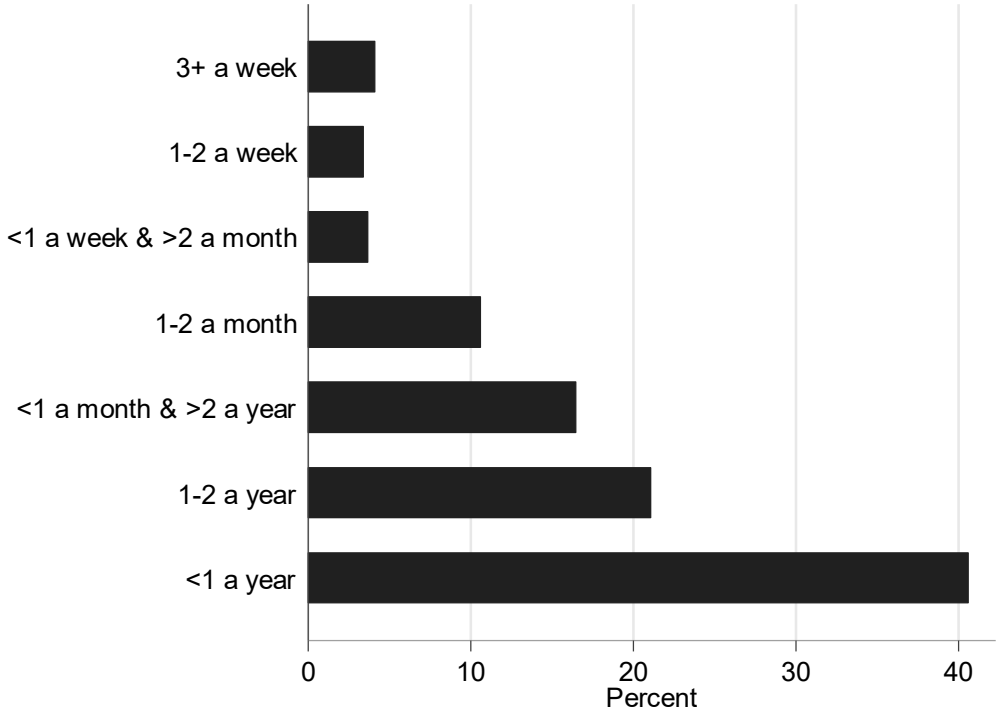
The responses to the interview question about frequency of bus use show a broadly bimodal distribution with peaks at both frequency extremes (Figure 6-1). 42% of participants used the bus less than once a year, while 17% of participants used buses three or more times per week and 11% used buses once or twice a week. Intermittent bus use was less common, with between 5% and 9% of respondents reporting bus use at least once a year but less than once a week.

Figure 6-1: The frequency of bus use among NTS participants from 2010-2014



40% of participants used a train less than once a year, which was comparable with the proportion reporting this frequency of bus use (Figure 6-2). However, unlike with bus use, there was a trend for fewer participants with increasing frequency of use, with 4% reporting train use frequency of three or more time per week.

Figure 6-2: Frequency of train use among NTS participants from 2010-2014



6.2.2 Analysis of travel diary data

Public transport use was reported at least once in the diary week by 32.5% of the sample (Table 6-1). Women were more likely to use public transport in the diary week than men (35.1% vs 29.6%, AOR = 1.22 (1.18, 1.27)). Those aged 40-59 were less likely to use public transport that those aged 17-25 (25.7% vs. 48.2%, AOR = 0.41 (0.38, 0.44)). Compared with White participants, South Asians were more likely to use public transport in the diary week in unadjusted data, 39.7% vs. 30.6% but less likely in adjusted analysis (AOR = 0.80 (0.72, 0.90)). Black participants were more likely to use public transport in the diary week than White participants (63.6% vs. 30.6%, AOR = 1.67 (1.47, 1.91)). In unadjusted data, those in households with an income of less than £25,000 were more likely to use public transport in the diary week than those with household incomes of £50,000 or more, 37.7% vs. 30.9%, but in adjusted analyses were less likely (AOR = 0.84 (0.79, 0.90)). In unadjusted analyses, participants living in rented accommodation were more likely to use public transport in the diary

week than those living in owned accommodation, 42.9% vs. 28.3%, but less likely in adjusted analysis (AOR = 0.93 (0.88, 0.99)). Those with no access to a car were more likely to use public transport in the diary week than those with car access (68.4% vs. 24.8%, AOR=5.89 (5.49, 6.32)). Residents of more population dense neighbourhoods were more likely to use public transport in the diary week than those living in lower population density areas, for example, comparing residents of areas with 75+ persons per hectare with these in areas of <10 persons per hectare, public transport use was 66.6% vs. 20.8%, AOR = 1.96 (1.68, 2.29). Residents of smaller conurbation types had lower public transport use than London residents, for example, compared with London residents, those who live in areas with fewer than 50,000 residents had public transport use of 20.3% vs. 59.8%, AOR = 0.27 (0.24, 0.30).

Table 6-1: Characteristic of public transport users and predictors of public transport use among NTS participant 2010-2014

	% using public transport in the diary week	Chi-square p-value*	AOR	95% CI
% reporting any use	32.5			
Sex				
Men	29.6	<0.001	1.00	
Women	35.1		1.22	(1.18, 1.27)
Age				
17-25	48.2	<0.001	1.00	
26-39	32.5		0.49	(0.45, 0.53)
40-59	25.7		0.41	(0.38, 0.44)
60+	33.8		0.61	(0.57, 0.66)
Ethnicity				
White	30.6	<0.001	1.00	
South Asian	39.7		0.80	(0.72, 0.90)
Black	63.6		1.67	(1.47, 1.91)
Other	46.9		1.05	(0.93, 1.19)
Household NS-SEC - Social Class				
Managerial	30.2	<0.001	1.00	
Intermediate	28.7		0.80	(0.75, 0.85)
Routine/manual	37.9		0.86	(0.80, 0.91)
Unclassified	49.9		0.77	(0.66, 0.89)
Household Income				
£50,000 and over	30.9	<0.001	1.00	
£25,000 to £49,999	27.5		0.84	(0.79, 0.90)
Less than £25,000	37.7		0.88	(0.82, 0.94)
Housing Tenure				
Owns	28.3	<0.001	1.00	
Rents	42.9		0.93	(0.88, 0.99)
Car Access				
Access to a car	24.8	<0.001	1.00	
No car access	68.4		5.89	(5.49, 6.32)
Population Density**				
<10	20.8	<0.001	1.00	
10-24.99	30.2		1.21	(1.11, 1.32)
25-39.99	33.9		1.26	(1.14, 1.38)
40-74.99	46.0		1.50	(1.35, 1.67)
75+	66.6		1.96	(1.68, 2.29)
Conurbation Type				
London	59.8	<0.001	1.00	
Metropolitan & >250k	35.1		0.39	(0.36, 0.43)
50k-250k	28.6		0.32	(0.29, 0.35)
<50k	20.3		0.27	(0.24, 0.30)

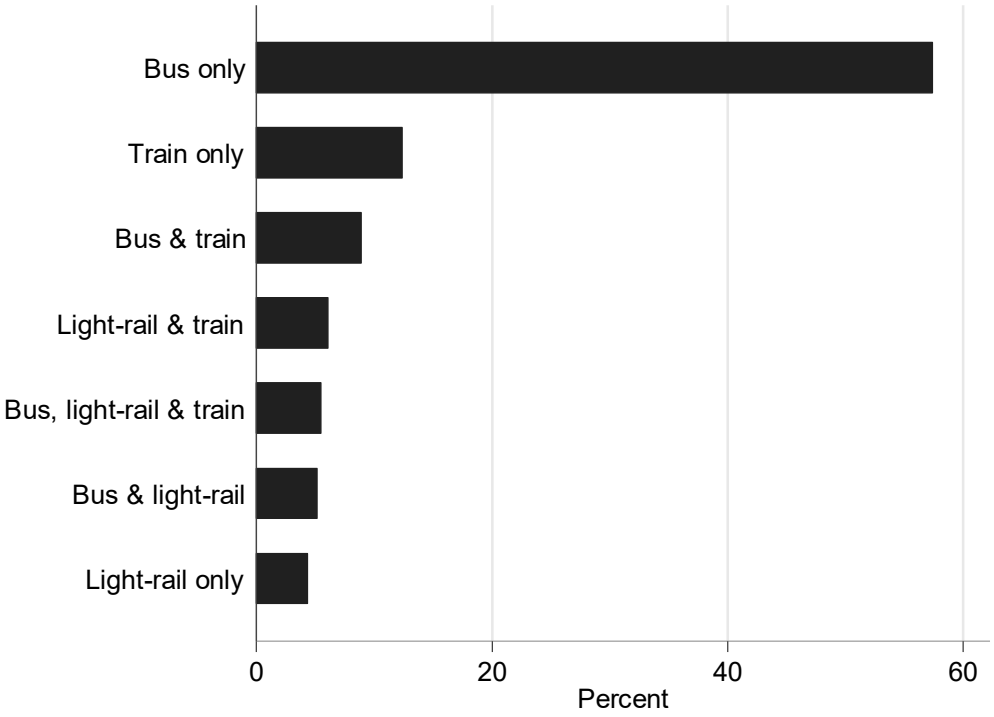
NS-SEC - National Statistic Socio-economic classification AOR – adjusted odds ratio

* - Pearson's Chi-squared test for difference in distribution by characteristics

**Population density of the post code sector of the household address, postcode sectors have a mean population of 7,000

57.5% of public transport users reported only using the bus, while 75.1% used only one public transport mode (Figure 6-3). However, among those participants who used public transport, the use of one public transport mode was associated with the use of others in descriptive analyses, differences here were tested with a Chi-squared test. Train use was more likely among bus users (18.7%) than non-bus users (7.95%, p<0.001). Light-rail use was 4.5% in non-bus users and 13.9% in bus users (p<0.001). 35.2% of train users used light-rail compared with 3.5% of non-train users (p<0.001).

Figure 6-3: The distribution of public transport modes among those who reported using public transport in the travel diary n=19,858



Bus travel was reported by 24.9% of participants, with women more likely to use a bus in the diary week than men (28.4% vs. 20.8%, AOR = 1.44 (1.38, 1.50)) (Table 6-2). Those aged 17-25 were most likely to use a bus in the diary week, while those aged 40-59 were least likely (37.5% vs 17.2% (AOR = 0.43 (0.39, 0.46)). Black participants were more likely to use a bus in the diary week than Whites

(55.4% vs. 23.2%, AOR = 2.16 (1.89, 2.48)). Those from households whose highest NS-SEC was a routine/manual occupation were more likely to use a bus in the diary week than those from managerial occupation households (34.6% vs. 19.7%, AOR = 1.16 (1.08, 1.24)). Those with household incomes of less than £25,000 were more likely to use a bus in the diary week than those in households with an income of £50,000 or more (33.3% vs. 17.1%, AOR = 1.24 (1.15, 1.33)). Those with no access to a car were more likely to use a bus in the diary week than those with car access (62.0% vs. 16.9%, AOR = 5.68 (5.28, 6.11)). Residents of high population density neighbourhoods were more likely to use a bus in the diary week than those in areas of lower population density. For example, those in postcode sectors with 75 or more persons per hectare were more likely to use a bus than those in sectors of less than 10 persons per hectare (51.3% vs. 15.0%, AOR = 1.65 (1.39, 1.95)).

Table 6-2: Characteristic of bus users and predictors of bus use among NTS participant 2010-2014

	% using a bus in the diary week	Chi-square p-value*	AOR	95% CI
% reporting any use	24.9			
Sex				
Men	20.9	<0.001	1.00	
Women	28.4		1.44	(1.38, 1.50)
Age				
17-25	37.5	<0.001	1.00	
26-39	21.8		0.44	(0.41, 0.49)
40-59	17.2		0.43	(0.39, 0.46)
60+	30.3		0.84	(0.77, 0.91)
Ethnicity				
White	23.2	<0.001	1.00	
South Asian	29.8		0.97	(0.85, 1.10)
Black	55.4		2.16	(1.89, 2.48)
Other	36.1		1.14	(0.99, 1.31)
Household NS-SEC - Social Class				
Managerial	19.7	<0.001	1.00	
Intermediate	23.5		1.00	(0.93, 1.07)
Routine/manual	34.6		1.16	(1.08, 1.24)
Unclassified	41.0		0.80	(0.68, 0.96)
Household Income				
£50,000 and over	17.1	<0.001	1.00	
£25,000 to £49,999	21.0		1.17	(1.09, 1.26)
Less than £25,000	33.3		1.24	(1.15, 1.33)
Housing Tenure				
Owns	20.3	<0.001	1.00	
Rents	36.2		0.99	(0.93, 1.06)
Car Access				
Access to a car	16.9	<0.001	1.00	
No car access	62.0		5.68	(5.28, 6.11)
Population Density**				
<10	15.0	<0.001	1.00	
10-24.99	23.0		1.17	(1.06, 1.28)
25-39.99	26.6		1.22	(1.10, 1.36)
40-74.99	36.2		1.46	(1.29, 1.65)
75+	51.3		1.65	(1.39, 1.95)
Conurbation Type				
London	43.3	<0.001	1.00	
Metropolitan & >250k	29.2		0.58	(0.53, 0.64)
50k-250k	22.8		0.45	(0.41, 0.50)
<50k	14.4		0.34	(0.31, 0.39)

NS-SEC - National Statistic Socio-economic classification AOR – adjusted odds ratio

** - Pearson's Chi-squared test for difference in distribution by characteristics*

***Population density of the post code sector of the household address, postcode sectors have a mean population of 7,000*

Light-rail use was reported in the travel diaries of 6.8% of participants and was less common among women than among men (6.4% vs. 7.3%, AOR = 0.88 (0.83, 0.94)) (Table 6-3). Those in older age groups were less likely to use light-rail than younger participants, for example, those aged 60 and above were less likely to use light-rail compared with those aged 17-25 (3.7% vs. 9.3%, AOR = 0.51 (0.44, 0.60)). In unadjusted data, light-rail use was 6.0% in Whites, 11.4% in South Asians and 16.8% in Black participants. However, in adjusted analyses White participants were more likely to use light-rail than both South Asian and Black participants, who had AORs = 0.59 (0.49, 0.71) and 0.75 (0.62, 0.91) respectively. Residents of households with an income of less than £25,000 were less likely to use light-rail in the diary week than residents of households with an income of £50,000 or more (4.5% vs. 11.5%, AOR = 0.52 (0.46, 0.59)). Those without car access were more likely to use light-rail in the diary week than those with access (12.0% vs. 5.7%, AOR = 2.30 (2.01, 2.63)). Participants living in higher population density neighbourhoods were more likely to use light-rail in the diary week than those in lower density neighbourhoods, for example, residents of areas with 75 or more persons per hectare had light-rail use of 31.4%, compared with 2.8% in areas of fewer than 10 persons per hectare (AOR = 2.75 (2.93, 3.66)).

Table 6-3: Characteristic of light-rail users and predictors of light-rail use among NTS participant 2010-2014

	% using light-rail in the diary week	Chi-square p-value*	AOR	95% CI
% reporting any use	6.8			
Sex				
Men	7.3	<0.001	1.00	
Women	6.4		0.88	(0.83, 0.94)
Age				
17-25	9.3	<0.001	1.00	
26-39	10.2		0.98	(0.86, 1.12)
40-59	6.8		0.72	(0.63, 0.81)
60+	3.7		0.51	(0.44, 0.60)
Ethnicity				
White	6.0	<0.001	1.00	
South Asian	11.4		0.59	(0.49, 0.71)
Black	16.8		0.75	(0.62, 0.91)
Other	15.5		1.00	(0.80, 1.24)
Household NS-SEC - Social Class				
Managerial	9.0	<0.001	1.00	
Intermediate	4.5		0.55	(0.48, 0.62)
Routine/manual	3.5		0.42	(0.37, 0.49)
Unclassified	9.8		0.66	(0.53, 0.81)
Household Income				
£50,000 and over	11.5	<0.001	1.00	
£25,000 to £49,999	5.7		0.64	(0.57, 0.71)
Less than £25,000	4.5		0.52	(0.46, 0.59)
Housing Tenure				
Owns	6.3	<0.001	1.00	
Rents	8.2		0.84	(0.76, 0.94)
Car Access				
Access to a car	5.7	<0.001	1.00	
No car access	12.0		2.30	(2.01, 2.63)
Population Density**				
<10	2.8	<0.001	1.00	
10-24.99	4.0		0.98	(0.78, 1.23)
25-39.99	5.2		1.23	(0.94, 1.61)
40-74.99	12.1		1.73	(1.33, 2.24)
75+	31.4		2.75	(2.06, 3.66)
Conurbation Type				
London	26.1	<0.001	1.00	
Metropolitan & >250k	3.9		0.15	(0.13, 0.18)
50k-250k	2.7		0.12	(0.10, 0.15)
<50k	2.4		0.12	(0.10, 0.16)

NS-SEC - National Statistic Socio-economic classification *AOR – adjusted odds ratio*

* - Pearson's Chi-squared test for difference in distribution by characteristics

**Population density of the post code sector of the household address, postcode sectors have a mean population of 7,000

Train use was reported in the travel diaries of 10.6% of participants, with women less likely to use a train in the diary week than men (9.9% vs. 11.4%, AOR of 0.86 (0.82, 0.91) (Table 6-4). Those aged 60+ were less likely to use trains than those aged 17-25 (6.0% vs. 16.6%, AOR= 0.37 (0.33, 0.41). In unadjusted data, South Asians were more likely to use a train in the diary week that White participants, 12.6% vs. 10.0%, but the opposite was true in adjusted analyses (AOR=0.67 (0.57, 0.78)). Those of Black ethnicity were also more likely to use a train in the diary week than Whites in unadjusted data, 19.7% vs. 10.0%, this was not seen in adjusted analyses (AOR = 1.03 (0.88, 1.20). Those in routine/manual occupation households were less likely to use a train in the diary week than those in managerial occupation households (5.9% vs. 13.6%, AOR of 0.44 (0.40, 0.49). Participants in households with an income of less than £25,000 were less likely to use a train in the diary week than those with household incomes of at least £50,000 (7.4% vs. 16.7%, AOR of 0.60 (0.54, 0.66)). Those with no access to a car were more likely to use a train in the diary week than those with car access (14.8% vs. 9.7%, AOR=2.14 (1.93, 2.38)). Participants living in London were more likely to use a train in the diary week than those in other conurbation types, for example, residents of conurbations of fewer than 50,000 inhabitants had an AOR of 0.32 (0.27, 0.37).

Table 6-4: Characteristic of train users and predictors of train use among NTS participant 2010-2014

	% using a train in the diary week	Chi-square p-value*	AOR	95% CI
% reporting any use train	10.6			
Sex				
Men	11.4	<0.001	1.00	
Women	9.9		0.86	(0.82, 0.91)
Age				
17-25	16.6	<0.001	1.00	
26-39	14.3		0.77	(0.69, 0.84)
40-59	10.4		0.55	(0.50, 0.60)
60+	6.0		0.37	(0.33, 0.41)
Ethnicity				
White	10.0	<0.001	1.00	
South Asian	12.6		0.67	(0.57, 0.78)
Black	19.7		1.03	(0.88, 1.20)
Other	15.9		0.89	(0.72, 1.10)
Household NS-SEC - Social Class				
Managerial	13.6	<0.001	1.00	
Intermediate	7.7		0.63	(0.57, 0.69)
Routine/manual	5.9		0.44	(0.40, 0.49)
Unclassified	14.7		0.84	(0.70, 1.00)
Household Income				
£50,000 and over	16.7	<0.001	1.00	
£25,000 to £49,999	9.4		0.67	(0.62, 0.73)
Less than £25,000	7.4		0.60	(0.54, 0.66)
Housing Tenure				
Owns	10.5	0.082	1.00	
Rents	11.0		0.80	(0.73, 0.87)
Car Access				
Access to a car	9.7	<0.001	1.00	
No car access	14.8		2.14	(1.93, 2.38)
Population Density**				
<10	7.4	<0.001	1.00	
10-24.99	9.3		1.14	(1.00, 1.30)
25-39.99	10.4		1.20	(1.04, 1.40)
40-74.99	15.0		1.30	(1.11, 1.52)
75+	22.8		1.17	(0.96, 1.43)
Conurbation Type				
London	24.8	<0.001	1.00	
Metropolitan & >250k	8.2		0.32	(0.28, 0.36)
50k-250k	8.3		0.33	(0.29, 0.38)
<50k	7.2		0.32	(0.27, 0.37)

NS-SEC - National Statistic Socio-economic classification *AOR – adjusted odds ratio*

* - Pearson's Chi-squared test for difference in distribution by characteristics

**Population density of the post code sector of the household address, postcode sectors have a mean population of 7,000

Among participant who reported at least one journey stage by public transport in the 7-day travel diary, the median stages reported was 4.5 (interquartile range (IQR) = 2.2 – 9.7), while the mean number of stages was 6.8 (95% CI = 6.7 – 6.8). For participants reporting at least one bus stage, the median stages reported was 4.1 (IQR = 2.1-8.3) and mean was 5.6 (95% CI = 5.5 – 5.7). For participants reporting at least one stage by light-rail, the median stages reported was 3.1 (IQR = 2.0 – 6.2), while the mean stages was 5.1 (95% CI = 4.9 – 5.2). For participants who reported at least one stage by train, the median stages reported was 2.2 (IQR = 2.0 – 6.2), while the mean stages was 4.2 (95% CI = 4.1 – 4.3).

Table 6-5: Amount of public transport stages reported in the travel diary of those reporting at least some use

Mode	N (% of population*)	Median stages	IQR	Mean stages	95% CI
Public Transport	20, 029 (32.5)	4.5	2.2 - 9.7	6.8	6.7 – 6.8
Bus	15, 308 (24.9)	4.2	2.1 – 8.3	5.6	5.5 – 5.7
Light-rail	4, 212 (6.8)	3.1	2.0 – 8.3	5.1	4.9 – 5.2
Train	6, 540 (10.6)	2.2	2.0 – 6.2	4.2	4.1 – 4.3

6.3 Discussion

6.3.1 Main findings of this chapter

These findings show than nearly one third of people use public transport at least once a week and that more than twice as many people use a bus in a given week than use a train. Public transport use was common among women, the oldest and the youngest, those of minority ethnicities, those in socio-economically disadvantaged households and those living in large conurbations. Of those that used public transport, bus use was the most commonly used mode, although nearly a quarter of public transport users used more than one public transport mode. However, the characteristics of the users of different public transport modes were distinct. Bus use was more common among women, those living in socio-economically disadvantaged households and those living in areas with higher population density than in men, those in socio-economically advantaged households and

those in areas with lower population density respectively. Train use was were more likely among participants who were men, aged less than 25, and from socio-economically advantaged households than in women, older people and those from less socio-economically advantaged households.

6.3.2 Strengths and weaknesses

Strengths of the analysis in this chapter include the use of a large sample from a representative data source and the use of a travel diary, which should help to reduce the reporting bias associated with self-reported surveys of travel behaviour.[200] Detailed data about modes of transport allowed for a disaggregation of different public transport modes, including separating the users of light-rail and trains. The inclusion of public transport use for all purposes means that, unlike most surveys of commute mode, it captures the use of multiple modes, within one day and across the week.[294] Furthermore, by examining the use of public transport modes descriptively and while adjusting for other factors, this analysis was able to explore the interrelated nature of different factors associated with the use of public transport modes.

Weaknesses of this study include the use of self-reported survey data, which are subject to reporting bias. Research to validate a travel diary similar to the one used in NTS, by comparing it with a body worn camera, found that the travel diary under-reported the number of journeys and over-reported journey duration.[204] The effect of this underreporting on the findings of this chapter are uncertain, with insufficient data available on whether the underreporting differs across public transport modes. It would only affect these findings if participants failed to report all journeys of a particular public transport mode.

The interview questions required participants to quantify their frequency of bus or train use in the preceding 12 months, which assumes a considerable level of recall. There is no evidence that recall

differed across pubic transport modes, however, it is plausible that train use is more memorable than bus use. Frequency of use data were only available for bus and train. The train use question explicitly excluded the use of light-rail or metro systems, such as the London Underground, and no separate question was asked about the frequency of light-rail use. This means that light-rail use of less than once a week could not be quantified and the examination of overall public transport use was not possible with interview data.

However, it is possible to compare bus and train use between the interview question, relating to the previous 12 months, and the travel diary, which sampled a single 7-day period, to enable some degree of validation. 28% of participants reported bus use at least once a week in the interview, compared with 33% in participant diaries. Train use at least once a week was seen in 8% of participant interviews and 11% of travel diaries. Although broadly comparable, these differences might suggest a slight underreporting of bus and train use when participants are asked in the interview to estimate their journey frequency in the preceding 12 months. In addition to recall bias leading to an underestimate in the interview questions, this might reflect the slightly different samples used, which was due to missing data for the interview questions. 2,623 participants were excluded due to missing data for bus use frequency, however, only 22 people failed to provide a frequency of train use. Finally, the interview question about frequency of bus use was restricted to local bus use, the analysis of the diary data did not make this restriction.

Travel diary data about the use of different public transport modes were recorded on a single week. It is uncertain whether this was representative of participants' normal travel behaviour. However, NTS data was gathered all year-round, with even coverage throughout the year to prevent seasonal variations.[202] As the sample size was large, variations from usual behaviour were expected to cancel out across the population.

All variables were simultaneously included in the models in order to statistically adjust for potential confounding, however, there was likely to be some residual confounding. Although several variables were included which capture socio-economic position, it is likely that the measures used were insufficient. The measure of ethnicity combined groups which are known to have some differences, for example, those of Indian ethnicity were combined with those of Pakistani and Bangladeshi ethnicity, therefore heterogeneity within ethnic groups might contribute to residual confounding.[93] However, more specific ethnic groups suffered from low numbers of participants and could not be examined without a larger sample size or a sample with an ethnic minority boost. Additionally, although geographical variables were included, these were unlikely to fully capture differences in access to a useful public transport service.

An important factor related to the use of public transport use is the distance to access public transport and the total distance travelled. Distance to access public transport was not available in the data used in this thesis so could not be accounted for. Total journey distance might be a determinant of the mode of travel used, for example, if the journey is long distance it might be less likely to be carried out by bus and more likely to be carried out by train. However, it is also plausible that causation runs in both directions, for example, if a bus were the only transport mode available (for geographical or financial reasons), an individual might be restricted to shorter distance travel. For this reason, distance of journeys was not included in these analyses.

6.3.3 Comparison with other studies

The most comparable data for transport mode use are from DfT analyses, which also uses NTS data.[43] The DfT analyses were carried out at the journey level, rather than the more granular journey stage, which was used in this chapter. They also restricted to local buses rather than including all buses and they also did not examine light-rail users. The DfT analyses found local bus

use of 24% and train use of 10%, which are very slightly lower than the findings in this chapter.[43] The lower findings use might be due to their restriction to local buses or the use of journeys rather than stages. The latter is also likely to have a greater impact on bus use than on train use as bus travel is generally of shorter distance than train travel, a journey containing both bus and train travel is likely to be categorised at a train journey, assuming the train stage is of greater distance than the bus stage.

The DfT analyses also characterised the users of buses and trains.[43] These analyses found similar age composition of bus and train users to those in this chapter, although used slightly different categorisations.[43] In addition, the DfT analyses found a higher proportion of bus users in the lowest two income quintiles and that higher income groups have greater train use, which is concordant with the finding in this chapter.[43] That these findings are very similar to those in this chapter are reassuring but not surprising. They use data from the same diaries that were used here over a very similar time period. They were however, descriptive and therefore not adjusted for potentially confounding factors.

The Census of England and Wales collects data on usual commute mode.[294] Similar to the findings of this chapter, census data from 2011 show that bus commuting is more common than train or light-rail commuting (7%, 5% and 4% of working adults respectively).[294] These figures are lower than the findings in this chapter, which is unsurprisingly as restricting to usual commute mode excludes travel for other purposes. It also means that each person only reports one (usual) mode, unlike the analyses in this chapter.

Public transport users in this study can be compared with the public transport commuters who were examined by research into the association between public transport and health.[47] This study used data from a representative sample of UK residents who participated in UKHLS and found lower

absolute levels of public transport use than analyses in this chapter, which is to be expected due to the restriction to commute mode. The ethnic profile of public transport commuters appears to be comparable with public transport users in this chapter and similar differences in public transport use between London and other areas were seen. The greater use of public transport by women is less pronounced among commuters, which might reflect a greater propensity for women to travel by public transport for reasons other than work. Younger people are more likely to commute by public transport, which is consistent with findings in this chapter. Data from the UK Biobank study shows that 13% of commuters used public transport, with or without walking/cycling.[180] A further 11% commuted using a car in addition to either public transport or walking/cycling.[180] This appears comparable with other commuting data, although uncertainty about how many of this 11% used public transport makes direct comparisons difficult.

6.3.4 Implications

These findings show than nearly one third of people used public transport at least once a week and that more than twice as many people used a bus in a given week than used a train. Bus, train and light-rail were all more common among younger adults, however, bus use was also common among older individuals. Among other factors, this may be related to the free bus pass for older people in England, which will be discussed further in Chapter 8. Bus use was also more common in some ethnic groups, for example, Black participants were more likely to use a bus than other groups, while White participants were more likely to use light-rail than those of other ethnicities. Although, in raw percentage terms, Black and South Asian participants were more likely to use light-rail than Whites. The difference between raw and adjusted findings might be due to those of minority ethnicity being more likely to live in large population-dense urban areas where light-rail is likely to be present. The number of stages reported by users of each mode show that bus users used buses more often than users of other modes used these. The findings that among those using each mode, the median

number of stages was lower than the mean stages reflects the right skew in the numbers of stages reported. The finding that the lower quartile was around two stages for each mode suggests that a substantial proportion of public transport users use public transport with a frequency of less than three times per week. This is likely to limit the potential health effects people might receive from their public transport use.

This chapter finds that socio-economically disadvantaged people are more likely to be bus users than those who are more advantaged, who in turn are more likely to be light-rail and train users. Increased conurbation size and increased population density are associated with bus use and light-rail use. Train use is greatest in London and is less likely in other conurbation types. The association between population density and train use is less pronounced. This might be because urban train networks serve predominantly suburban and peri-urban areas, which are less densely populated, while bus and light-rail is most common in inner city areas, which are often the most population dense.[14, 295, 296] The socio-economic make-up of inner city residents is also likely to differ from those in the outer city areas, although this differs depending on the marker of socio-economic position used.[297, 298] This might affect some of the socio-economic patterns in the use of different public transport modes seen here. The absence of important variables made definitive investigation of built environment determinants of public transport use in this thesis impossible.

In addition to the availability of different transport choices, other factors might affect how different groups use public transport. For example, bus journeys are likely to be shorter than those by rail transport.[26] Longer distance commutes are associated with higher occupational group (e.g. professional) compared with those in other occupation groups.[299] In addition to their length, public transport mode use differs according to the purpose of the journey. 22% of bus journeys are for commuting purposes, compared with 47% of train journeys.[300] Shopping and education related journeys, including talking children to school, are more likely to be by bus.[300] Gender

differences in journey purpose are also seen, with women making more journeys than men taking children to school and to go shopping and fewer journeys than men commuting.[18, 45]

6.4 Conclusions

These findings show than nearly one third of people use public transport at least once in a given week and that more than twice as many people per week use buses than trains. Train use is most common among the socio-economically advantaged and men, while bus use is most common in the socio-economically disadvantaged and women. There is additionally some evidence that a substantial number of people use multiple public transport modes.

Chapter 7 – Physical activity accrued as part of public transport use in England

In England in 2016, 42% of women and 34% of men were insufficiently physically active; these high levels of physical inactivity are the result of reduced energy expenditure in several domains of daily life.[144] Physical inactivity is defined as not meeting global physical activity recommendations of 150 minutes of moderate intensity physical activity per week or the equivalent.[141] In high income countries, levels of physical inactivity have increased from 31.6% (27.1, 37.2) in 2001 to 36.8 (35.0, 38.0) in 2016.[145] This is partly explained by a trend towards more sedentary occupations and a reduced need for physical activity in the home following the automation many domestic chores.[301, 302] Levels of physical activity from transport have also been declining, for example, transport walking in England reduced between 2002 and 2015, both in terms of journeys per person and distance travelled.[6, 17] For example, walking decreased from 241 journeys per person per year in 2002 to 200 in 2015.[6]

The use of physically active travel modes can lead to incidental health benefits, this includes public transport use, which often involves some walking or cycling in order to reach a communal access point, for example, walking to a bus stop.[248] These seemingly modest amounts of physical activity often occur at each end of public transport journeys and are sometimes required to transfer between public transport modes. Walking and cycling have established health benefits, for example, walking and cycling for transport is associated with lower adiposity [172, 176, 180], and a lower risk of CVD and all-cause mortality.[171, 174, 178] Other potential benefits include reduced depressive symptoms [246], reduced diastolic blood pressure [247] and a reduced risk of type 2 diabetes [178] and cancer.[179] Where dose-response relationships have been examined, these often demonstrate

a non-linear relationships with the greatest benefits seen among those who move from little or no walking or cycling to some.[174, 179]

There is some evidence for an association between public transport and physical activity. A systematic review in 2012 found that public transport use was associated with between 7 and 33 minutes per day of physical activity.[184] This review included data from 27 studies encompassing the USA, Canada and Japan, however, most of the included studies used small and highly selective populations. There were two UK studies included in this review, one measured the number of steps per day in those aged 70+ using an accelerometer, finding that each additional public transport journey per week was associated with an additional 413 steps per day, which was converted to 8 minutes of walking by the reviewers to allow comparison.[184, 186] The second study found that train users walked an average of 0.9km per journey, which was converting to 10-12 minutes.[184, 185] No large studies have quantified the physical activity associated with public transport use using representative data about public transport users in England.

The walking and cycling associated with public transport users has not been evaluated using large representative survey of the travel patterns of England residents therefore this chapter aims to address the following research questions:

- How much physical activity do public transport users in England who walk or cycle as part of public transport journeys accrue in the course of public transport journeys?
- Does the level of physical activity accrued differ between users of different public transport modes?
- Does the level of physical activity accrued vary according to individual or neighbourhood characteristics?

7.1 Methods

7.1.1 Data

Data for this chapter come from NTS which is discussed in detail in Section 6.1.1 with further information available from survey documentation.[202, 288] In brief, NTS is an annual cross-sectional survey of the residents of private households in England, which is representative in terms of age, sex and geographical region. All those living in sampled households are invited to participate in the survey, which consists of two elements, an interview and a 7-day travel diary. The interview includes questions about demographic and socio-economic characteristics, such as age and occupation, in addition to travel-related information, such as household access to a car. Additional variables are derived from participants' home address, including the population density of their local area and the size of their conurbation of residence. The travel diary involved recording the details of all journeys made during a 7-day period, the mode, the distance covered and the time taken. In addition, each stage of a journey should also be recorded, such that the details of the walk to the bus stop are recorded, in addition to the details of the bus journey itself. NTS assigns all journeys an overall mode, for journeys with more than one mode, the overall mode is that used for the longest stage, by distance. In order to reduce the burden on participants, short walks were only recorded on the seventh and final day of the travel diary.[202] Short walks are those of less than 1 mile, or 20 minutes in length, while walks of less than 50 yards were always excluded.[202]

NTS data from 2010 to 2014 were pooled to augment the sample size and boost statistical power. Short walks (<1 mile) were expected to make a substantial contribution to physical activity in the course of public transport use, therefore, only data from the day on which these were recorded were included in these analyses. Included participants were those aged 17 years and above (n=61,612), who recorded a journey on the short walk day (48,662). Of these, 7,458 participants reported a journey with public transport designated as the main mode, 4,312 of which contributed

data for how they got to or from the public transport. Due to the focus on quantifying physical activity accrued by those walking or cycling as part of public transport journeys, 671 participants who used only private vehicles to access public transport were excluded. In addition, three participants were excluded as they failed to provide details of which public transport mode they used, resulting in a final sample of 3,638.

The exclusion of those not reporting how they got to or from public transport was to exclude those underreporting short walks, a known bias in surveys of this kind.[204] A public transport journey recorded with no stage by another mode at either end was deemed to be incomplete. This was because all walks of greater than 50 yards (45 metres) should have been recorded. Although some people may travel to or from locations within this distance of public transport, more than 50% of public transport users in this data suggest that their origin and destination were both within this distance for all their public transport journeys reported on that day. This was deemed to be unrealistic and more likely to be due to underreporting. The exclusion of those using exclusively car travel to access and egress public transport was also due to the potential for the underreporting of short walks. This was because, while it is plausible that car travel could include no walking sufficient to require reporting, there is no way to distinguish journeys which genuinely contain no walking from those which contained unreported walking. The exclusion of those who access or egressed public transport exclusively by car allowed a focus on quantifying the physical activity as part of public transport journeys among those public transport users who incorporated at least some walking or cycling in their public transport journeys.

The outcomes for these analyses were the total minutes of physical activity (walking or cycling) carried out as part public transport journeys, and whether this met a threshold of 30 minutes a day, which has been used in previous research.[173, 303-305] Based on an assumption of commuting 5 days a week, this threshold broadly corresponds to the World Health Organization (WHO) global

recommendations on physical activity for health, which advocates 150 minutes of moderate intensity aerobic physical activity a week.[141] For all journeys categorised as public transport, which was based on their main mode (by distance), each stage of the journey was categorised as physically active (walk or cycle) or non-active (bus, train or light-rail). For each individual participant, the total number of minutes of physical activity accrued during public transport journeys was calculated.

Physical activity levels were compared across different public transport modes. Public transport users were classified as users of buses, trains or light-rail, with users of more than one mode classified as multimode public transport users. This was based on any use of the mode during the diary day. Light-rail included users of several urban rail public transport systems including: Tyne and Wear Metro, Manchester Metrolink and London Underground.

NTS participants additionally provide data on several individual, household and neighbourhood level covariates. Covariates included: age, sex, ethnicity, household access to a car, size of their conurbation of residence, and population density of the household's post code sector (persons/hectare). The socio-economic position of participants was estimated using household income, housing tenure and a household measure of occupation related socio-economic position. This was based on the National Statistics Socio-economic Classification (NS-SEC). Additional details of variable categorisation are presented in Section 6.1.1.

7.1.2 Analyses

A comparison was made between sample participants and those public transport users who were excluded in order to examine whether they differed and whether this might lead to bias, differences were assessed using a Pearson's Chi squared test. Exclusion was for either not providing information about how they accessed public transport or for the exclusive use of private vehicles to access public

transport. The characteristics of participants that used public transport during the diary day were compared with those that did not, in order to compare the characteristics of these public transport users with non users. Finally, the characteristics of users of the different public transport modes (bus, train, light-rail and multimode) were then compared.

In order to examine the minutes of walking or cycling associated with public transport among sample members, a linear regression model was specified and the average marginal effects were used to make adjusted predictions of minutes per day of physical activity for each level of each characteristic.[306] This was carried out using a log-transformed measure of minutes of physical activity as these data were right skewed.[307] In order to improve the interpretability of results, rather than present coefficient relative to a reference group, average marginal effects were used to predict the total minutes per day of physical activity for each level of included covariates. Average marginal effects are estimates of the effect across each variable in the model, for each variable in turn they were calculated by comparing hypothetical populations, one for each potential value of the variable in question. These populations differed only in the value for that variable and were identical with respect to the other variables, which took their observed value.[306] Comparing these populations, which differed only with respect to the variable in question, allowed the estimation of differences in outcome across the levels of the variable, this process was repeated for each variable in the model. Antilogs were taken, converting these predictions back to the original scale to give the total number of minutes a day of physical activity. The number of minutes was calculated for each public transport mode, and for each level of the other model variables.

Logistic regression was then used to estimate the odds ratio of meeting the threshold of 30 minutes per day of physical activity.. Again, the average marginal effect were used to predict the percentage of participants meeting the 30 minutes per day threshold, this was considered more easily interpretable than the coefficient (odds ratio) relative to a reference group. A percentage was

estimated for each public transport mode, in addition to each level of the other included variables. In both analyses, bivariable regression was carried out separately for each explanatory variable and a maximally adjusted model included all variables simultaneously. Analyses took account of the complex survey design by accounting for clustering within primary sampling units. Analyses were carried out using weights supplied by NTS. The weights account for differences in journey rates across the days of the week and other biases at the level of the diary journey. Weighting also accounts for non-response and other potential biases at household and individual level. In addition, as short walks are only collected on day 7 of the diary, these must be weighted to adjust for the day of the week (Monday-Sunday).[202]

7.2 Results

A comparison of the sample with those public transport users who were excluded from the analysis is given in Appendix Table A-4. Participants were excluded for either not providing details of how they got to or from public transport or for accessing public transport exclusively by private vehicle. The excluded participants were more likely to be bus users, with 75.5% using the bus, compared with 47.4% in the sample ($p<0.001$). 34.3% of the excluded group were aged 60+ compared with 22.0% of the sample participants ($p<0.001$). Those excluded were also more socio-economically disadvantaged than those included in the sample, as measured by household NS-SEC, household income, and housing tenure ($p<0.001$). For example, 34.4% of those in the sample were from households with incomes of £50,000 or more, compared with 21.0% of those excluded. 29.7% of those excluded were London residents, compared with 48.5% of the sample ($p<0.001$).

Table 7-1 compares the sample of public transport users who combined public transport use with some walking or cycle with NTS participants who reported no public transport use. Of the participants who made a journey on the diary day, 8.1% (n=3,638) carried out some walking or

cycling as part of a public transport journey. This is a lower figure than overall public transport use, due to the substantial number of public transport users excluded from this analysis. These participants differed from NTS participants who did not use public transport on every attribute considered, except gender. 14.8% of participants aged 17-25 used public transport, compared with 6.1% of those aged 60+ ($p<0.001$). Among participants of Black ethnicity, 27.0% used public transport, compared with 14.2% of South Asians and 7.0% of Whites ($p<0.001$). 12.4% of participants living in rented accommodation were public transport users compared with 6.6% of those living in owned accommodation ($p<0.001$). Of participants living in households without access to a car, 25.9% used public transport, compared with 5.5% among those with access to a car ($p<0.001$). 31.4% of those living in an area of 75 or more persons per hectare used public transport, compared with 3.8% in those living in areas with less than 10 persons per hectare ($p<0.001$).Living in London was associated with higher public transport use than other conurbation types, 25.5% compared with 6.9% or lower in other conurbations types.

Table 7-1: Characteristics of public transport users and non-users from NTS 2010-2014

	Public Transport Users	Non Public Transport Users	p-value*
All	3638 (8.1%)	41204 (91.9%)	
Gender			
Men	7.8%	92.2%	0.024
Women	8.4%	91.6%	
Age			
17-25	14.8%	85.2%	<0.001
26-39	10.3%	89.7%	
40-59	6.3%	93.7%	
60+	6.1%	93.9%	
Ethnicity			
White	7.0%	93.0%	<0.001
South Asian	14.2%	85.8%	
Black	27.0%	73.0%	
Other	16.7%	83.3%	
Household NS-SEC - Social Class			
Managerial	8.3%	91.7%	<0.001
Intermediate	6.7%	93.3%	
Routine/manual	7.8%	92.2%	
Unclassified	15.0%	85.0%	
Household Income			
£50,000 and over	9.3%	90.7%	<0.001
£25,000 to £49,999	6.7%	93.3%	
Less than £25,000	8.5%	91.5%	
Housing Tenure			
Owns	6.6%	93.4%	<0.001
Rents	12.4%	87.6%	
Household Car Access			
Access to a car	5.5%	94.5%	<0.001
No car access	25.9%	74.1%	
Population density**			
0-9.99	3.8%	96.2%	<0.001
10-24.99	5.8%	94.2%	
25-39.99	7.4%	92.6%	
40-74.99	14.2%	85.8%	
75+	31.4%	68.6%	
Conurbation Type			
London	25.5%	74.5%	<0.001
Metropolitan & >250k	6.9%	93.1%	
50k-250k	5.5%	94.5%	
<50k	3.3%	96.7%	

NS-SEC - National Statistic Socio-economic classification

* - Pearson's Chi-squared test for difference in distribution by characteristics

**Population density of the post code sector of the household address, postcode sectors have a mean population of 7,000

Of the 3,638 sample members who used public transport combined with walking or cycling, 47.4% were bus users (n=1,723), 20.6% were train users, 9.6% used light-rail (n=350) and 22.4% were categorised as multimode public transport users (n=816) (Table 7-2). Of women public transport users, 55.0% were bus users and 17.0% used trains, compared with 38.7% of men using buses and 24.6% using trains ($p<0.001$). Bus use was most likely among those age 17-25 and 60+, 50.7% and 72.4% respectively, compared with 33.5% and 39.5% in those aged 26-39 and 40-59. The opposite pattern was seen with light-rail, which was used by 13.2% of those aged 26-39 and 10.7% of those aged 40-59 compared with 9.1% and 4.0% in those aged 17-25 and 60+ respectively. ($p<0.001$). 58.9% of Black participants were bus users, compared with 46.9% and 44.4% of White and South Asian participants respectively. While train use was 10.5% among Black participants, 22.5% among Whites and 15.6% Asian participants ($p<0.001$). Of those living in a household where the highest NS-SEC was a managerial occupation, 33.4% used a bus and 26.5% used a train. For those in households where the highest NS-SEC was routine/manual, these figures were 75.7% and 9.6% respectively ($p<0.001$). Of those residing areas with the highest population density (75+ persons/hectare), 20.0% used light-rail, compared with 5.2% or fewer in areas with fewer than 40 persons per hectare. 30.9% of participants living in areas with fewer than 10 people per hectare used trains, compared with 9.9% of those in areas with 75 or more people per hectare ($p<0.001$). Participants living in London were most likely to use light-rail (16.6%) and be multimode public transport users (31.8%) when compared with those living in other conurbation types, for example, in areas with fewer than 50,000 residents these were 1.4% and 16.8% respectively ($p<0.001$).

Table 7-2: Characteristic of public transport users in NTS 2010-2014 by mode of transport used

	Bus	Train	Light-Rail	Multi-mode	p-value*
All	1723 (47.4%)	749 (20.6%)	350 (9.6%)	816 (22.4%)	
Gender					
Men	38.7%	24.6%	11.3%	25.4%	<0.001
Women	55.0%	17.0%	8.1%	19.9%	
Age					
17-25	50.7%	22.0%	9.1%	18.2%	<0.001
26-39	33.5%	25.3%	13.2%	28.0%	
40-59	39.5%	23.7%	10.7%	26.1%	
60+	72.4%	9.1%	4.0%	14.5%	
Ethnicity					
White	46.9%	22.5%	9.5%	21.1%	<0.001
South Asian	44.4%	15.6%	13.6%	26.4%	
Black	58.9%	10.5%	6.1%	24.5%	
Other	41.0%	15.6%	12.7%	30.7%	
Household NS-SEC - Social Class					
Managerial	33.4%	26.5%	12.6%	27.5%	<0.001
Intermediate	55.3%	16.9%	7.9%	19.9%	
Routine/manual	75.7%	9.6%	3.8%	10.9%	
Unclassified	59.5%	13.5%	6.3%	20.7%	
Household Income					
£50,000 and over	24.9%	29.5%	14.2%	31.4%	<0.001
£25,000 to £49,999	48.0%	21.8%	8.3%	21.8%	
Less than £25,000	67.3%	11.6%	6.4%	14.7%	
Housing Tenure					
Owns	42.1%	24.7%	9.5%	23.6%	<0.001
Rents	55.1%	14.4%	9.8%	20.7%	
Household Car Access					
Access to a car	37.5%	27.5%	10.8%	24.2%	<0.001
No car access	61.4%	10.7%	8.0%	19.9%	
Population density**					
0-9.99	48.2%	30.9%	3.7%	17.3%	<0.001
10-24.99	52.3%	26.6%	4.3%	16.9%	
25-39.99	51.6%	23.4%	5.2%	19.8%	
40-74.99	47.2%	16.9%	11.4%	24.5%	
75+	39.5%	9.9%	20.0%	30.6%	
Conurbation Type					
London	36.4%	15.3%	16.6%	31.8%	<0.001
Metropolitan & >250k	65.5%	19.8%	4.7%	10.0%	
50k-250k	56.5%	25.3%	2.2%	16.0%	
<50k	47.8%	34.0%	1.4%	16.8%	

NS-SEC - National Statistic Socio-economic classification

* - Pearson's Chi-squared test for difference in distribution by characteristics

**Population density of the post code sector of the household address, postcode sectors have a mean population of 7,000

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The results of regression analyses of minutes of walking or cycling are presented both unadjusted and maximally adjusted in Table 7-3. Among public transport users who incorporated some walking or cycling into public transport journeys, there were a predicted 20.5 minutes per day (19.8, 21.2), this was unchanged by adjustment for relevant covariates. The number of accumulated minutes differed between users of different public transport modes. In maximally adjusted analyses, bus users accumulated 16.0 minutes (15.3, 16.8) with train users on 28.1 minutes (26.3, 30.0). Users of light-rail and multimode public transport users accumulated 23.8 (21.9, 25.8) and 23.3 minutes (21.7, 25.2) respectively. Figure 7-1 shows the frequency of active travel minutes by mode. The daily recorded minutes spanned from <5 to >100, a high frequency of bus users are seen reporting 15-20 minutes a day, with smaller peaks for other modes appearing to be associated with the accumulation of slightly more physical activity. After the significantly larger peak, the number of bus users accumulating more than approximately 45 minutes a day was similar to that of other modes.

Table 7-3: Regression analyses showing the number of minutes of daily physical activity accumulated in the course of public transport use

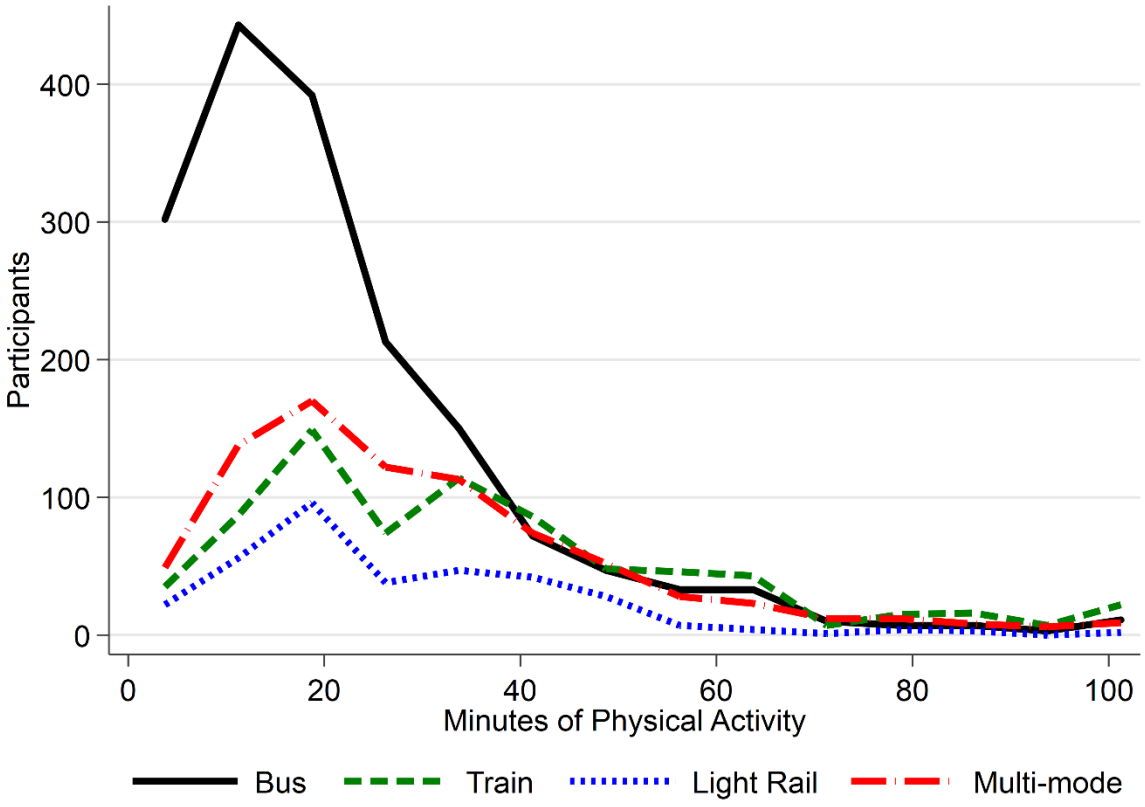
	Minutes of daily physical activity during public transport use (95% CI)			
	Unadjusted* (95% CI)		Adjusted** (95% CI)	
	20.5 (19.8, 21.2)		20.5 (19.8, 21.2)	
Public Transport Mode		**p-value**		**p-value**
Bus	16.2 (15.5, 16.8)	ref	16.0 (15.3, 16.8)	ref
Train	28.7 (27.0, 30.6)	<0.001	28.1 (26.3, 30.0)	<0.001
Light-rail	22.9 (21.2, 24.7)	<0.001	23.8 (21.9, 25.8)	<0.001
Multimode	22.9 (21.3, 24.7)	<0.001	23.3 (21.7, 25.2)	<0.001
Gender				
Men	21.9 (21.0, 22.8)	ref	21.1 (20.2, 22.0)	ref
Women	19.3 (18.5, 20.1)	<0.001	19.9 (19.1, 20.7)	0.024
Age				
17-25	19.8 (18.6, 21.0)	ref	19.9 (18.8, 21.1)	ref
26-39	20.8 (19.5, 22.1)	0.251	19.8 (18.6, 21.1)	0.903
40-59	22.1 (21.0, 23.3)	0.005	21.5 (20.4, 22.6)	0.054
60+	18.7 (17.5, 19.9)	0.194	21.1 (19.7, 22.6)	0.210
Ethnicity				
White	20.9 (20.2, 21.6)	ref	20.5 (19.7, 21.3)	ref
South Asian	19.8 (17.7, 22.2)	0.396	20.6 (18.3, 23.1)	0.961
Black	17.8 (16.3, 19.5)	<0.001	20.5 (18.7, 22.4)	0.997
Other	20.1 (17.6, 23.0)	0.590	20.4 (17.9, 23.1)	0.918
Household NS-SEC - Social Classification				
Managerial	22.0 (21.2, 22.9)	ref	20.8 (19.9, 21.7)	ref
Intermediate	19.7 (18.0, 21.7)	0.035	20.3 (18.5, 22.3)	0.659
Routine/manual	17.7 (16.6, 19.0)	<0.001	20.0 (18.6, 21.5)	0.386
Unclassified	18.7 (16.6, 21.2)	0.014	20.3 (18.1, 22.7)	0.713
Household Income				
≥£50,000	22.6 (21.5, 23.7)	ref	20.8 (19.7, 22.0)	ref
£25,000-£49,999	20.6 (19.5, 21.7)	0.014	20.6 (19.6, 21.7)	0.811
<£25,000	18.5 (17.5, 19.6)	<0.001	20.1 (18.7, 21.5)	0.499
Housing Tenure				
Owns	21.8 (20.9, 22.6)	ref	20.9 (20.0, 21.8)	ref
Rents	19.0 (18.1, 20.0)	<0.001	20.0 (19.0, 21.1)	0.273
Car Access				
Access to a car	21.6 (20.8, 22.5)	ref	20.0 (19.1, 21.0)	ref
No car access	19.1 (18.2, 20.1)	<0.001	21.1 (20.0, 22.2)	0.156
Population Density* **				
<10	21.3 (19.8, 22.9)	ref	19.7 (18.0, 21.6)	ref
10-24.99	22.2 (20.7, 23.8)	0.446	21.8 (20.3, 23.3)	0.065
25-39.99	20.0 (18.5, 21.6)	0.242	19.9 (18.4, 21.5)	0.851
40-74.99	20.6 (19.4, 21.9)	0.502	21.2 (20.0, 22.4)	0.202
75+	19.2 (17.9, 20.7)	0.053	19.7 (18.2, 21.4)	0.975
Conurbation Type				
London	20.1 (19.2, 21.1)	ref	19.4 (18.5, 20.4)	ref
Metropolitan & >250k	20.6 (19.2, 22.1)	0.554	22.2 (20.8, 23.8)	0.003
50k-250k	19.9 (18.3, 21.6)	0.838	20.2 (18.6, 21.9)	0.470
<50k	22.5 (20.9, 24.3)	0.012	22.2 (20.2, 24.4)	0.025

NS-SEC - National Statistic Socio-economic classification. CI – Confidence Interval.

*Separate bivariable regression between each explanatory variable and the outcome. **Multivariable regression adjusted for all variables presented simultaneously. ***Population density of the post code sector of the household address, postcode sectors have a mean population of 7,000.

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Figure 7-1: The number of minutes of daily activity for each participant by mode of public transport



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Among public transport users who incorporated some walking or cycling in their public transport journeys, the predicted percentages achieving 30 minutes a day or more of physical activity in the course of public transport journeys are given in Table 7-4. The maximally adjusted figure across all participants was 34.0% (32.1%, 36.0%). This was lower among bus users at 21.3% (19.0%, 23.6%) and highest among train users, with 51.7% (47.3%, 56.2%) reaching the threshold, among light-rail and multimode users this was 41.9% (35.4%, 48.4%) and 39.5% (35.3%, 43.7%) respectively. Differences in the minutes of activity between covariates were relatively small, all being less than 2.8 minutes, however, these differences translated into substantial differences in the percentage reaching 30 minutes a day. For example, 31.1% of London residents met the threshold, compared with 38.9% of

those living in conurbations of less than 50,000 residents, when controlling for all other characteristics in the model.

Table 7-4: Regression analyses showing the percentage achieving at least 30 minutes of daily physical activity accumulated in the course of public transport use

	Unadjusted* (95% CI)		Adjusted** (95% CI)	
	34.1 (32.1, 36.0)		34.0 (32.1, 36.0)	
Public Transport Mode		**p-value**		**p-value**
Bus	21.2 (19.0, 23.3)	ref	21.3 (19.0, 23.6)	ref
Train	54.1 (50.1, 58.2)	<0.001	51.7 (47.3, 56.2)	<0.001
Light-rail	40.1 (34.1, 46.1)	<0.001	41.9 (35.4, 48.4)	<0.001
Multimode	38.7 (34.4, 42.9)	<0.001	39.5 (35.3, 43.7)	<0.001
Gender				
Men	37.6 (34.9, 40.3)	ref	35.5 (33.0, 38.1)	ref
Women	30.7 (28.4, 33.1)	<0.001	32.6 (30.1, 35.0)	0.066
Age				
17-25	30.0 (26.1, 33.8)	ref	30.7 (27.1, 34.4)	ref
26-39	36.9 (33.5, 40.3)	0.008	34.8 (31.6, 37.9)	0.103
40-59	38.1 (34.8, 41.5)	0.001	36.2 (32.8, 39.6)	0.027
60+	28.4 (24.7, 32.1)	0.567	33.7 (29.2, 38.3)	0.291
Ethnicity				
White	35.7 (33.6, 37.8)	ref	34.6 (32.5, 36.8)	ref
South Asian	32.5 (25.5, 39.5)	0.391	34.6 (27.7, 41.5)	0.996
Black	24.1 (19.1, 29.0)	<0.001	31.2 (25.3, 37.1)	0.299
Other	28.7 (20.5, 36.9)	0.120	29.6 (21.6, 37.6)	0.241
Household NS-SEC - Social Classification				
Managerial	38.1 (35.6, 40.5)	ref	34.4 (31.9, 37.0)	ref
Intermediate	33.6 (29.2, 38.1)	0.082	35.4 (31.0, 39.9)	0.694
Routine/manual	25.5 (21.7, 29.3)	<0.001	32.1 (27.2, 37.1)	0.442
Unclassified	26.8 (19.6, 34.0)	0.007	32.0 (25.0, 39.1)	0.543
Household Income				
≥£50,000	39.7 (36.6, 42.8)	ref	34.5 (31.2, 37.7)	ref
£25,000-£49,999	34.0 (30.4, 37.6)	0.017	33.8 (30.3, 37.3)	0.769
<£25,000	28.5 (25.6, 31.3)	<0.001	33.8 (30.3, 37.3)	0.799
Housing Tenure				
Owns	37.8 (35.4, 40.1)	ref	35.3 (32.7, 37.9)	ref
Rents	29.5 (26.6, 32.4)	<0.001	32.4 (29.3, 35.6)	0.190
Car Access				
Access to a car	37.6 (35.3, 39.9)	ref	33.2 (30.8, 35.7)	ref
No car access	29.7 (26.7, 32.7)	<0.001	35.2 (31.8, 38.6)	0.363
Population Density* **				
<10	37.8 (33.8, 41.9)	ref	32.8 (27.9, 37.7)	ref
10-24.99	38.8 (34.4, 43.2)	0.742	36.9 (32.4, 41.5)	0.182
25-39.99	32.6 (28.3, 36.9)	0.084	31.9 (27.5, 36.4)	0.794
40-74.99	32.5 (28.6, 36.3)	0.059	34.5 (30.9, 38.2)	0.602
75+	31.5 (27.2, 35.8)	0.035	33.8 (29.1, 38.4)	0.800
Conurbation Type				
London	32.6 (29.7, 35.4)	ref	31.1 (28.2, 34.0)	ref
Metropolitan & >250k	32.4 (28.4, 36.4)	0.943	37.0 (32.7, 41.2)	0.031
50k-250k	35.8 (31.0, 40.6)	0.250	36.6 (31.5, 41.7)	0.075
<50k	40.8 (36.3, 45.2)	0.002	38.9 (32.9, 44.9)	0.030

NS-SEC - National Statistic Socio-economic classification. CI – Confidence Interval. *Separate bivariable regression between each explanatory variable and the outcome. **Multivariable regression adjusted for all variables presented simultaneously. ***Population density of the post code sector of the household address, postcode sectors have a mean population of 7,000.

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7.3 Discussion

7.3.1 Main finding of this chapter

Public transport users who walk or cycle as part of public transport journeys accumulated an average of 20.5 minutes a day of physical activity on average and a third of them accumulated at least 30 minutes of physical activity a day through their use of public transport. The accumulated physical activity was highest among train users and lowest among bus users. These findings suggest that public transport could be a practical approach to integrate physical activity into people's everyday lives and increase levels of physical activity in the population.

7.3.2 Strengths and Limitations

These analyses are the first to use a representative data source to quantify the physical activity associated with public transport use in England. These analyses use data from a comprehensive breakdown of all journeys, including those using multiple modes, and was not restricted commutes, it therefore gives a more rounded picture of public transport use in England. NTS also contains details of potentially confounding characteristics of participants and their environment.

Nonetheless, data used in this chapter come from self-reported survey responses, which are subject to bias. When compared with data from a wearable camera, a travel diary like the one used by NTS overestimated journey times by 12%.[204] The same study also found that almost 15% of journeys were not recorded in the diary. 63% of these unrecorded journeys were walking journeys.[204] The combined impact of this underreporting is uncertain, but it is possible that this has led to an underestimation of walk/cycling among the sample. The exclusion of those who did not provide details of how they accessed public transport should in part mitigate against this.

Bus use was much higher among those excluded than among participants, suggesting the potential for bias. Among those in the analytical sample, bus use was associated with lower levels of walking or cycling than other modes. If the distribution of minutes of activity varied across public transport modes in those excluded in the same way that it does for those included, the total figure might be an overestimate of that for all public transport users. However, analyses by NTS into the underreporting of short walks compared those who recorded short walks on day-one of the diary with those who recorded short walks on day seven.[308] Fewer short walks were recorded on day-seven than on day-one, but among those that recorded any short walks, the number of short walks and the length of those walks were comparable.[308] This suggests that individuals excluded due to underreporting might have levels of walking to access public transport comparable with those included in the sample. It is possible that some of the differences between modes are due to differences in the number of users who exclusively access and egress by car, for example, if a greater proportion of train users than bus users access and egressed exclusively by car. While the estimates here are of the physical activity accumulated by those who combined public transport with walking and cycling, differences in the use of cars to access public transport will affect the population health impact of different public transport modes.

The data used in these analyses are subject to additional limitations. These analyses were restricted to a single diary day, it is uncertain whether this is representative of travel patterns more generally. Although, participants were evenly assigned to different days of the week across the sample, which means that any differences across the week should even out. Measuring the duration of walking fails to capture the intensity of the physical activity involved. Intensity will vary according to the pace, participant fitness and the gradient, among other factors. However, research has linked walking with improved health, regardless of the duration.[174, 175, 246] In addition, objective measures of physical activity, which use accelerometers and GPS, have found that transport walking, including

that to access public transport, is associated with moderate-to-vigorous physical activity (MVPA), however the MVPA is less than the total self-reported walking time.[188, 189, 192]

The investigation of a 30 minutes per day threshold was selected to broadly correspond to global and UK physical activity recommendations of 150 minutes per week of moderate intensity physical activity.[140, 141] The 150 minutes per week recommendation has been widely accepted by national governments and by the WHO [140, 141, 309, 310], despite the fact that its selection appears to have been at least somewhat arbitrary.[311] The widespread use of the 150-minute recommendation has led to this being extensively studied, with many positive health outcomes found the be associated with this level of physical activity.[310, 311] Many of the health conditions associated with physical activity have apparently different relationships which makes the selection of a single threshold problematic, especially when attempting to increase physical activity among all.[310, 311] For example, a threshold which is too high might discourage some inactive people who may feel that it is unachievable.[311] This is further complicated by differences in impact seen with populations of differing baseline physical activity and fitness levels, in addition comparing evidence which used differing questionnaires to measure activity and express active with different units of measurement.[152, 312, 313] There is growing evidence that even relatively small amounts of physical activity are beneficial and that bouts of physical activity are beneficial whatever their length. In addition the dose-response relationship between physical activity and many outcomes demonstrate that large benefits are seen with relatively small amounts of physical activity.[314-316] Despite this, the WHO physical activity guidelines currently continue to recommend that aerobic activity be accumulated in bouts of at least 10 minutes.[141, 310, 311]. There have been recommendations[141] that the UK drops this requirement when its guidelines are updated.[311]

7.3.3 Comparison with other work

The estimate of 21 minutes a day of physical activity related to public transport use is comparable with the existing international literature on this topic. A 2012 literature review found that public transport was associated with between 7 and 33 minutes of physical activity.[184] These findings span from a small contribution to daily physical activity to one that exceeds current daily recommendations.[141] These differences possibly reflect the small sample sizes, the selected populations and the heterogeneous methods used by the included studies. One contributing study investigated US public transport users and used a similar design to that used here. This study found that public transport users accumulated a median of 19 minutes per day of physical activity in course of public transport journeys.[248] Studies that use GPS and accelerometers to measure physical activity objectively, generally find lower levels of physical activity.[207, 249] Studies of this kind have found that public transport use is associated with 15 minutes a day of walking [192] and 10 minutes a journey of MVPA.[189]

This chapter found differences between users of different public transport modes, with bus users accumulating the least and rail users accumulating the most physical activity. This is consistent with research that found people are willing to walk further to reach a train station than a bus stop, and that this might be necessary due to a lower density of train stations compared with bus stops.[317, 318] Differences between public transport modes are not present in all studies, for example ,a US study found no difference between the levels of physical activity associated with the use of buses and trains.[248] More research is required in order to explain these inconsistencies, for example, it is possible that different countries have different public transport infrastructure and/or behavioural norms. Alternatively, methodological differences between the studies may explain the discordant findings seen.

7.3.4 Implications

Walking and cycling to access public transport might form an important contribution to population levels of physical activity. The distance involved may be a barrier to people commuting by walking or cycling alone. In England and Wales average commute distance increased from 13.4km in 2001 to 15km in 2011, which is equivalent to >2.5 hours of brisk walking each way.[299, 319] Public transport may bridge this gap, allowing commuters to accrue some physical activity in the course of their daily lives. Data from Section 6.2.2 shows that in England from 2010 to 2014, 33% of adults use public transport in a given week. If 10% of those that do not were to take up public transport use alongside some walking or cycling, this research suggests that 34% would reach recommended levels of physical activity. This could mean 1.2 million additional people meeting the recommended levels of physical activity, whereas currently 44% of people in England fail to meet these guidelines.[320]

7.4 Conclusion

This chapter shows that public transport use allows the incorporation of incidental physical activity into everyday life and that one third of those who combine public transport use with walking or cycling achieved 30 minutes or more per day. This suggests that public transport can be used to meet physical activity recommendations and that a shift from sedentary to more active travel modes could lead to substantial increases in population levels of physical activity.

Chapter 8 – The association between the free older person's bus pass and active travel and ethic differences in bus pass use

The national free older person's bus pass scheme was introduced in 2006 and entitled those aged 60 and over to free off-peak local bus travel.[65] The policy was then expanded in 2008 to include local buses throughout England between 9.30am and 11pm on weekdays and all day at weekends [65], more details of the background to the policy and the scheme are given in Section 2.2. The bus pass was not introduced to improve the health of recipients; its aims were to guarantee the financial security of those in older age and to alleviate social exclusion.[83, 84] The bus pass had very high uptake among those eligible, increasing from 60% in 2006 following implementation, to 75% in 2009.[321] There is some evidence which suggests that the national free bus pass scheme has been effective in reducing depressive symptoms, although the mechanisms involved are not clear, with researches finding no association between the bus pass and a measure of social isolation.[85] There is also evidence that the free bus pass may have physical health benefits. Two years following the implementation of the bus pass policy, it was found that bus pass holders were more likely to use the bus and more active forms of travel and that these associations were consistent in homeowners and in those who rent.[80] Research has also shown that the bus pass was associated with lower adiposity and increased walking speed among women, although this was not seen in men.[81, 82] Previous research has focused on the associations of bus pass holdership with active travel in the two years following implementation, which means that there are no long term data on the travel patterns of bus pass holders.[80] .

While buses are the most common form of public transport in England, the use of public transport modes differ across ethnic groups.[12, 49] One reason bus use is higher than train use is the greater density of bus stops when compared with rail stops, meaning that most people have some access to a bus stop.[287] Buses provide access to shops, health services and other local amenities, in addition to social networks. Analyses using NTS data from 2011 to 2015 found that Black residents of England reported 31% of journeys by public transport and 24% by bus, compared with 16% and 10% in Asian and 8% and 5% in White residents.[49] In addition to differences in the travel modes used, levels of total travel, of any mode, also varied between ethnic groups, with White people making an average of 955 journeys per person per year, while in Black and Asian people this was 779 and 775 respectively.[49]

Ethnic minorities in England are often found to suffer the greatest ill effects of ethnic health inequalities, despite being a diverse group encompassing many heterogeneous communities.[322, 323] Elevated adiposity is often more prevalent in minority ethnic groups, for example, higher levels of overweight and obesity have been seen in those of Black ethnicity, while abdominal obesity has been seen to be higher in South Asians than in Whites.[324] Those of South Asian and Black ethnicity in England also have greater risk of diabetes and CVD than Whites.[221] These differences can be explained in part by lower levels of physical activity – ethnic minority women and South Asians of both genders in England are less likely to be sufficiently physically active than equivalent White people.[219, 224, 309] Although the bus pass has been linked with greater active travel and those of minority ethnicities have greater bus use than White people, it is uncertain whether bus pass use differs across ethnic groups.

As most existing research into the bus pass and active travel does not extend more than a few years following implementation and because the associations between the bus pass and active travel have not been compared across ethnic groups, the research questions address in this chapter were:

- How has bus pass possession changed between 2006 and 2014?
- Which individual and neighbourhood characteristic are associated with holding a free older person's bus pass in England?
- Among those with a bus pass what are bus and active travel levels?
- Is the possession of a free bus pass for older people in England associated with higher bus and active travel levels?
- Does the association between the free bus pass and active travel differ across ethnic groups?

8.1 Methods

8.1.1 Data

A detailed description of the National Travel Survey is presented in Section 6.1.1, but in brief, NTS is an annual cross-sectional survey of the travel patterns of England residents.[288] NTS employs a complex survey design to arrive at sample of England residents, representative in terms of age, sex and region. Participants are asked to take part in an interview and complete a 7-day travel diary. The interview questionnaire covers the household and individual characteristics of participants, such as household income in addition to travel patterns, such as frequency of walking. The travel diary records all journeys undertaken in the course of a week. In addition to recording the mode, destination and time taken for each journey, participants should also record details of each stage of each journey, e.g. details of the walk to the bus stop in addition to details of the bus journey itself.

In order to examine the association between the bus pass and active travel, these analyses used data collected from 2006, the year the national bus pass policy was implemented, up until 2014. Data was restricted to those participants who were eligible for a free bus pass. From an initial sample of

35,843 participants, a total of 7% (n=2,529) were excluded, 2,447 were excluded for not leaving the house due to walking difficulties, a further 28 were excluded for reporting over 75 journeys during the diary week, which was deemed unusually high. Finally, 24 were excluded due to missing data for ethnicity, which left an analytical sample of 33,344 participants, of which 75% (25,152) held a bus pass.

The bus pass was initially available to those aged 60 and over, however, since 2010 the age of eligibility has been increasing in line with the state pension age for women, which is due to reach 66 by 2020.[74] The changes to the age of eligibility were accounted for by the NTS data. Possession was assessed with the question: "*Do you have any of these special tickets or passes, valid for a week or longer?*" Participants were able to choose from a list of 11 ticket types, and those who selected "*Concessionary passes for older people*" were deemed to have a free bus pass.

There were three outcomes which were derived from the travel diary (bus stages, active stages and active stages as part of a bus journey), in addition to a measure of walking frequency, ascertained during the interview. Each journey recorded in the travel diary was assigned a main mode by NTS, which was that of the longest constituent stage, by distance. Each journey was categorised as being a bus journey or not, based on this main mode. Additionally, each stage of every journey was categorised as either active or inactive. Active modes were: cycling, walking and public transport modes, such as bus or train. Inactive modes included: car, motorcycle and taxi. The categorisation of public transport as active was because participants in surveys of this kind under-report short walks, such as walks to and from public transport.[204, 325-327] This categorisation enabled us to include all public transport users, even those who failed to record how they accessed public transport. The outcomes were the total number of bus stages, active stages and active stages as part of a bus journey reported by participants in the diary week. The interview stage of NTS contained the question: "How frequently do you walk anywhere for 20 minutes or more without stopping. Please

count each single trip as one journey and each return trip as two?" Participants were asked to select from a list of seven potential walking frequencies, ranging from never to three or more times a week. For these analyses, participants were categorised into those that walked three or more times a week and those that walked fewer than 3 times a week. Three or more times per week was the highest walking frequency available in the data and lower frequencies were thought less likely to confer health benefits of sufficient magnitude to be detected. The threshold of walking three or more times a week has also been found to be associated with health benefits in older people compared with those that walk less frequently.[219, 328, 329]

Although categorising bus stages as active was necessary to include all public transport users, this means that bus stages could drive the findings of all three outcomes derived from this travel diary. The use of interview data, in addition to the travel diary, allowed a more rounded picture of the associations between the free bus pass and active travel. The inclusion of data from the interview question allowed the investigation of an outcome which did not include bus travel, providing data on whether changes to bus-related walking was compensated for in walking for other purposes.

Ethnic group was self-defined by NTS participants, selected from a list of ethnicities in line with the categorisation used by the ONS in the Census of England and Wales. As the study period spanned the 2011 Census, there was a change in the ethnicity categorisation used across the survey years. For this reason, and due to small numbers of participants in some ethnic groups, the ethnic groups have been combined to allow comparison. The categorisation used in these analyses were: White (White British & other White), South Asian (Indian, Pakistani and Bangladeshi), Black (Caribbean, mixed White & Black Caribbean, Black African, mixed White & Black African and other Black) and other (other mixed, other Asian & any other). Additional details of the breakdown of these groups are available in Appendix Table A-5.

NTS also collects data on potentially confounding variables at the individual and neighbourhood level. Those used in this analysis were: age, sex, size of conurbation of residence (categorised as: London, metropolitan built-up areas/large urban >250k population, medium urban 25k-250k population, small/medium urban 3k-25k population, and rural), population density in persons/hectare of the household's post code sector and household access to a car. Socio-economic position was measured using the National Statistics Socio-economic Classification (NS-SEC) in four categories (based on current or previous employment) and housing tenure (owns or rents).

8.1.2 Impacts of the free bus pass on active travel

The characteristics of the entire sample of older people in England were summarised by each category of the variables considered, alongside bus pass holdership in these groups. Characteristics associated with bus pass possession in this sample were evaluated using logistic regression to estimate the adjusted odds ratio (AOR) of holding a bus pass when adjusting for the other relevant factors. Levels of bus pass possession were then compared across the years of participation, from 2006 to 2014.

In order to establish whether those who held a bus pass carried out more bus and active travel than those that did not hold a bus pass, the associations between an individual possessing a free bus pass and reporting active travel stages, bus travel stages, and active travel stages as part of a bus journey were also investigated. A substantial proportion of participants accumulated no active or bus travel which meant that there was a large number of zeros in the outcomes data. A zero-inflated negative binomial model was used to take account of the large number of participants who reported no (or zero) active or bus travel. The zero-inflated negative binomial model takes account of excess zeroes in the data, it does this by allowing zeros to be generated by two separate processes.[330] The first step is for the model the separate participants into two latent groups, one group with a probability

of a zero outcome of one, i.e. they are always zero, and a second group which might have any count outcome, including zero.[330] Membership of the always-zero group is modelled using the logistic element of the model. The second stage involved modelling the count outcome among those who are not in the always-zero group, which is modelled using the negative binomial element of the model.[330] The outcomes from the two stages are combined to give an odds ratio of not being in the always-zero group, i.e. the odds of potentially having a non-zero outcome, and an incident rate ratio for the count outcome, among those who were not in the always-zero group.[330] Models in these analyses therefore provide an odds ratio, presented as an AOR, of reporting any stages during the diary week and an incident rate ratio (IRR) for the number of stages reported in the week, among those who do some travel. To test the model selection, a Vuong test was carried out to compare the zero-inflated negative binomial model to a negative binomial model and a likelihood ratio test was used to compare the zero-inflated negative binomial model with a zero-inflated Poisson model.[331]

In order to establish whether those who held a bus pass were more likely to report walking frequency of three of more times per week than those who did not hold a bus pass, the association between bus pass possession and walking frequency was assessed using logistic regression to give an odds ratio of reporting walking three or more time a week. The walking frequency question in the interview only took into account walks of 20 minutes of greater.

Regression analyses took place at the level of the individual and took account of the complex survey design by accounting for clustering. In addition, NTS provides weights for use in analyses which aim to correct for biases in different levels of data. Weights were separately applied to calculations at the journey level, e.g., when calculating each participant's number of journeys. Individual and household level weighs were then applied to regression of individuals' travel patterns.

8.1.3 Ethnic differences in bus pass use

To examine ethnic differences, participant characteristics were summarised separately by ethnic group. For those who recorded one or more active journey stage, the proportion who held a bus pass was calculated along with levels of bus use and active travel.

A zero-inflated negative binomial regression model was used to carry out analyses of the associations between bus pass possession and active stages, bus stages and active stages as part of bus journeys in the entire pooled sample. The data contained a substantial number of participants who reported no active or bus travel and therefore had zero values for the outcomes. As discussed above, zero-inflated models are recommended when the number of zero outcomes is high and where the process of being a zero is separate from that which leads to an increase in the outcome. In order to establish whether those who held a bus pass were more likely to report walking frequency of three of more times per week than those who did not hold a bus pass, the association between bus pass possession and walking frequency was assessed using logistic regression to give an odds ratio of reporting walking three or more time a week.

In order to address the question of whether the association between the free bus pass and each outcome differs between ethnic groups, an interaction term was included between bus pass possession and ethnicity. An interaction term allows the effect of one variable to vary across the levels of another variable [307], in this case the effect of the bus pass was able to vary across ethnic groups. The interaction was included in analyses irrespective of statistical tests for an interaction, this was because these tests are liable to provide a false negative result due to a lack of statistical power.[307] The interaction term allowed the comparison of ethnic groups by comparing those with a bus pass (or those without a bus pass) in different ethnic groups, in addition to allowing a comparison of those with a bus pass to those without a bus pass within each ethnic group.

Models were adjusted for the covariates listed in Section 8.1.1 above. Differential missingness between the two outcomes led to samples of 33,267 for the zero-inflated negative binomial models and 33,176 for analysis of walking frequency. Regression analyses took account of the complex survey design by accounting for clustering within primary sampling units. Weights supplied by NTS were used to account for the complex survey design, non-response, and differences seen in diary completion on different days of the diary week.[202]

8.1.4 Additional analyses

In order to establish the impact of adjusting for potential confounders, additional analyses were carried out adjusting only for age and sex. To examine potential differences in associations over time, analyses were carried out with additional adjustment for year of data collection.

Sensitivity analyses were also carried out to test several assumptions made during these analyses. First, the categorisation of ethnic groups was investigated by separating participants of Indian ethnicity from South Asians of Pakistani and Bangladeshi ethnicity and restricting the Black group to only those of Black Caribbean and mixed White and Black Caribbean ethnicity. Further details of this categorisation of ethnicity are provided in Appendix Table A-6. These analyses were to investigate heterogeneity within ethnic groups as differences in socio-economic advantage are known to exist, for example, between those of Indian and those of Pakistani or Bangladeshi ethnicity.[322] However, it was necessary to combine these for the main analysis due to low numbers of participants in some ethnic groups. Second, the categorisation of active stages was refined to include only walking and cycling in order to examine the effect of including public transport stages as active stages. This was necessary due to the expected underreporting of short walks, such as those to or from bus stops.[204, 325-327] Finally, the main analyses were repeated after excluding London residents. This was because London differs substantially from other areas of the country in terms of population

density and levels of bus use, and also because London residents with a bus pass are additionally entitled to free use of the underground train and other public transport.[19, 65, 67, 68] London also has a disproportionately large proportion of ethnic minority residents.

8.2 Results - Impacts of the free bus pass on active travel

52.9% of participants were women and 25.2% of participants were aged 60-64, while 31.0% were aged 75+ (Table 8-1). 41.6% of participants lived in areas with 50,000 inhabitants or fewer, compared with 13.3% living in London. The majority of participants were home owners (81.9%) and had access to a car (76.9%). Managerial occupation households comprised 44.4% of participants, while 30.5% were of routine/manual occupation households (2.6% were not classified).

Table 8-1: Composition of National Travel Survey sample 2006-2014

	Number (%)	Chi-squared p-value*
All participants	33,344	
Age group		
60-64	8,407 (25.2)	<0.001
65-69	8,156 (24.5)	
70-74	6,440 (19.3)	
75+	10,341 (31.0)	
Sex		
Men	15,719 (47.1)	<0.001
Women	17,625 (52.9)	
Ethnicity		
White	32,030 (96.1)	0.001
South Asian	557 (1.7)	
Black	403 (1.2)	
Other	354 (1.1)	
Geographical area		
London	4,434 (13.3)	<0.001
250k people (except London)	8,553 (25.7)	
50k-250k people	6,492 (19.5)	
<50k people	13,865 (41.6)	
Housing Tenure		
Owns	27,410 (81.9)	<0.001
Rents	6,026 (18.1)	
Area population density persons/hectare*		
0-14.99	16,306 (48.9)	<0.001
15-29.99	7,841 (23.5)	
30-49.99	6,023 (18.1)	
50-74.99	1,980 (5.9)	
75+	1,194 (3.6)	
Car access		
Have car access	2,5647 (76.9)	<0.001
No car access	7,696 (23.1)	
Highest NS Socio-Economic Classification (current or last job)		
Managerial	14,794 (44.4)	<0.001
Intermediate	7,517 (22.5)	
Routine/manual	10,166 (30.5)	
Not classified	867 (2.6)	

NS - National Statistics

** - Pearson's Chi-squared test for difference in distribution by characteristics*

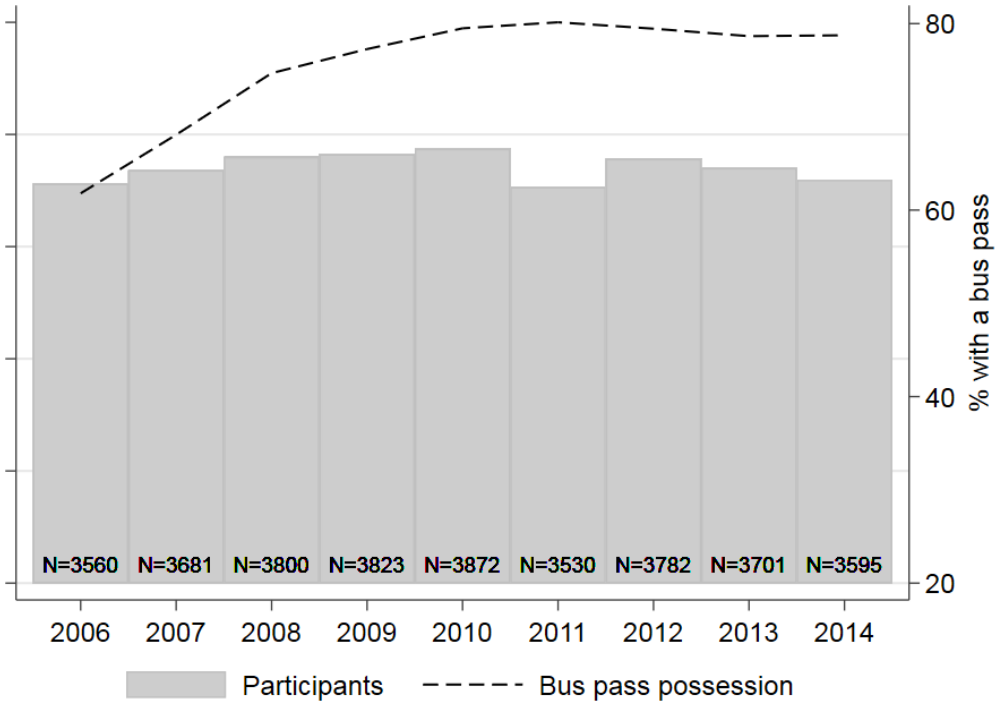
***Population density of the post code sector of the household address, postcode sectors have a mean population of 7,000*

Bus pass possession increased in the years immediately following the introduction of the policy, from 62.8% in 2006 to 77.3% in 2009 (Table 8-2 and Figure 8-1). Levels of bus pass possession have remained between 77% and 80% from 2009 to 2014.

Table 8-2: Levels of bus pass holding among eligible population 2006 – 2014 in the National Travel Survey

Year	2006	2007	2008	2009	2010	2011	2012	2013	2014
Participants (N)	3560	3681	3800	3823	3872	3530	3782	3701	3595
No bus pass	38.2%	31.9%	25.3	22.7%	20.5%	19.9%	20.5%	21.4%	21.3%
Bus pass	62.8%	68.1%	74.7%	77.3%	79.5%	80.1%	79.5%	78.7%	78.8%

Figure 8-1: Levels of bus pass holding among eligible population 2006 – 2014 in the National Travel Survey



75.4% of participants between 2006 and 2014 had a free bus pass (Table 8-3). Levels of bus pass possession increased with age, it was 80.7% among those aged 75+, compared with 65.2% among those aged 60-64 (AOR = 1.97 (1.84, 2.11)). Women were more likely to hold a bus pass then men (79.4% vs. 70.9%, AOR = 1.50 (1.42, 1.58)). Participants who lived in conurbations of less than 50,000

inhabitants were the least likely to hold a bus pass, for example, compared with London residents bus pass possession was 67.3% vs. 85.4% (AOR = 0.42 (0.37, 0.47)). Of participants with no access to a car, 86.6% held a bus pass, in those with access to a car, this was 72.1% (AOR = 1.87 (1.72, 2.03)). Those in routine/manual occupation households were more likely to hold a bus pass (80.6%) than managerial occupation households, who reported bus pass possession of 73.0% (AOR = 1.22 (1.14, 1.30).

Table 8-3: Associations between individual and neighbourhood characteristics and bus pass possession in the National Travel Survey 2006 - 2014

	% with a bus pass	Adjusted Odds Ratio	95% Confidence Intervals
All participants	75.4%		
Age group			
60-64	65.2%	ref	ref
65-69	76.2%	1.74	1.63, 1.87
70-75	79.3%	2.02	1.88, 2.19
75+	80.7%	1.97	1.84, 2.11
Sex			
Men	70.9%	ref	ref
Women	79.4%	1.50	1.42, 1.58
Ethnicity			
White	75.3%	ref	ref
South Asian	73.6%	0.58	0.48, 0.71
Black	83.6%	0.89	0.67, 1.18
Other	78.5%	0.82	0.63, 1.07
Geographical area			
London	85.4%	ref	ref
>250k people (except London)	82.4%	0.79	0.70, 0.88
50k-250k people	76.8%	0.58	0.52, 0.65
<50k people	67.3%	0.42	0.37, 0.47
Housing Tenure			
Owns	74.9%	ref	ref
Rents	77.7%	0.75	0.70, 0.81
Area population density persons/hectare*			
0-14.99	69.4%	ref	ref
15-29.99	78.8%	1.19	1.11, 1.29
30-49.99	81.9%	1.29	1.18, 1.41
50-74.99	85.2%	1.39	1.20, 1.61
75+	86.8%	1.46	1.20, 1.78
Car access			
Have car access	72.1%	ref	ref
No car access	86.6%	1.87	1.72, 2.03
NS Socio-Economic Classification (current or last job)			
Managerial	73.0%	ref	ref
Intermediate	73.4%	0.93	0.87, 0.99
Routine/manual	80.6%	1.22	1.14, 1.30
Not classified	74.3%	0.69	0.59, 0.82

NS - National Statistics

*Population density of the post code sector of the household address, postcode sectors have a mean population of 7,000

55.2% of participants (n = 18,420) did at least one active travel stage on the diary day, of whom, 85.3% held a bus pass (Table 8-4). The median number of total active journeys stages in this group was eight, while the median bus travels stages and active stages as part of bus journeys was two and one respectively. 31.4% of total active journeys stages were part of bus journeys.

Table 8-4: Travel patterns of those participants who reported any active travel in the diary week

N who did any active travel in the diary week (%)	18,420 (55.2%)
% with a bus pass	85.3%
Bus travel*	2 (0-4)
Active travel as part of a bus journey*	1 (0-4)
Total active travel*	8 (4-16)
% of total active stages which are part of a bus journey	31.4%

**median number of stages/week (interquartile range) from the travel diary*

Table 8-5 shows the results of zero-inflated negative binomial regression of participants' travel diary data from the entire sample and gives the AOR of reporting any active travel stages among bus pass holder compared with non-holders, in addition to the IRR for the amount of active stages in bus pass holders compared with non-holders. Participants were much more likely to travel by bus if they held a bus pass compared with those who did not, (AOR = 10.31 (9.18, 11.56)) (Table 8-5). Among those who did at least some bus travel, bus pass holders carried out more bus journey stages than non-holders, IRR = 1.19 (1.06, 1.33). There were no clear trends in bus travel over time, with confidence intervals crossing the no-effect for each year. Participants aged 75+ years had a lower odds of doing any bus travel (AOR = 0.69 (0.63, 0.75)) and accumulated fewer bus journey stages than younger participants (IRR = 0.91 (0.87, 0.96)). Women participants were more likely than men to do any bus travel (AOR = 1.36 (1.30, 1.43)), however, among participants that did some bus travel, women accumulated less than men (IRR = 0.93 (0.90, 0.96)). Black participants had a greater odds of any bus travel than Whites (AOR = 1.54 (1.14, 2.09)), this was not the case for South Asians. Each minority

ethnic group accumulated a greater amount of bus travel than White participants, for example, among South Asians the IRR = 1.34 (1.17, 1.54).

Bus pass holders were 12 times as likely to record some active travel as part of a bus journey than non-holders, AOR = 12.27 (10.73, 14.04). Among those who accumulated some active travel as part of bus journeys, bus pass holders also reported more than non-holders, IRR = 1.38 (1.17, 1.63). No association was seen with year of data collection. Among Black participants there was a greater odds of accumulating some active travel as part of bus travel than among White participants (AOR = 1.78 (1.19, 2.66)), among those who accumulated at least some active stages as part of bus travel, levels were higher among South Asians than White participants, IRR = 1.42 (1.13, 1.78).

Bus pass holders were more likely to report an active stage than non-holders, AOR = 3.54 (3.31, 3.78), while among those that accumulated at least one active stage, bus pass possession was associated with more active stages IRR = 1.09 (1.04, 1.13). The accumulation of active stages was less likely in the more recent years of data collection, for example in 2012, the AOR for any active travel was 0.78 (0.69, 0.89) compared with 2006, while the IRR for those participants in 2012 was 0.89 (0.83, 0.95). South Asian participants were less likely to report active travel than White participants (AOR = 0.61(0.49, 0.77)). Of those accumulating some active travel, Black participants accumulated fewer stages than their equivalent White participants, IRR = 0.84 (0.73, 0.97).

Table 8-5: Association between bus pass possession and reporting active travel stages in the NTS diary 2006 – 2014

	Bus Stages		***Active stages as part of a bus journey***		***Total active stages***	
	AOR	***IRR***	***AOR***	***IRR***	***AOR***	***IRR***
Bus Pass Possession						
No pass	ref	ref	ref	ref	ref	ref
Has a pass	10.31*** (9.18, 11.56)	1.19** (1.06, 1.33)	12.27*** (10.73, 14.04)	1.38*** (1.17, 1.63)	3.54*** (3.31, 3.78)	1.09*** (1.04, 1.13)
Year						
2006	ref	ref	ref	ref	ref	ref
2007	1.05 (0.90, 1.22)	0.98 (0.91, 1.06)	1.08 (0.90, 1.29)	0.97 (0.85, 1.11)	0.98 (0.86, 1.11)	0.95 (0.88, 1.01)
2008	1.01 (0.87, 1.16)	0.97 (0.90, 1.05)	1.00 (0.84, 1.19)	0.94 (0.83, 1.08)	0.95 (0.84, 1.08)	0.88*** (0.82, 0.94)
2009	1.01 (0.88, 1.17)	1.00 (0.93, 1.08)	1.03 (0.86, 1.22)	0.94 (0.82, 1.08)	0.87* (0.76, 0.99)	0.94 (0.87, 1.00)
2010	0.96 (0.83, 1.11)	0.97 (0.90, 1.05)	0.93 (0.78, 1.11)	0.96 (0.84, 1.09)	0.73*** (0.65, 0.83)	0.91** (0.85, 0.97)
2011	0.91 (0.79, 1.06)	0.97 (0.90, 1.05)	0.85 (0.72, 1.02)	1.05 (0.91, 1.21)	0.80*** (0.71, 0.91)	0.91** (0.85, 0.98)
2012	0.99 (0.85, 1.14)	0.95 (0.88, 1.02)	0.97 (0.81, 1.15)	0.96 (0.83, 1.10)	0.78*** (0.69, 0.89)	0.89*** (0.83, 0.95)
2013	0.94 (0.81, 1.09)	0.98 (0.91, 1.06)	0.91 (0.76, 1.09)	0.98 (0.85, 1.13)	0.77*** (0.68, 0.88)	0.89*** (0.83, 0.95)
2014	1.03 (0.89, 1.20)	0.93 (0.86, 1.00)	0.99 (0.83, 1.18)	0.99 (0.86, 1.14)	0.77*** (0.67, 0.87)	0.91** (0.85, 0.97)
Age						
60-64	ref	ref	ref	ref	ref	ref
65-69	0.99 (0.91, 1.08)	0.96 (0.91, 1.01)	1.05 (0.95, 1.16)	0.91* (0.83, 0.99)	0.93 (0.86, 1.00)	0.93*** (0.89, 0.97)
70-74	1.00 (0.91, 1.10)	0.96 (0.91, 1.02)	1.10 (0.98, 1.23)	0.89** (0.81, 0.97)	0.82*** (0.75, 0.89)	0.90*** (0.86, 0.94)
75+	0.69*** (0.63, 0.75)	0.91*** (0.87, 0.96)	0.76*** (0.68, 0.84)	0.82*** (0.75, 0.89)	0.49*** (0.46, 0.53)	0.80*** (0.76, 0.83)
Sex of person						
Men	ref	ref	ref	ref	ref	ref
Women	1.36*** (1.30, 1.43)	0.93*** (0.90, 0.96)	1.47*** (1.39, 1.56)	0.91*** (0.86, 0.96)	0.99 (0.95, 1.04)	0.87*** (0.84, 0.89)
Ethnicity						
White	ref	ref	ref	ref	ref	ref
South Asian	0.87 (0.68, 1.11)	1.34*** (1.17, 1.54)	0.93 (0.70, 1.23)	1.42** (1.13, 1.78)	0.61*** (0.49, 0.77)	1.07 (0.93, 1.23)
Black	1.54** (1.14, 2.09)	1.21** (1.07, 1.37)	1.78** (1.19, 2.66)	1.11 (0.93, 1.32)	1.28 (0.93, 1.74)	0.84* (0.73, 0.97)
Other	1.23 (0.90, 1.68)	1.29*** (1.13, 1.48)	1.50* (1.02, 2.20)	1.18 (0.94, 1.47)	1.01 (0.76, 1.34)	0.96 (0.84, 1.10)
Geographic Area						
London	1.27*** (1.12, 1.44)	1.19*** (1.12, 1.26)	1.12 (0.97, 1.30)	1.23*** (1.10, 1.38)	1.15* (1.02, 1.30)	1.17*** (1.10, 1.25)
>250k people (except London)	1.05 (0.95, 1.16)	1.14*** (1.09, 1.20)	1.05 (0.93, 1.18)	1.10* (1.00, 1.20)	0.90* (0.82, 0.99)	0.99 (0.95, 1.04)
50k-250k people	ref	ref	ref	ref	ref	ref
<50k people	0.67*** (0.60, 0.74)	0.86*** (0.81, 0.91)	0.62*** (0.55, 0.70)	0.87** (0.78, 0.96)	0.85*** (0.78, 0.93)	1.04 (0.99, 1.09)

	Bus Stages		*Active stages as part of a bus journey*		*Total active stages*	
	AOR	***IRR***	***AOR***	***IRR***	***AOR***	***IRR***
Housing tenure						
Owns	ref	ref	ref	ref	ref	ref
Rents	0.96 (0.88, 1.04)	1.05* (1.01, 1.10)	0.99 (0.89, 1.10)	1.02 (0.95, 1.09)	0.74*** (0.68, 0.81)	0.99 (0.95, 1.03)
Area population density persons/hectare*						
0-14.99	ref	ref	ref	ref	ref	ref
15-29.99	1.11* (1.01, 1.22)	1.01 (0.96, 1.06)	1.19** (1.07, 1.33)	0.98 (0.90, 1.07)	1.11* (1.02, 1.21)	1.01 (0.96, 1.05)
30-49.99	1.15** (1.03, 1.28)	1.01 (0.95, 1.06)	1.20** (1.06, 1.36)	1.06 (0.96, 1.17)	1.19*** (1.08, 1.31)	1.07** (1.02, 1.13)
50-74.99	1.45*** (1.23, 1.70)	1.04 (0.96, 1.11)	1.57*** (1.29, 1.92)	1.09 (0.96, 1.25)	1.40*** (1.21, 1.63)	1.16*** (1.08, 1.25)
75+	1.41** (1.14, 1.75)	1.13** (1.03, 1.23)	1.75*** (1.33, 2.31)	1.17* (1.00, 1.37)	1.43*** (1.16, 1.77)	1.39*** (1.27, 1.53)
Car Access						
Car Access	ref	ref	ref	ref	ref	ref
No Car Access	4.52*** (4.16, 4.93)	1.72*** (1.65, 1.80)	5.63*** (5.05, 6.28)	1.81*** (1.69, 1.94)	3.84*** (3.52, 4.18)	1.46*** (1.40, 1.52)
Household NS Socio-Economic Classification (current or last job)						
Managerial	ref	ref	ref	ref	ref	ref
Intermediate	1.04 (0.95, 1.13)	1.03 (0.98, 1.09)	1.09 (0.98, 1.20)	1.02 (0.93, 1.12)	0.85*** (0.79, 0.92)	0.92*** (0.88, 0.96)
Routine/manual	1.12** (1.04, 1.22)	1.11*** (1.06, 1.16)	1.25*** (1.14, 1.37)	1.03 (0.95, 1.11)	0.83*** (0.77, 0.90)	0.92*** (0.88, 0.95)
Not classified	0.76** (0.62, 0.92)	1.09 (0.98, 1.21)	0.80 (0.62, 1.01)	0.98 (0.84, 1.15)	0.78** (0.64, 0.94)	0.89* (0.82, 0.98)

NS – National Statistics NTS – National Travel Survey AOR – Adjusted Odds Ratio IRR – Incident Rate Ratio

*Population density of the post code sector of the household address, postcode sectors have a mean population of 7,000

Table 8-6 shows the results of a logistic regression giving the odds ratio of reporting walking for 20+ minutes three or more times per week in the NTS interview. Those with a bus pass were more likely to report walking three or more times a week than non-holders, AOR = 1.43 (1.34, 1.53). Those aged 75 and over were less likely walk three or more times per week than younger participants (AOR = 0.82 (0.76, 0.89)). Women participants were less likely to walk three or more times per week than men, AOR = 0.46 (0.43, 0.50).

Table 8-6: Maximally adjusted association between holding a bus pass and reporting a walking frequency of 3 or more time a week in the NTS interview 2006-2014

	Walking ≥ 3 times/week %	***Walking ≥ 3 times/week AOR***
Bus Pass Possession		
No pass	30.5	ref
Has a pass	35.1	1.43*** (1.34, 1.53)
Year of participation		
2006	32.2	ref
2007	33.8	1.43*** (1.34, 1.53)
2008	31.5	1.05 (0.93, 1.18)
2009	34.7	0.93 (0.82, 1.05)
2010	33.2	1.06 (0.93, 1.20)
2011	34.0	0.96 (0.85, 1.09)
2012	33.7	1.02 (0.90, 1.16)
2013	35.9	1.02 (0.90, 1.16)
2014	36.8	1.12 (0.98, 1.27)
Age		
60-64	39.1	ref
65-69	39.9	0.95 (0.73, 1.23)
70-74	35.9	0.98 (0.92, 1.05)
75+	23.9	0.82*** (0.76, 0.89)
Sex		
Men	36.0	ref
Women	32.1	0.46*** (0.43, 0.50)
Ethnicity		
White	34.1	ref
South Asian	31.1	1.17** (1.04, 1.32)
Black	28.8	0.80* (0.65, 0.98)
Other	35.6	0.77* (0.60, 0.99)
Geographic Area		
London	34.3	0.83*** (0.79, 0.86)
>250k people (except London)	30.7	0.96 (0.86, 1.07)
50k-250k people	34.2	ref
<50k people	35.7	0.86*** (0.79, 0.94)
Housing Tenure		
Owns	35.6	ref
Rents	26.5	0.73*** (0.61, 0.88)
Area population density persons/hectare		
0-14.99	35.0	ref
15-29.99	32.9	0.70*** (0.65, 0.75)
30-49.99	31.9	0.99 (0.91, 1.07)
50-74.99	33.6	0.98 (0.89, 1.08)
75+	36.7	1.07 (0.93, 1.24)
Car Access		
Car Access	28.8	ref
No Car Access	35.5	1.08 (0.99, 1.18)
NS Socio-Economic Classification (current or last job)		
Managerial	37.6	ref
Intermediate	33.0	1.11** (1.03, 1.19)
Routine/manual	30.0	0.86*** (0.81, 0.93)
Not classified	26.8	0.81*** (0.75, 0.86)

AOR-adjusted odds ratio, IRR-incident rate ratio, NS-National Statistics, NTS-National Travel Survey

*Population density of the postcode sector of the household address, postcode sectors have a mean population of 7,000.

*** p<0.001, ** p<0.01, * p<0.05

8.3 Results - Ethnic differences in bus pass use

Table 8-7 gives the characteristics of the study sample separately for each ethnic group. White participants made up 96.1% of the study sample, which is representative of the ethnic make-up of England residents in this age group.[68] Participants of Black ethnicity were the most likely to be bus pass holders, with 83.6% holdership, compared with 73.6% of South Asian and 75.3% of White participants ($p<0.001$). Just 11.5% of White participants resided in London, compared with 50.8% of South Asians and 61.3% of Black participants ($p<0.001$). South Asians were more likely to be homeowners, with 87.4% home ownership, compared with 82.1% of White participants and 64.4% of Black participants ($p<0.001$). Black participants were more likely to live in more densely populated areas: 31.0% of Black participants lived in areas of 75+ persons per hectare, compared with 18.0% of South Asians and 2.8% of Whites. Just 51.1% of Black participants had access to a car, compared with 77.3% of White participants and 80.4% of South Asians ($p<0.001$).

Table 8-7: Characteristics of NTS participants from 2006 to 2014 who were eligible for a free older peoples bus pass (aged 60-99) by ethnic group

	White N. / %	South Asian N. / %	Black N. / %	Other N. / %	p-value*	Total N. / %
All participants	32 030	557	403	354		33 344
Mean age	71.0	69.3	70.2	69.0		70.9
Age group						
60-64	25.1%	27.8%	26.1%	33.3%	p<0.001	25.2%
65-69	24.3%	29.1%	29.0%	27.1%		24.5%
70-74	19.3%	21.4%	18.1%	20.1%		19.3%
75+	31.4%	21.7%	26.8%	19.5%		31.0%
Sex						
Men	47.1%	52.1%	44.9%	49.2%	p=0.076	47.1%
Women	52.9%	47.9%	55.1%	50.8%		52.9%
Geographical area						
London	11.5%	50.8%	61.3%	59.3%	p<0.001	13.3%
>250k people (except London)	25.7%	30.7%	26.3%	13.3%		25.7%
50k-250k people	19.8%	10.8%	6.7%	16.9%		19.5%
<50k people	43.0%	7.7%	5.7%	10.5%		41.6%
Housing Tenure						
Owns	82.1%	87.4%	64.4%	70.3%	p<0.001	81.9%
Rents	17.9%	12.6%	35.6%	29.7%		18.1%
Area population density persons/hectare						
0-14.99	50.4%	12.4%	8.9%	16.7%	p<0.001	48.9%
15-29.99	23.8%	13.3%	16.6%	19.8%		23.5%
30-49.99	17.7%	33.8%	21.3%	23.4%		18.1%
50-74.99	5.3%	22.6%	22.1%	18.6%		5.9%
75+	2.8%	18.0%	31.0%	21.5%		3.6%
Car access						
Have car access	77.3%	80.4%	51.1%	67.2%	p<0.001	76.9%
No car access	22.7%	19.6%	48.9%	32.8%		23.1%
NS Socio-Economic Classification (current or last job)						
Managerial	44.4%	45.6%	36.5%	51.1%	p<0.001	44.4%
Intermediate	22.7%	20.1%	16.9%	20.6%		22.5%
Routine/manual	30.5%	28.5%	40.7%	22.9%		30.5%
Not classified	2.5%	5.7%	6.0%	5.4%		2.6%
Walking frequency						
Walk < 3x /week	65.9%	68.9%	71.2%	64.4%	p=0.061	66.0%
Walk ≥ 3x /week	34.1%	31.1%	28.8%	35.6%		34.0%
Bus pass possession						
No bus pass	24.7%	26.4%	16.4%	21.5%	p<0.001	24.6%
Have a bus pass	75.3%	73.6%	83.6%	78.5%		75.4%

NTS=National Travel Survey, NS=National Statistics. *- Pearson's Chi-squared test

Ethnicity categorisation: White (White British and other White), South Asian (Indian, Pakistani and Bangladeshi), Black (Black African, mixed White & Black African, Black Caribbean, mixed White & Black Caribbean and other Black) and other (other mixed, other Asian and any other).

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8.3.1 Patterns of Active Travel

The percentage of participants of each ethnicity reporting any active journey stages during the diary week is given in Table 8-8, alongside information about their bus and active travel levels. 72.2% of Black participants did some active travel, this was 55.0% among Whites and 51.0% among South Asian participants. Levels of bus pass possession among these participants were similar across ethnic groups: 85.2% of White, 84.5% of South Asian and 89.0% of Black participants (p=0.186). Black participants each carried out a median of four bus stages during the diary week, this compared with two in both South Asian and White participants. The median number of active stages as part of a bus journey in the diary week reflected this, with Black participants accumulating four, South Asians two and Whites just one (p<0.001). The median of total active stages was greatest among South Asian participants who accumulated 12 in the diary week, compared with eight for both White and Black participants (p<0.001). The percentage of total active stages which formed part of a bus journey was 56.2% among Black participants, 44.4% among South Asian participants and 28.9% among Whites (P<0.001).

Table 8-8: Travel patterns of those participants who reported any active travel stages in the diary week

	White	South Asian	Black	Other	p-value
N who did any active travel (%)	17 619 (55.0%)	284 (51.0%)	291 (72.2%)	226 (63.8%)	p<0.001[a]
% with a bus pass	85.2%	84.5%	89.0%	88.1%	p=0.186[a]
Bus travel*	2 (0-4)	2 (0-6)	4 (2-8)	4 (0-8)	p<0.001[b]
Active travel as part of a bus journey*	1 (0-4)	2 (0-8)	4 (1-9)	4 (0-8)	p<0.001[b]
Total active travel*	8 (4-16)	12 (4-17)	8 (4-17)	11 (4-18)	p<0.001[b]
% of total active stages which are part of a bus journey	28.9%	44.4%	56.2%	46.2%	p<0.001[a]

Ethnicity categorisation: White (White British and other White), South Asian (Indian, Pakistani and Bangladeshi), Black (Black African, mixed White & Black African, Black Caribbean, mixed White & Black Caribbean and other Black) and other (other mixed, other Asian and any other).
*median number of stages/week (interquartile range)
[a] - Pearson's Chi-squared test, [b] - Kruskal-Wallis test
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8.3.2 Bus Pass Possession and Active Travel

Table 8-9 shows the results of the zero-inflated negative binomial regression which compares the active travel stages among bus pass holders and non-holders, providing and AOR for reporting any stages and the IRR for the amount of stages reported. In all ethnic groups, bus travel was more likely among bus pass holders than non-holders. For example, among Black participants, AOR = 0.31 (0.17, 0.57) among non-holders and AOR = 1.33 (0.99, 1.80) among holders. In each minority ethnic group, bus pass holders did a greater amount of bus travel than White bus pass holders: IRR = 1.33 (1.16, 1.53) in South Asian participants and IRR=1.22 (1.08, 1.37) in Black participants.

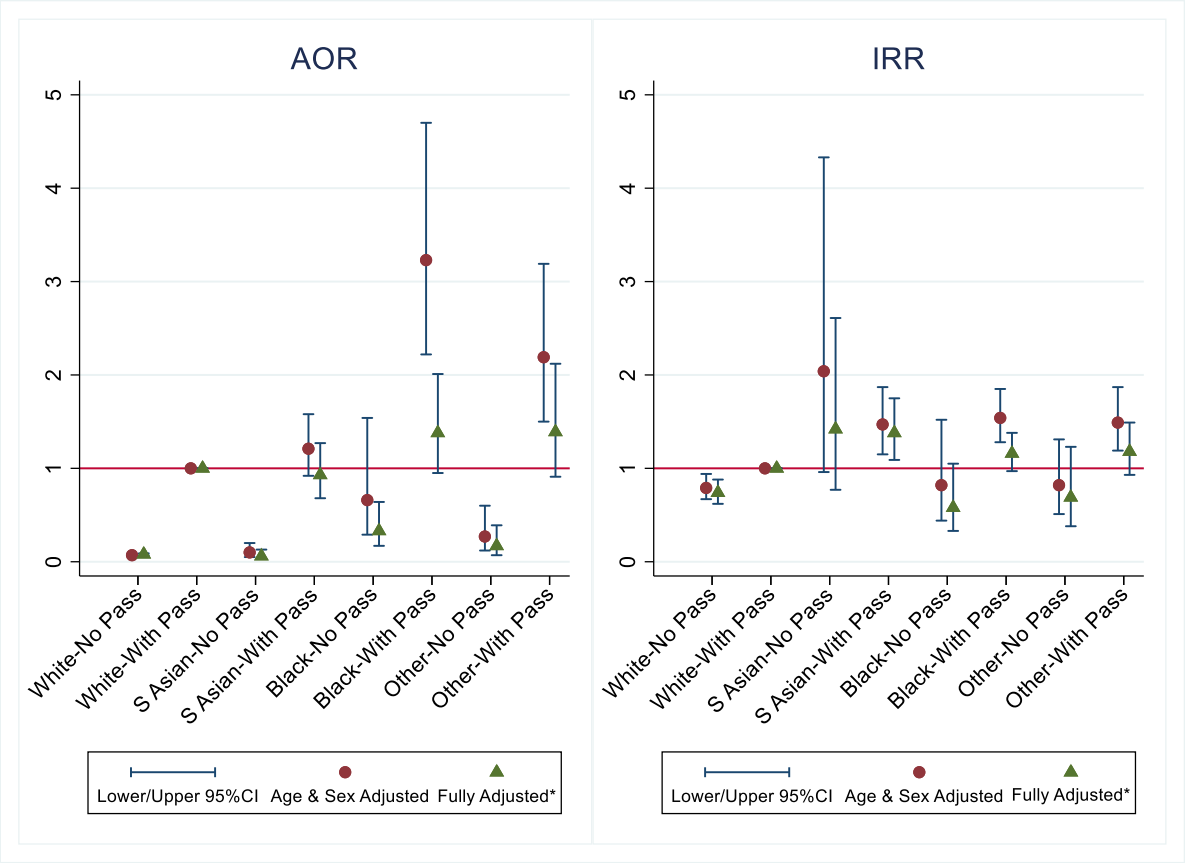
Table 8-9: Association between holding a bus pass and reporting active travel stages in the diary week by ethnic group

	White		South Asian		Black		Other	
	AOR/IRR (95% CI)		AOR/IRR (95% CI)		AOR/IRR (95% CI)		AOR/IRR (95% CI)	
Bus Stages								
AOR of doing any travel								
No Bus Pass	0.09***	(0.08, 0.10)	0.08***	(0.04, 0.16)	0.31***	(0.17, 0.57)	0.17***	(0.08, 0.36)
With Bus Pass	1.00	(ref)	0.87	(0.66, 1.13)	1.33	(0.99, 1.80)	1.14	(0.82, 1.58)
IRR of amount of travel								
No Bus Pass	0.85**	(0.76, 0.96)	1.06	(0.65, 1.75)	0.96	(0.55, 1.68)	1.00	(0.57, 1.76)
With Bus Pass	1.00	(ref)	1.33***	(1.16, 1.53)	1.22**	(1.08, 1.37)	1.29***	(1.12, 1.48)
Active stages as part of a bus journeys								
AOR of doing any travel								
No Bus Pass	0.08***	(0.07, 0.09)	0.06***	(0.03, 0.13)	0.33**	(0.17, 0.64)	0.17***	(0.07, 0.39)
With Bus Pass	1.00	(ref)	0.93	(0.68, 1.27)	1.38	(0.95, 2.01)	1.39	(0.91, 2.12)
IRR of amount of travel								
No Bus Pass	0.74***	(0.62, 0.88)	1.42	(0.77, 2.61)	0.58	(0.33, 1.05)	0.69	(0.38, 1.23)
With Bus Pass	1.00	(ref)	1.38**	(1.09, 1.75)	1.16	(0.97, 1.38)	1.18	(0.93, 1.49)
Total Active Journey Stages								
AOR of doing any travel								
No Bus Pass	0.29***	(0.27, 0.31)	0.16***	(0.11, 0.25)	0.38**	(0.21, 0.68)	0.24***	(0.14, 0.41)
With Bus Pass	1.00	(ref)	0.60***	(0.46, 0.78)	1.21	(0.84, 1.73)	1.05	(0.74, 1.50)
IRR of amount of travel								
No Bus Pass	0.94**	(0.90, 0.98)	1.17	(0.88, 1.55)	0.46***	(0.30, 0.70)	0.85	(0.59, 1.23)
With Bus Pass	1.00	(ref)	1.03	(0.88, 1.20)	0.88	(0.76, 1.01)	0.95	(0.83, 1.10)

Ethnicity categorisation: White (White British and other White), South Asian (Indian, Pakistani and Bangladeshi), Black (Black African, mixed White & Black African, Black Caribbean, mixed White & Black Caribbean and other Black) and other (other mixed, other Asian and any other).
Covariates: Age (continuous), sex, size of area of residence, access to a car, National Statistics Socio-Economic Classification (NS-SEC), population density of household's post code sector (continuous) and home ownership.
AOR-adjusted odds ratio, IRR-incident rate ratio. *** p<0.001, ** p<0.01, * p<0.05
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In each ethnic group, participants with a bus pass reported more active stages as part of a bus journey than those without, for example, among White participants without a bus pass AOR = 0.08 (0.07,0.09) (Figure 8-2). South Asians bus pass holders also carried out more active stages as part of a bus journey than White bus pass holders (IRR = 1.38 (1.09, 1.75).

Figure 8-2: Active Stages as Part of Bus Journeys



1 - indicates the reference level of white participants with a bus pass
AOR – Adjusted odds ratio IRR – Incident rate ratio
**Covariates: Age (continuous), sex, size of area of residence, access to a car, National Statistics Socio-Economic Classification (NSSEC), population density of household's post code sector (continuous) and home ownership.*
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Bus pass holders were more likely to report active journey stages compared with non-holders in each ethnic group, for example, among Black participants without a bus pass the AOR was 0.38 (0.21, 0.68) and among bus pass holders the AOR was 1.21 (0.84, 1.73). However, South Asian bus pass holders were less likely than their respective White bus pass holders to do any active journeys stages, AOR=0.60 (0.46, 0.78). White and Black bus pass holders accumulated more active journey stages than those without a bus pass, this was not the case for South Asian bus pass holders. Among those with a bus pass, levels of active travel were similar across ethnic groups with an IRR of 1.03 (0.88, 1.20) among South Asians and IRR = 0.88 (0.76, 1.01) among Black participants.

Table 8-10: Association between holding a free bus pass and reporting a walking frequency of 3 or more times per week in the NTS interview by ethnic group

	White		South Asian		Black		Other	
	AOR (95% CI)		**AOR (95% CI)**		**AOR (95% CI)**		**AOR (95% CI)**	
Walking ≥ 3 times/week								
No Bus Pass	0.69***	(0.65, 0.73)	0.46***	(0.30, 0.70)	0.43*	(0.22, 0.82)	0.43**	(0.24, 0.79)
With Bus Pass	1.00	(ref)	0.86	(0.68, 1.08)	0.82	(0.63, 1.07)	1.04	(0.78, 1.39)

Ethnicity categorisation: White (White British and other White), South Asian (Indian, Pakistani and Bangladeshi), Black (Black African, mixed White & Black African, Black Caribbean, mixed White & Black Caribbean and other Black) and other (other mixed, other Asian and any other).
Covariates: Age (continuous), sex, size of area of residence, access to a car, National Statistics Socio-Economic Classification (NS-SEC), population density of household's post code sector (continuous) and home ownership.
AOR-adjusted odds ratio, IRR-incident rate ratio. *** p<0.001, ** p<0.01, * p<0.05
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Thirty-four percent of participants reported walking three times per week or more. This did not vary appreciably between ethnic groups, with 28.8%, 31.1% and 34.1% of Black, South Asian and White participants respectively (p=0.061) (Table 8-7). Holding a bus pass was statistically associated with achieving this level of walking only among Whites, with an AOR of 0.69 (0.65, 0.73) among non-bus pass holders, with suggestive evidence for an association in other ethnic groups (Table 8-9). For example, South Asians without a bus pass AOR = 0.46 (0.30, 0.70), compared with bus pass holder with an AOR = 0.86 (0.68, 1.08). The odds of reaching this higher level of walking did not vary by ethnic group, for example, Black bus pass holders had an AOR of 0.82 (0.63, 1.07).

8.3.3 Sensitivity analyses

The main analyses are presented with adjustment for only age and sex in Appendix Table A-11, these show that adjustment for potentially confounding variables led to some attenuation when compared with the minimally adjusted models. For example, in South Asian bus pass holders the age and sex adjusted IRR of active stages as part of a bus journey was 1.47 (1.15, 1.87) compared with fully adjusted results of 1.38 (1.09, 1.75). Adding the year of data collection as a covariate in the main analyses led to only minor effects and did not change the direction or size of associations (Appendix Table A-10). This indicated no evidence for a secular trend in associations over time.

The results of analyses to examine the effect of the chosen ethnic categorisation is presented in Appendix Table A-7 to Appendix Table A-9. These analyses suggest that there may be differences between participants of Indian ethnicity and those of Pakistani and Bangladeshi ethnicity. Appendix Table A-7 shows that participants of Indian ethnicity were more likely to reside in London than those of Pakistani/Bangladeshi ethnicity, 56.5% and 40.4% respectively. 91.9% of participants of Indian ethnicity were homeowners, compared with 79.3% of those of Pakistani/Bangladeshi ethnicity, which indicates greater socio-economic advantage among those of Indian ethnicity. The regression analyses suggested some differences between these South Asian groups but not with any statistical certainty, for example, the IRR for bus stages among those with a bus pass was 1.40 (1.19, 1.66) and 1.15 (0.92, 1.43) in participants of Indian and Pakistani/Bangladeshi ethnicity respectively. These results also indicate that the re-categorised Black group appeared to have similar outcomes to the original Black group, which was used in the main analyses. Insufficient numbers of participants in each of these minority ethnic groups meant that conclusive interpretation of these analyses was not possible. The exclusion of participants resident in London led to some changes to individual results and some loss of statistical significance, for example, South Asians with a bus pass no longer

accumulated more active travel as part of bus journeys than White bus pass holders with an IRR of 1.29 (0.98, 1.72) (Appendix Table A-13).

Including only walking or cycling in the categorisation of active stages (i.e. excluding bus stages) led to some loss of statistical significance, indeed for the analyses of active stages as part of a bus journeys, models would not converge on estimates with this revised categorisation. Where the analyses were possible, the overall findings were unchanged (Appendix Table A-12).

8.4 Discussion

8.4.1 Main findings

This chapter found that bus pass holdership was associated with higher bus use and greater levels of active travel over the eight years for which data were available. Furthermore, these associations were of greater magnitude among those of minority ethnic groups.

8.4.2 Strengths and Limitations

This chapter is the first to use data from up to eight years following the implementation of the free bus pass policy in England and the first to examine potential ethnic differences in associations with bus and active travel. The data used in these analyses include detailed data on participants' travel behaviours, in addition to potentially confounding characteristics of participants and their neighbourhood of residence.[202] The NTS response rate is commensurable to that of other similar national surveys [290], giving a sample which was representative of the general population aged 60 years and above in England in terms of age, sex and ethnicity.[68]

Limitations of these analyses include the cross sectional nature of the data, this means that establishing causation was not possible and that findings may be influenced by reverse causality. The associations between the free bus pass and active travel may be due to more active participants being more likely to apply for, and hold, a free bus pass. The data collected by NTS is self-reported and is therefore susceptible to reporting errors. The use of a travel diary is intended to minimise biases associated with these errors, but despite this, and the use of weighting to correct for some known biases, it is unlikely that they are eliminated completely.[200] There is no evidence that non-response was associated with bus pass possession or active travel, however, the possibility cannot be discounted. A detailed analysis of more disaggregated ethnic groups was not possible due to the low number of participants of some minority ethnicities, indeed, the estimates from the main analyses suffered from a lack of statistical precision. The sensitivity analyses showed that with a sample which includes more ethnic minority participants, it might be possible to explore these associations in greater detail. This might be possible when additional years of NTS data become available or with a dataset with an ethnic boost to the sample.

There are notable differences between the ethnic compositions of large conurbations when compared with more rural areas in England, with a greater proportion of ethnic minorities in large cities. These cities, which are characterised by increased population density, also have a greater provision of bus services and other public transport.[287, 332, 333] Furthermore, bus pass provision in different areas of England differed both before and after bus pass was introduced in 2006. Before the 2006 national policy was rolled out, residents of some local authority areas were entitled to free bus travel, albeit with certain restrictions.[334] After the introduction of the free bus pass, some areas have seen particularly high levels of uptake, in London for example, where the bus pass entitles holders to free travel on other public transport modes, such as the Underground train.[80] It was not possible to assess the impact of pre-existing local policies on bus pass uptake, however,

analyses in this chapter did account for the geospatial differences by adjusting for the size of conurbation of residence and the population density of postcode sector of residence.

The inclusion of public transport stages in the classification of active stages was necessary as short walks, such as those to or from bus stops, are disproportionately underreported in surveys of this kind.[204, 325-327] In order to capture all bus users, including those who did not report how they accessed the bus, public transport was categorised as active. In any case, this decision impacted on only two of the four outcomes (total active stages and active stages as part of bus journeys) and when considered together, the four outcomes give a more complete understanding.

8.4.3 Comparison with other work

Several studies have previously examined the travel associations of the free bus pass for older people in England. A study using NTS data up to 2008 showed that the bus pass was associated with bus use, active travel and walking frequency, with associations comparable with those in this chapter.[80] The findings in this chapter extend this by using data over a much greater time period, indicating that the associations found immediately following implementation have been maintained and have not faded over time. Other research, using the English Longitudinal Study of Aging (ELSA), has found that the free bus pass was associated with higher bus use, lower adiposity and greater gait speed, although these findings appeared strongest in women.[81, 82]

Evaluation of a free bus pass for young people in London (aged 12-16), introduced in 2005, found that among those eligible, the distance and number of journeys by bus did not increase following implementation and that proportion of short journeys which were walked decreased, although the total distance walked did not decrease.[335] Differences in the associations of free bus travel between age groups might be due to different mode preferences in the respective eligible

populations. Younger people in England are unable to drive until they reach 17 years of age, although they can be car passengers. It is plausible that free public transport might displace walking journeys in younger people and driving journeys in older people. However, more research would be needed to explore this further.

8.4.4 Implications

Access to transport facilitates healthy behaviours and can act to buffer the impacts of the social determinants of health.[336] This includes transport's importance for maintaining social networks and for accessing healthcare, the loss of which are important contributors to health inequalities.[227, 336] Together with these factors, policies promoting public transport may have physical activity benefits associated with walking and cycling to access public transport. This may be particularly important in those for whom walking or cycling an entire journey is not possible and those who may not participate in sport or other leisure time physical activity. Although transport is only one domain of physical activity, people that participate in active travel generally accumulate greater levels of total physical activity.[171, 337]

It was differences in geospatial characteristics, in addition to socio-economic position which led to some differences between unadjusted and adjusted findings. For example, Table 8-8 shows that bus pass holdership is much higher in Black participants than in White or South Asian participants but when adjusting for socio-economic and geospatial factors, these ethnic differences were no longer seen (Table 8-3). Ethnic minority groups are more likely to travel by active modes than Whites and some minority ethnic groups also accumulate lower levels of leisure physical activity than Whites. Groups with greater levels of bus pass uptake and with greater levels of bus use can take greater advantage of the bus pass policy. The bus pass is associated with higher active travel and this appears to be the case across ethnic groups. These findings indicate that those of minority

ethnicities may benefit to a greater extent from a free bus pass policy and that some of these benefits are driven by the socio-economic position of those in minority ethnic groups; this does not affect the fact that ethnic minority groups benefit disproportionately. It has previously been shown that the benefits of the free bus pass are similar across socio-economic groups, based on housing tenure.[80] It must be noted however, that the higher use of bus and active travel modes among those of minority ethnicities in the zero-inflated negative binomial regression analyses in Section 8.3 persist after adjustment for several markers of socio-economic position, including housing tenure. There are several additional confounding factors which were not considered in this analysis, such as distance travelled. However, the differences in travel behaviour between the ethnic groups was not considered a result of ethnicity itself but as a result of their circumstance and social context and therefore, to adjust for every aspect of these circumstances would potentially eliminate the differences seen between ethnic groups. However, as the ethnic differences act through this context rather than through any inherent or genetic differences between ethnic groups, this was considered to be over adjustment.

8.5 Conclusion

This chapter found that possession a free bus pass was associated with higher bus use and active travel. Additionally these findings suggest that these associations were greater among minority ethnic groups and that they did not change over time.

Chapter 9 – Commute mode and mortality and cancer incidence using longitudinal census data

Research into the health effects of transport has primarily focused on walking and cycling. Systematic reviews and meta-analyses have shown an association between walking and a reduced risk of elevated blood pressure, CVD mortality and all-cause mortality [174, 175, 177] and between cycling and reduced risk of adiposity, diabetes and all-cause mortality.[174, 176, 177] Examination of commute mode specifically found that walk commuting was associated with a reduced risk of CVD incidence and cancer mortality, while cycle commuting was associated with a reduced risk of all-cause mortality, cancer mortality, CVD incidence, and cancer incidence.[178, 179] Systematic reviews of walking and cycling often pool multiple cardiovascular endpoints, including ischaemic heart disease (IHD), stroke and heart failure.[171, 178, 338] Differences between these outcomes are not then explicitly considered, despite some evidence that risk profiles differ in different cardiovascular outcomes.[339] This is likely to be due to insufficient studies for each specific outcome, which would indicate that this is a potentially neglected area of study. Breast cancer specific risk has been examined, with a systematic review and meta-analyses finding no association seen between commuting by walking, cycling or a combined measure of the two, although the absence of a definitive finding might have been due to a lack of precision.[178]

Chapter 7 of this thesis found that public transport users in England accumulated 21 minutes per day of physical activity in the course of public transport journeys. This is consistent with the findings of a 2012 systematic review, which found that public transport was associated with 7 - 33 minutes per

day of physical activity, although several of the included studies had small or selective samples.[184] Data from more recent objective measures of physical activity suggested that public transport use was associated with 10 minutes per journey of MVPA and 15 minutes per day of physical activity.[189, 192]

Recent analyses using UK Biobank data have investigated the mortality and cancer effects of walking and cycling, in addition to other transport modes.[181, 182] UK Biobank is a population based cohort of approximately 500,000 adults aged 40+, with data-linkage to mortality and cancer registrations.[340] One of these studies found that using a combination of motorised transport and cycling was associated with a reduced risk of all-cause mortality, cancer mortality and cancer incidence, when compared with an inactive reference category.[181] No associations were seen between a combination of motorised transport and cycling and CVD incidence or mortality, or between a combination of motorised mode and walking and any of the examined outcomes.[181] Motorised modes included car and public transport users, therefore it was not possible to make specific statements about the associations of public transport use. Another study using the same data found that using alternatives to car travel was associated with a lower risk of all-cause mortality, CVD incidence and CVD mortality.[182] Health benefits were seen for commuting and non-commuting travel, including among those who did not regularly commute. However, all those who didn't exclusively travel by car were aggregated into a single group, this included public transport users and others.[182] Neither of these studies were able to examine the effects of public transport use specifically due to the categorisations of transport mode used. These studies both had a relatively short available follow-up and consequent low numbers of events, follow-up was five years for one study [181] and seven years for the other.[182] However, if public transport use was associated with health benefits this would be important due to the large numbers of people who use public transport, for example, 16% of commuters in the 2011 Census of England and Wales did so by public transport.[272]

Because there is no existing research in to the mortality and cancer incidence effects of public transport commuting, research questions addressed in this chapter are:

- Which individual and neighbourhood characteristics are associated with commute mode in England and Wales?
- Is commute mode associated with cancer incidence, cancer mortality, CVD mortality or all-cause mortality?
- Does commute distance effect the association between commute mode and cancer and mortality outcomes?
- Does the socio-economic position of commuters effect the association between commute mode and cancer and mortality outcomes?

9.1 Methods

9.1.1 Data

Data come from the Office for National Statistics – Longitudinal Study (ONS-LS) which contains data from each decennial Census of England and Wales between 1971 and 2011. However, analyses in this chapter will be restricted to data from the Censuses of 1991, 2001 and 2011, due to important variables being unavailable for foregoing Censuses. The Census of England and Wales aims to include all usual residents and individuals visiting on the census date, regardless of age. Census participation is a legal requirement in the UK and considerable effort and resource is spent to ensure that participation rates are maximised because these data are used to plan provision of public services.[341] The England and Wales Census response rates are therefore high, achieving 94% in 2011, however, considerable challenges are posed capturing some populations, for example, the homeless and rough sleeping populations.[342]

The ONS-LS samples approximately 1% of the population (around 500,000 individuals) from each Census, based on those born on four undisclosed dates in the calendar year (4 out of 365). Participants are traced to the NHS register, with tracing completed for 98.8% of eligible participants in 2011, this allows census data from consecutive Censuses to be linked together, in addition to enabling the linkage of events data, such as mortality and cancer registrations.[343] After the exclusion of those known to have died or emigrated, 87.7% of participants from 2001 were linked to the 2011 Census, with missingness likely to be due to unreported emigration, census non-response or misreported dates of birth.[343]

Census questions have changed slightly over time reflecting changes in society, for example, a question about outside toilets was dropped after 1991, the same year that a question about central heating was added.[343] Census data are self-reported and include individual characteristics, such as age, ethnicity, marital status and occupation, in addition to household data such as housing tenure. Traditionally, data were collected by postal form or by specially employed enumerators, however, in 2011 16% of census returns were via the internet.[343] In addition to individual level data, the ONS-LS is linked to data about participant's neighbourhood of residence, including population density and area-based measures of socio-economic position.

Outcomes for these analyses were: (1) all-cause mortality, assessed by death registrations. As this is mandatory in the UK, participants who have been traced to their NHS record are expected to have very high rates of mortality linkage.[344] (2) Specific causes of death were provided using the International Classification of Diseases, since January 2001 the 10th revision (ICD 10) has been used, prior to this, ICD 9 was used. Specific outcomes examined were: CVD mortality (ICD10 – I20-25 + I60-69), IHD mortality (ICD10 – I20-25), stroke mortality (ICD10 – I60-69), cancer mortality (ICD10 – C00-C97 + D37-84), colon cancer mortality (ICD10 – C18) and breast cancer mortality (ICD10 - C50). (3) Incident cancer was examined, in addition to incident colon cancer and incident breast cancer.

Cancer registration data are collected by the eight English Cancer Registries and the Welsh Cancer Intelligence and Surveillance Unit, which have recorded cancer diagnoses using ICD 10 codes since 1995, and ICD 9 prior to that.[343]

The specific causes of death investigated all have known associations with physical activity, however, disaggregation is indicated as the epidemiology and risk factors associated with IHD are known to differ from those of stroke [345, 346], while colon and breast cancer also differ substantially.[347] It was therefore not known whether associations between commute mode and cause specific outcomes would differ.

Dates of death and cancer registrations were provided by the ONS-LS to the nearest month, more specific time of death was not available due to the risk of individual disclosure and data security concerns. Analyses in this chapter considered only participants' first incidence of cancer registration, as subsequent diagnoses might be recurrences, metastases or another primary cancer, all of which are likely to have differing prognoses.[348] Breast cancer analyses were restricted to women due to potential modification by gender and insufficient cases among men to investigate this fully.[349] Follow-up data were available until the end of 2016 for mortality outcomes and the end of 2015 for incident cancer.

Travel data in the Census were restricted to usual commute mode, which participants selected from a list of options, the possibilities varied slightly from Census to Census, but have been categorised for these analyses as: sedentary modes (e.g. car, motorbike), public transport (e.g. bus, train), walk or cycle; those who reported working from home were excluded. The full list of modes available for each Census is given in Appendix Table A-14. Further analyses were conducted with public transport users disaggregated into bus (bus, minibus) and rail (train, light-rail). Straight-line distance between work address and home address was derived for participants in the 2001 and 2011 Censuses, this

was used to dichotomise walk and cycle commuters into long and short distance commuters. This was based on their distance to work being above or below the mode-specific median commute distance, calculated separately for each census year. Commute distance allowed an examination of whether any health benefits which were due to physical activity exhibited a dose-response relationship, for example, whether greater benefits were seen in those walking longer distances. The cut offs at median distance were calculated separately for each Census and in 2011 the median one-way distances to work were 0.8km for walk and 2.9km for cycle commuters. The distances used were not based on any existing evidence, with median distances selected in order to conduct exploratory analyses. More details of median distances are presented in Appendix Table A-15.

Potentially confounding variables included in these analyses were: age; age^2; sex; ethnicity (minority ethnic group, white); housing tenure (homeowner, non-homeowner); marital status (married, non-married); education (no degree, has a degree); access to a car (yes, no); National Statistics Social-economic Classification (higher, intermediate, routine/manual); year entered study and presence of a long term illness (yes, no). In addition, neighbourhood measures which were included were population density (<2000 persons per km^2, 2000+ persons per km^2) and Carstairs quintile (a composite of male unemployment, lack of car ownership, overcrowding and head of household in low social class).[350-352] Individuals were assigned the Carstairs value of their ward of residence and quintiles were calculated. The Carstairs index is calculated at the ward level (average population approximately 6,500 people [353]), however, as more deprived wards have greater populations than less deprived wards, quintiles were calculated for individuals rather than wards, to ensure that each quintile contained approximately equal numbers of participants.

From the initial 804,090 people who provided data for any of the Censuses in 1991, 2001 or 2011, 19,413 were excluded as they could not be traced to the NHS register and 5,379 were excluded as they emigrated during the follow-up period. 358,176 participants were excluded who did not

provide a commute mode, which included those who did not work and those who worked from home, while an additional 14,782 were excluded due to missing data for at least one covariate. A complete case analysis was therefore carried out on an analytical sample of 391,894, although samples differed slightly between analyses.

9.1.2 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 the earliest census data-point provided.

In order to establish whether commuting by active or public transport modes was associated with health outcomes, analyses were carried out using a time-varying Cox proportional hazards model, which is a type of survival analysis.[354] Survival analyses estimate the relationship between the time to an event and the included covariates, which might be associated with that length of time. The Cox model estimates the ratio of the rate of events between two levels of an explanatory variable, known as a Hazard Ratio (HR).[355] HR has an interpretation similar to that of relative risk (RR), if HR=1 there is no difference between groups, i.e. a null finding, if HR = 0.5 this group has half the hazard of the reference group.[355] The Cox model makes no direct estimate of the baseline hazard and makes no assumptions about the form of the hazard over time, it is able to increase, decrease , remain constant or could incorporate a combination of these, for example, increasing initially and falling later. In Cox regression, the order in which events occur is important for the calculation of likelihoods, when events occur at the same time, and are said to be tied, the model can handle this in several ways. Analyses in this chapter use the Breslow approximation of the exact marginal probability when dealing with ties, the marginal approach assumed that the events did not actually occur simultaneously but that we did not know in which order they occurred. As the time of

events in this data were only known to the nearest month, many ties were seen for events which did not actually occur simultaneously (actually taking place throughout the month). The Breslow approximation is appropriate when the proportion of the risk group experiencing an event is small, which was the case these data.[356]

A time-varying approach was used as this allowed participants who reported different modes in different Censuses to contribute data to different commute modes, in addition, this allowed covariate data to change where values differed across Censuses. The resulting hazard ratios reflect an average which is weighted by the amount of follow-up associated with each commute mode. Time-varying covariates were: housing tenure, marital status, education, access to a car, National Statistics Social-economic Classification, Carstairs quintile and population density. Time constant covariates took their values from the baseline year and were: age at baseline; age at baseline^2; sex; ethnicity, year entered study and presence of a long term illness at baseline. As having a long-term illness was potentially a result of commute mode and therefore an intermediate on the causal pathway, it was not considered time-varying and its baseline value was therefore a time-constant covariate.

In maximally adjusted proportional hazard models, a proportionality test based on Schoenfeld residuals indicated the assumption was violated for gender and car access. However, the plots of Schoenfeld residuals versus time demonstrated the absence of a gross violation of the proportionality assumption (Appendix Figure A-4 & Appendix Figure A-5), therefore these variables were retained in the analyses.

The main analyses were conducted using a four-category measure of commute mode (sedentary, public transport, walk, cycle) and examined all-cause mortality, CVD mortality, cancer incidence and cancer mortality. In addition, analyses were carried out to investigate more specific outcomes, these

were: IHD mortality, stroke mortality, colon cancer incidence, colon cancer mortality, breast cancer incidence and breast cancer mortality. Analyses were then conducted with public transport users disaggregated into bus and rail users in order to examine difference between these two modes. Additional analyses were conducted to investigate the impact of commute distance on walk and cycle commuters, this was done using data from 2001 and 2011 as there were the only years for which commute distance was available. Finally, results were presented stratified by NSSEC and population density, in order to examine whether associations varied by these factors.

Self-reported health was added to the Census in 2001, however, the question changed between 2001 and 2011 meaning that responses were not comparable. In order to examine whether adjustment for self-reported health would have affected the finding of the analyses, models with 10 years of follow-up (1991-2001) were estimated, with and without adjustment for self-report health (good or fairly good vs. not good). In order to investigate potential reverse causality, additional analyses were conducted excluding the first 2 years of follow-up subsequent to each Census.

9.2 Results

9.2.1 Characteristics of commuters

65.6% of participants were sedentary commuters, 18.8% were public transport commuters, 12.4% walk and 3.2% cycle commuters (Table 9-1). Participants aged between 30 and 59 were more likely to be sedentary commuters than those older or younger. For example, 68.1% of those aged 30-44 were sedentary commuters compared with 62.0% of those aged 29 years or less. Those aged 29 years or less were most likely to be public transport commuters, 22.5%, compared with 15.7% in those aged 45-59. Men were more likely than women to be sedentary commuters (71.6% vs. 58.7%) or cycle commuters (4.0% vs 2.3% respectively) but were less likely to be public transport commuters (15.6% vs. 22.4%) or walk commuters (8.7% vs. 16.6%). Participants of White ethnicity

were more likely to be sedentary 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 who do not hold a degree were more likely than those with a degree to be sedentary commuters (66.3% vs. 62.7%) or walk commuters (13.4% vs. 8.6%) but were less likely to be public transport commuters (17.1% vs. 25.3%). Those in areas of less than 2,000 persons per square kilometre were more likely to be sedentary 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%).

Table 9-1: Characteristics of participants by commute mode from ONS Longitudinal Study 1991-2016

	Sedentary (%)	Public Transport (%)	Walk (%)	Cycle (%)	Total
All	65.6%	18.8%	12.4%	3.2%	391,894
Age					
16-29	62.0%	22.5%	12.3%	3.2%	148,257
30-44	68.1%	17.0%	11.6%	3.3%	141,857
45-59	67.8%	15.7%	13.5%	3.0%	85,319
60+	64.3%	16.8%	15.7%	3.2%	16,461
Sex					
Men	71.6%	15.6%	8.7%	4.0%	208,119
Women	58.7%	22.4%	16.6%	2.3%	183,775
Housing tenure					
Homeowner	71.4%	15.7%	10.0%	2.9%	286,795
Non-homeowner	49.8%	27.1%	18.9%	4.2%	105,099
Marital status					
Unmarried	60.0%	23.5%	13.0%	3.4%	189,152
Married	70.8%	14.3%	11.9%	3.0%	202,742
Ethnicity					
White	67.3%	16.9%	12.4%	3.4%	351,378
Minority ethnicity	50.9%	35.2%	12.5%	1.4%	40,516
Education					
No degree	66.3%	17.1%	13.4%	3.2%	311,601
Has a degree	62.7%	25.3%	8.6%	3.4%	80,293
Car access					
No car access	17.9%	47.5%	27.9%	6.7%	53,488
Has access to a car	73.1%	14.2%	10.0%	2.7%	338,406
Population density					
0-2,000 persons/km^2	75.3%	10.6%	11.2%	2.9%	171,229
2,000+ persons/km^2	58.0%	25.1%	13.4%	3.5%	220,665
NSSEC – social class					
Higher	70.6%	19.6%	7.3%	2.6%	128,788
Intermediate	69.4%	19.0%	9.6%	1.9%	97,664
Routine/Manual	59.4%	18.0%	18.1%	4.5%	165,442
Carstairs quintile					
Least deprived	78.2%	11.0%	8.0%	2.8%	76,324
2	72.4%	13.8%	10.6%	3.1%	78,956
3	66.8%	16.6%	13.2%	3.5%	79,892
4	61.1%	20.8%	14.6%	3.4%	80,597
Most deprived	49.3%	31.9%	15.6%	3.2%	76,125
Long term illness					
No illness	65.7%	18.7%	12.3%	3.2%	374,198
Has an illness	63.2%	19.8%	14.3%	2.7%	17,696
Entered study					
1991	68.4%	16.2%	12.0%	3.3%	207,809
2001	65.3%	19.2%	12.4%	3.1%	87,817
2011	59.7%	23.9%	13.3%	3.1%	96,268

NSSEC – National Statistics socio-economic classification
Source ONS Longitudinal Study

When public transport commuters were disaggregated, 10.3% of participants were bus commuters and 8.5% were rail commuters (Appendix Table A-16). Women were more likely be bus commuters than men (14.1% vs. 6.9%) and slightly less likely to be rail commuters (8.3% vs. 8.7%). Those holding a degree were less likely to be bus commuters (6.9% vs. 11.2%) and more likely to be rail commuters (18.4% vs. 5.9%) than those without a degree. Those in routine/manual occupations were more likely to be bus commuters than those in managerial occupations (13.9 vs. 5.9%) and less likely to be rail commuters (4.1% vs. 11.9%).

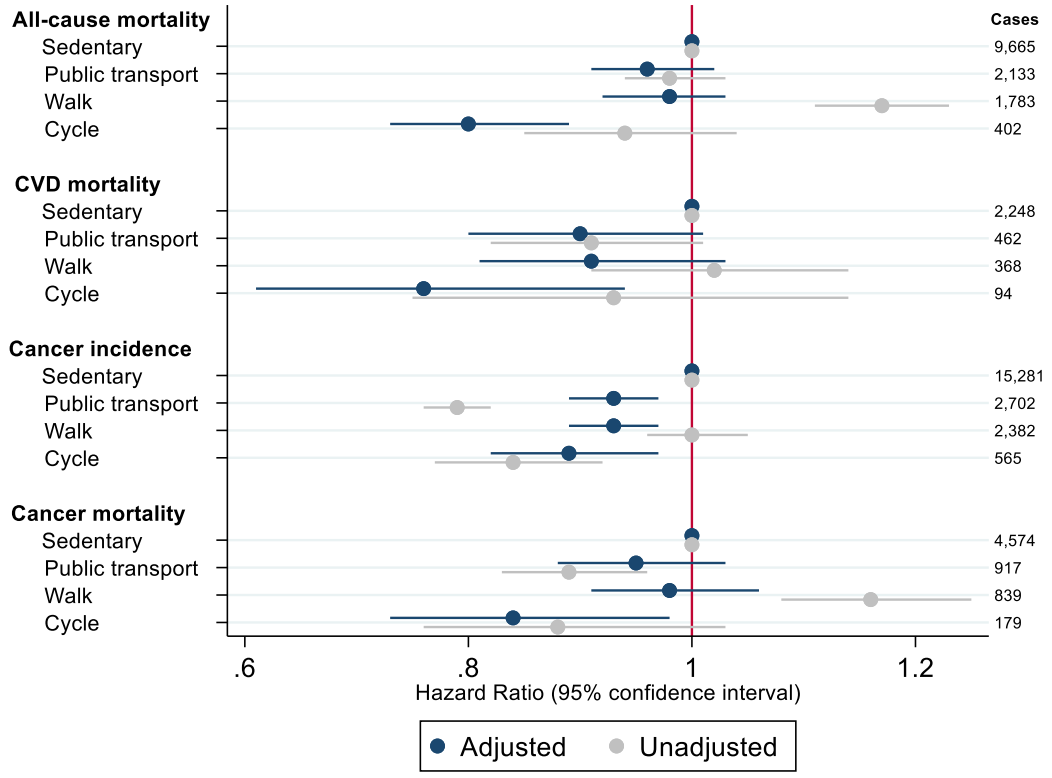
Those aged 16-29 were less likely to be short walk commuters than older people, for example, when compared with those aged 60+ short walk commuters were 5.4% and 8.1% of participants respectively, however, the opposite was true with long distance walk commuters (7.4% vs. 5.3%) (Appendix Table A-17). Those with a degree were more likely to be long cycle commuters than those without a degree (2.0% vs. 1.4%) but this was not seen in short cycle commuters (1.3% vs. 1.7%). Those living in areas with a population density of 2,000 person per km^2 or above were more likely to be long walk commuters than those in less dense settings (6.9% vs. 4.1%), this was not the case with short distance walk commuters (5.9%. vs. 6.1%). Those in the most deprived Carstairs quintile were more likely to be walk commuter than those in the least deprived quintile, this gradient appeared greater for long walk commuters (8.0% vs 2.9%) than short walk commuters (6.8% vs. 4.5%).

9.2.2 Commute mode and health

Of the 391,894 people who contributed data to these analyses, 13,983 died during the follow-up period. Public transport commuters had a lower risk of incident cancer than sedentary commuters (HR = 0.93 (0.89, 0.97)), with other outcomes there is suggestive evidence for a small, but statistically non-significant, protective effect from public transport commuting (Figure 9-1 & Appendix Table A-18 & Appendix Table A-19). Walk commuters had a reduced risk of incident cancer

(HR = 0.93 (0.89, 0.97)) and statistically non-significant positive associations with other outcomes. Cycle commuters had a reduced risk of all-cause mortality (HR = 0.80 (0.73, 0.89)), CVD mortality (HR = 0.76 (0.61, 0.94)), incident cancer (HR = 0.89 (0.82, 0.97)) and fatal cancer (HR = 0.84 (0.73, 0.98)). In unadjusted analyses, walk commuters had considerably higher risk of all-cause (HR = 1.17 (1.11, 1.23)) and cancer mortality (HR = 1.16 (1.08, 1.25)) than other modes, suggesting that these groups had poorer risk profile generally, these associations were not apparent after adjustment for socio-economic and other factors.

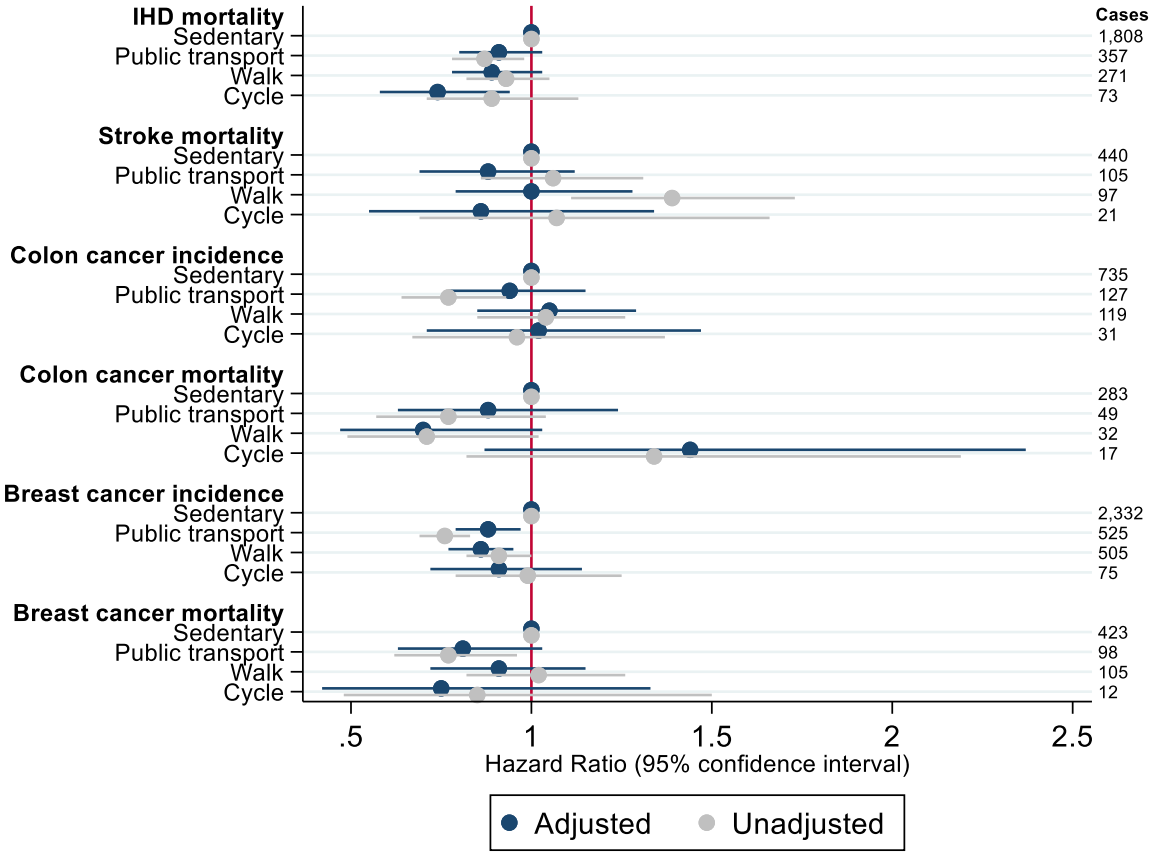
Figure 9-1: Hazard ratio of mortality and cancer outcomes by commute mode from the ONS Longitudinal Study 1991-2016



Analyses of specific disease outcomes showed that public transport commuters had a reduced risk of incident breast cancer (HR = 0.88 (0.79, 0.97) and had statistically non-significant positive associations with each of the other disaggregated outcomes (Figure 9-2, Appendix Table A-22, Appendix Table A-23 & Appendix Table A-24). Walk commuters also had a reduced risk of incident breast cancer (HR = 0.86 (0.77, 0.95)), while cycle commuters had a reduced risk of IHD mortality (HR

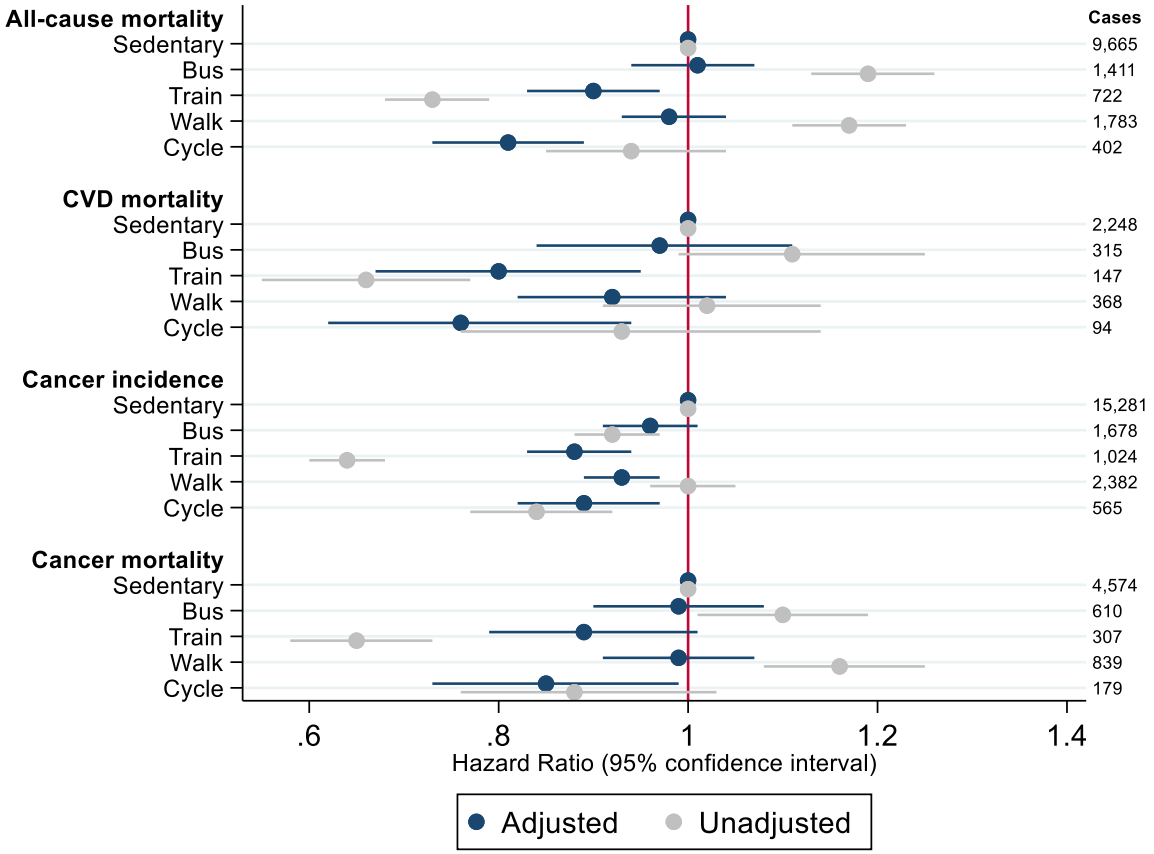
= 0.74 (0.58, 0.94)). Other associations with these modes were mixed, with relatively low numbers of events leading to a lack of precision for some estimates, especially for cycle commuting.

Figure 9-2: Hazard ratio of disaggregated mortality and cancer outcomes by commute mode from the ONS Longitudinal Study 1991-2016



Findings with public transport commuters disaggregated showed that rail commuters had a reduced risk of all-cause (HR = 0.90 (0.83, 0.97)) and CVD mortality (HR = 0.80 (0.67, 0.95)), in addition to cancer diagnosis (HR = 0.88 (0.83, 0.94)), while bus commuters had no beneficial effects (Figure 9-3, Appendix Table A-20 & Appendix Table A-21). It is notable however, that in unadjusted analyses bus commuters had poorer outcomes than rail commuters which might reflect the risk profile of bus 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).

Figure 9-3: Hazard ratio of mortality and cancer outcomes by commute mode with disaggregated public transport users from the ONS Longitudinal Study 1991-2016



There is some suggestive evidence that long distance walk commuters had a lower risk of all-cause mortality, CVD mortality and incident and fatal cancer than the equivalent short distance commuters (Figure 9-4, Figure 9-5, Appendix Table A-25 & Appendix Table A-26). However, in most cases no statistically significant differences were seen, either between long and short distance commuters or between long distance commuters and the car commuter reference groups. For example, the HR of CVD morality for short and long distance walk commuters was 1.03 (0.82, 1.29) and 0.90 (0.69, 1.17) respectively. Unadjusted analyses show that short distance walking commuters have statistically significantly poorer all-cause mortality and cancer incidence risk than long distance walk commuters, based on non-overlapping confidence intervals. Cycle commuters showed a more mixed picture, with long distance not consistently associated with magnitude or direction of associations. This might be due to cycle commuters having particularly few events in each distance group leading to very wide confidence intervals around some estimates.

Figure 9-4: Hazard ratio of mortality outcomes by commute mode and distance from the ONS Longitudinal Study 1991-2016

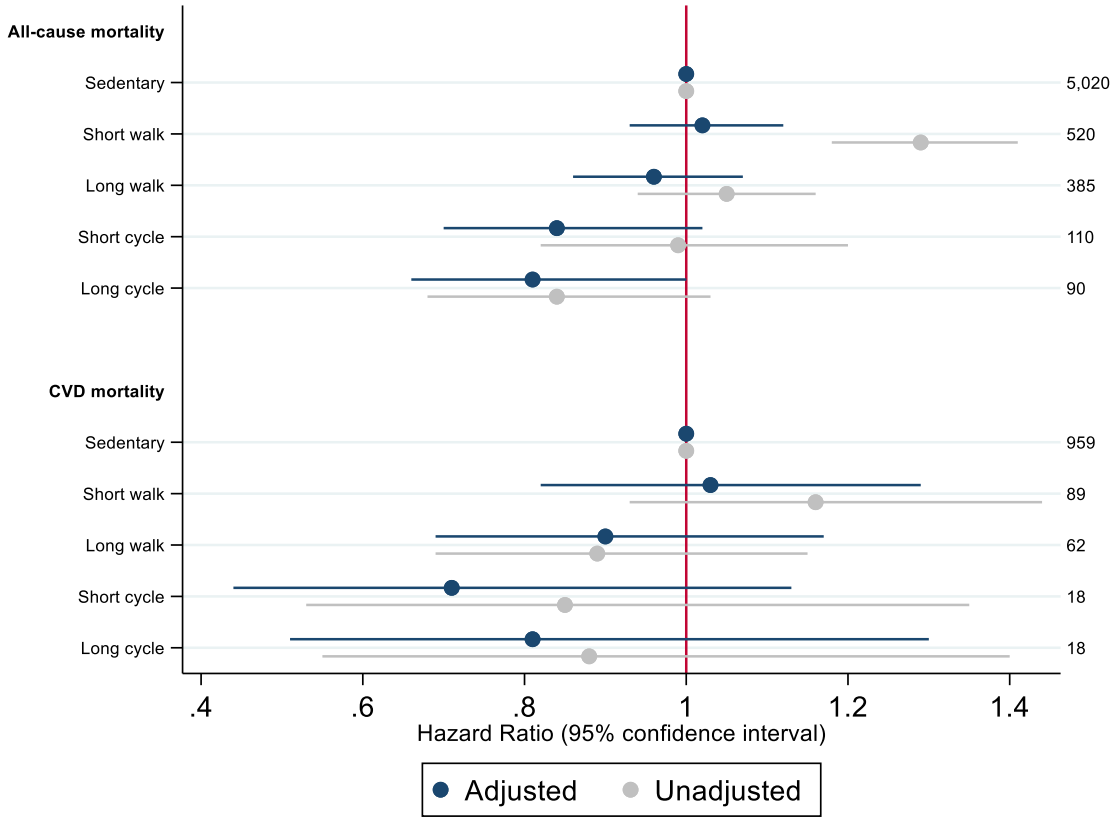
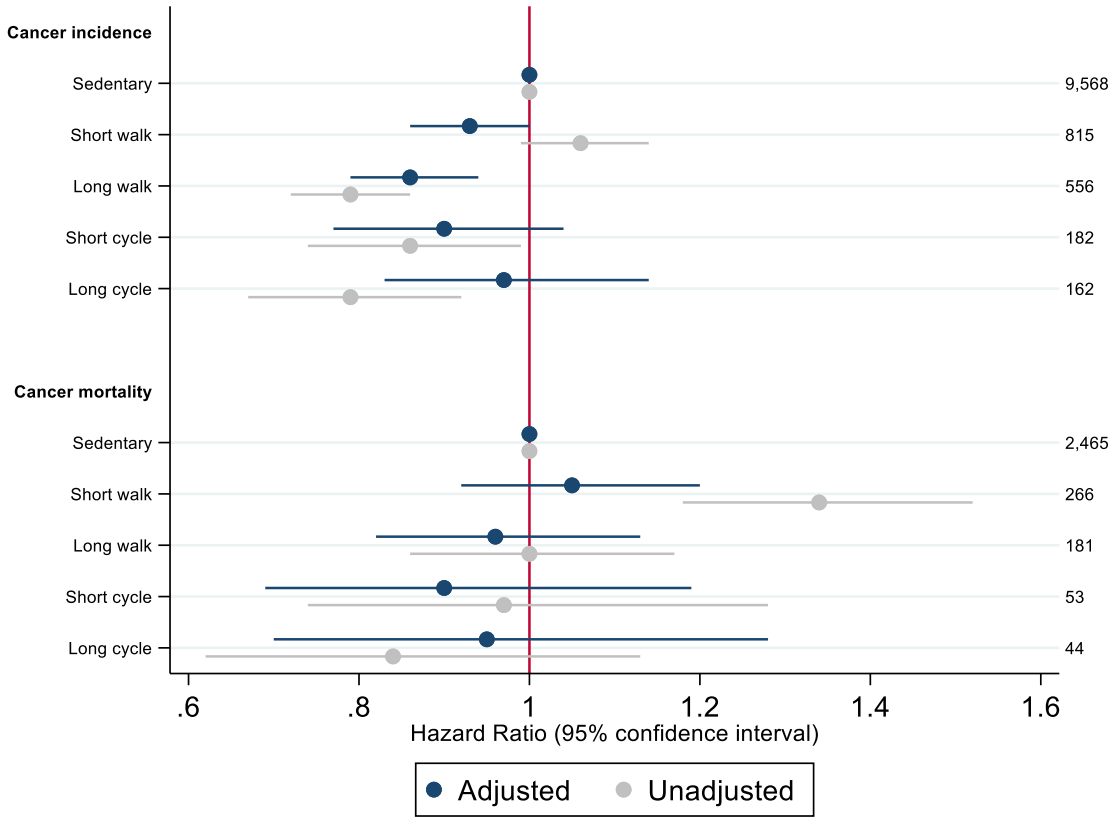


Figure 9-5: Hazard ratio of cancer outcomes by commute mode and distance from the ONS Longitudinal Study 1991-2016



Analyses stratified by NSSEC social classification provides little evidence for a differential effect by occupation based socio-economic position (Appendix Figure A-6, Appendix Figure A-7 & Appendix Table A-29 – Appendix Table A-38). Although the point estimates for some modes showed lower risk of all-cause mortality among the managerial group than for other groups, these were not statistically significant differences and were not consistent. Likewise, the analyses stratified by population density showed no statistically significant differences and point estimates did not paint a consistent picture.

Adjusting for self-reported health had little impact of the association of commute mode and health (Appendix Table A-27). Finally, analyses to examine the impact of excluding the first 2 years of follow-up subsequent to each census showed no substantial differences from the main analyses (Appendix Table A-28).

9.3 Discussion

9.3.1 Main findings

Analyses of a large sample of census participants found that commuting by public transport was associated with a reduced risk of incident cancer. Cycle commuting was associated with a reduced risk of all-cause, CVD and cancer mortality, in addition to incident cancer, while walk commuting was associated with a reduced risk of incident cancer. When bus and rail commuters were examined separately, rail commuting had a reduced risk of all-cause and CVD mortality, in addition to incident cancer, while bus commuting showed more modest and statistically non-significant associations. There was suggestive evidence of a dose response from walking, with long walk commuting appearing to have more positive associations than short walk commuting, this was not seen for cycle commuting.

9.3.2 Strengths and limitations

Strengths of these analyses include the large representative sample of census participants with high levels of linkage to the NHS register, which means that few events were missed. Participants could each contribute up to 25 years of follow-up, which resulted in a considerable period of observation. The large sample size allowed public transport users to be examined independently, rather than being combined with users of other modes, it also allowed bus, rail, walk and cycle commuters to be analysed separately. Examination of specific outcomes were possible due to the large sample and detailed outcome data, for example, IHD was separated from stroke. Nonetheless, the focus on those of working age means that a relatively low number of events seen in users of some modes.

Limitations of these analyses include the use of usual commute mode as the exposure, which fails to capture travel for other purposes, use of different modes during the same day and use of different modes on different days. Usual commute mode was only available every 10 years, it was therefore assumed that commute mode did not change during the subsequent 10 years of follow-up. This is often not the case and in addition, levels of mode changing might differ between users of different modes, for example, 78% of car commuters in 1991 were still commuting by car in 2001 but just 28% of cycle commuters and 33% of walk commuters continued with these modes.[357] The assumption that the values provided will be constant over the 10 years between censuses also applies to other covariates, which might also be expected to change for a substantial proportion of participants. The 10 year gap between waves also meant that the impact of changes in commute mode were not examined as it was impossible to know when changes occurred.

Data on potentially important confounding variables were not available due to limitations of the scope of the census, meaning they could not be taken into account in these analyses. The census contains no data on a range of covariates such as: diet quality, adiposity, smoking, air pollution, non-

commuting physical activity, medications and comorbidities. The impact of the inability to take these factors into account might is not entirely clear. Several of these factors are known to be detrimental to the health of the socio-economically disadvantaged, including smoking, BMI and diet quality.[358] Therefore, additional adjustment might lead to improved outcomes for bus commuters, who are generally socio-economically disadvantaged, and worse outcomes among train users who are generally more advantaged. However, studies of the BMI status of public transport users show that public transport users have lower BMI than car users, unadjusted and in some case adjusted for other factors.[172, 180] The impact of air pollution across socio-economic groups is contested with findings in Europe particularly mixed.[359] The air pollution exposure of users of different transport modes is context dependant and is dependant of ventilation rate in addition to ambient concentrations of pollutants.[121, 360] Meaning that although pedestrians may have lower ambient pollutant levels, the increased ventilation volume due to the physical activity might lead to greater harms.[121, 361] Similarly, cycling among motorised vehicles is likely to lead to higher exposure than cycling on a separated cycle track. Data are collected on long-term illness and in more recent censuses a question on self-report health was added, although the latter could not be included in these analyses as it was unavailable for all the time periods used. Additional analyses using data from the 2001 census were carried out with the inclusion of a binary variable for self-reported health (good or fairly good vs. not good). These analyses showed the additional adjustment made little impact on the association between commute mode and health outcomes (Appendix Table A-27). However, it is plausible that more detailed medical history data would have allowed for more complete adjustment for participants' health status, an important potentially confounding factor.

The study period included a change in the ICD coding used to classify disease, differences between ICD 9 to ICD 10 could affect the consistency of outcome data. The most substantial changes related to the attribution of main cause of death where an underlying chronic disease and acute ill-health contributed to mortality.[362] The changes meant that deaths which might previously have been

attributed to acute ill-health (e.g. pneumonia) using ICD 9, were attributed to the underlying chronic illness using ICD 10, where the underlying chronic illness was a direct cause of the acute ill-health.[362] This led to quantified changes in the numbers of deaths attributable to different causes [362], however, the impacts of these changes on the association between commute mode and death are uncertain. Other potential limitations of the events data include known regional variation in the registration of uncertain and unknown neoplasm types, in addition to specific issues like the decrease seen in registrations of carcinoma-in-situ of skin, which is no longer a registered condition.[363]

9.3.3 Comparison with other work

An official ONS data release from the 2011 England and Wales Census found similar commute mode share to that in this chapter.[272] The official statistics found that 64% commuted by sedentary modes, 16% by public transport and 14% by either walking or cycling, compared with the thesis findings of 66% by sedentary modes, 19% by public transport and 16% by walking or cycling.[272] Any differences might be because the official figures retained those working from home and those commuting by 'other' modes, while these were both excluded from analyses in this chapter. ONS data are also restricted to the 2011 Census, whereas this thesis combined data from 1991, 2001 and 2011, based on which was the participant's baseline year.[272]

Comparing the prevalence of public transport commuting with public transport use for any purpose seen in Chapter 6 of this thesis show that 19% of commuters do so by public transport compared with 33% who used public transport for any purpose. The differences are even more pronounced for bus use, which was used by 25% of people for any purpose and by 10% of commuters, whereas train was used by 11% of people for any purpose and by 8.5% of commuters. This is likely to reflect the

greater use of train travel for commuting compared with buses, which have greater use for other purposes.[300]

Existing research found that walking and cycling for any purpose was associated with an 11% and 10% reduction in all-cause mortality respectively, with the greatest benefits seen among those moving from little or no active transport, to some.[174] These findings are lower than the associations with cycling found in this chapter (20% risk reduction) and greater than the association seen with walk commuting (no evidence for a risk reduction). This might be because the meta-analysis assumed that both walkers and cyclists accumulated 11.25MET-hrs per week from their active travel, this value was selected to correspond to global recommendation of 150 minutes per week of moderate intensity physical activity.[141] However, median commute distances in the 2011 ONS-LS, which were used in this thesis, indicated that commuting resulted in 8km of walking or 29km of cycling a week, based on two-way commuting five days-a-week. Assuming an average walk speed of 4.8km/h and an average cycle speed of 17.7km/h, walking commuters are likely to accumulate only about 5.8MET-hours per week on average, while cycle commuters are likely accumulate 11.1MET-hours.[139, 319] A greater understanding of the duration and intensity of walk and cycle commuting would be necessary to examine this in greater detail.

A 2018 systematic review and meta-analyses by Dinu et al. examined the impact of walk and cycle commuting on a range of outcomes. For every association examined by the systematic review and in this chapter, the systematic review found greater effect sizes than seen here. The review found that cycle commuting was associated with risk reductions of 24% for all-cause mortality and 25% for cancer mortality, with no associations seen with CVD mortality or breast cancer incidence. Walk commuting was associated with a 27% reduction in risk of CVD incidence with no association seen with other outcomes. These differences could be due to the review comparing the most active commuters with the least active, often discarding data from those between.[178, 364, 365] This

approach is likely to yield larger differences than the analyses in this chapter, which was not restricted to commuters on these extremes. A separate systematic review which examined only cycle commuting found that it was associated with reduced risk of incident and fatal cancer, although meta-analyses were not conducted.[179]

The association between walking and cycling commuting has also been reviewed by pooling the results of studies examining walking with those examining cycling and those which used a combined measure of both.[171, 178] One analysis of walking and cycling combined found walk/cycle commuting was associated with an 8% reduction in all-cause mortality and a 9% reduction in CVD incidence, with no association seen with CVD morality, cancer mortality or breast cancer incidence.[178] These findings are broadly compatible with the findings of this chapter, given that they would be expected to be between the findings for walk commuters and cycle commuters, which is the case for most outcomes. Another meta-analysis examining commute mode found that a combined measure of walking and cycling was associated with an 11% reduced risk of CVD (fatal and non-fatal), with these finding stronger among women than men.[171] Again this sits between the finding in this chapter for walk commuters and those for cycle commuters when examining CVD mortality.

A 2018 study using UK Biobank data with 5 years of follow-up found that, when compared with non-active commuting, cycle commuting was associated with lower risk of several outcomes, including: all-cause mortality, CVD morality, and cancer mortality, while walk commuting was associated with lower risk of CVD incidence and CVD mortality.[181] The associations seen in this study were of greater magnitude than found in this chapter, for example, HRs for cycle commuting and all-cause and CVD mortality were 0.59 (0.42, 0.83) and 0.48 (0.25, 0.92) respectively, compared with HR = 0.80 (0.73, 0.89) and HR = 0.76 (0.61, 0.94) in this chapter. This UK Biobank study also investigated whether commute distance led to a dose response, with those walking or cycling further to work

accumulating greater benefits than those travelling shorter distances. This was seen for cycle commuters with all outcomes and for walk commuters with CVD outcomes.[181] The analyses in this chapter provide some suggestive evidence for a dose-response relationship for walk commuters but not for cycle commuters. A possible explanation for why a dose response was not seen in the analyses of cycle commuters in this chapter is that long and short distance cycle commuters may have also accumulated relatively large amounts of leisure time physical activity which might mean that the difference in commute distance had a relatively smaller impact on overall physical activity levels. Because the census data do not have data on leisure physical activity, it is not possible to be certain whether this is the case here. However, the UK Biobank study found that walk commuters accumulated less leisure time physical activity than cycle commuters and so the distance walked to work might be a more important contributor to total physical activity.[181] The difference between this chapter and the findings of the UK Biobank study could be due to the restriction of UK Biobank to older people, who are generally less active than younger people.[144]

Another study using UK Biobank investigated commuting, in addition to non-commuting travel.[182] Modes were dichotomised into those who exclusively travelled by car and those who used any other mode or combination of modes.[182] The outcomes were also all-cause mortality, CVD morality, CVD incidence, cancer mortality, cancer incidence. Active travel was associated with lower all-cause mortality, incident CVD and CVD mortality, with positive associations seen for commuting and non-commuting, including among those who were not regular commuters.[182] The two studies using UK Biobank data are broadly consistent with the findings of this chapter that travel modes other than cars are associated with health benefits. Differences between these studies and the analyses in this chapter could be due to UK Biobank participants being able to select multiple travel modes, meaning that those reporting only walking or cycling might be more select groups than those reporting walking or cycling as usual commute mode. UK Biobank recruited only those aged 40+, meaning that these studies were likely to have older populations, UK Biobank studies were also able to adjust for

comorbidities, smoking, diet, non-commuting physical activity and smoking. However, due to the limited available follow-up and complications categorising travel modes, these studies used aggregated mode classifications that do not provide any data specifically about public transport users.

9.3.4 Implications

This chapter found that commuting by public transport was associated with a reduced risk of incident cancer. Cycle commuting was associated with the most advantageous outcomes but benefits were also seen among walk commuters. This is important for policy makers, who should consider policies to discourage car use and promote the use of more active modes, including public transport.

After adjusting for potentially relevant factors, public transport was associated with health benefits when compared with commuting by sedentary modes. This was statistically significant for cancer incidence, with suggestive evidence for mortality outcomes. The positive associations appeared to be largely driven by rail commuters, who had reduced risk of several outcomes, bus commuters saw no health associations. There were notable differences in the unadjusted health associations, with bus commuters having poorer unadjusted outcomes than either the sedentary commuter reference category (in the case of all-cause and cancer mortality) or the unadjusted rail commuters (in the case of all-cause, CVD mortality, cancer mortality and cancer incidence). This reflects the characteristics of those that use these differing commute modes and the differences in health outcomes they experience. Chapter 6 found that bus users have less socio-economic advantage than rail users, and known associations exist between socio-economic disadvantage and poorer health.[227] The impact of differences in the unadjusted associations of bus and rail commuters is uncertain and will depend of the comprehensiveness of the adjustments made for socio-economic position and other

confounding factors. Given the potentially important confounding factors which could not be considered in these analyses, it is plausible that residual confounding led to bus commutes appearing less favourable than would have been the case had more complete adjustment been possible. However, as the associations with rail commutes tended to attenuate from strong health benefits in unadjusted analyses, it would then also be possible that rail commuters would demonstrate less favourable associations if more complete adjustment were possible.

Public transport and walk commuting were associated with a reduced risk of cancer incidence but were not associated with any mortality outcomes, which might be a result of the more chronologically proximal nature of this outcome. One reason this might have an impact is that many additional factors might affect a mortality outcome that would not affect incident disease, for example, quality of healthcare and treatment received.[366, 367] Another reason might be the lower number of mortality events compared with incident events, which will have affected the precision of subsequent estimates, for example, 20, 930 incident cancer cases, compared with 6, 509 cancer deaths. This effect is likely to be exacerbated by the relative youth of the participants, which was a consequence of all participants reporting an occupation and commute mode, i.e. not being retired. This means that for most participants, any mortality outcome would be premature mortality.[368]

Analyses stratified by NSSEC social classification show no obvious patterns in the associations of commute mode and health outcomes. There were some differences in the point estimates for some outcomes, however, these were always seen along with overlapping confidence intervals and the position of the point estimates relative to one another did not appear consistent. Although stratified analyses were limited by low numbers of events and therefore low power, these findings provide no evidence for a difference across socio-economic groups (at least not those based on occupation), suggesting that associations were not modified by this factor. A similar finding was seen in analyses

stratified by population density, therefore it appears that the findings of this study are generalizable to those of all occupation categories whatever the population density of their neighbourhood.

9.4 Conclusion

Public transport commuting was associated with a reduced risk of cancer incidence, with some suggestive evidence for an association with reduced risk of other outcomes, which appeared to be driven by rail users. Cycling is associated with a reduced risk of all-cause, CVD and cancer mortality, in addition to incident cancer, while walk commuting was associated with a reduced risk of cancer incidence. Stratified analyses indicate that no socio-economic or population density groups see greater or lesser benefits, suggesting that these finding are generalizable across these groups. An increase in the numbers of people commuting by public transport may therefore lead to reduced rates of cancer incidence.

Chapter 10 - Discussion

10.1 Summary of main findings

The main findings of this thesis are:

- Public transport use is more common among some groups, including those of minority ethnicity and the socio-economically disadvantaged
- Public transport use is associated with physically active behaviour
- The free bus pass was associated with higher bus and active travel levels among older people and this may be greater among those of minority ethnicity
- Public transport users benefit from reduced adiposity and lower risk of cancer incidence
- Together these findings suggest that encouraging public transport use in order to improve health and reduce inequalities might be an effective and equitable health improvement strategy

The systematic review of the association between public transport and cardio-metabolic outcomes identified 10 studies. Meta-analysis of five of these studies showed that initiating public transport use was associated with a reduction in BMI of 0.30 kg/m^2, while studies of the association between distance to bus stops and adiposity had mixed findings. Analyses of NTS found that bus use was more likely in women, the less socio-economically advantaged and those living in areas with high population density, while train use was more likely among men, the young and those from socio-economically advantaged households. Those who combined public transport use with walking or cycling in England accumulated an average of 21 minutes a day of physical activity in the course of public transport journeys, with one third of these public transport users reaching at least 30 minutes. The free bus pass was associated with higher bus use and active travel, with these associations of greater magnitude among those of minority ethnic groups. Analyses of census data

found that public transport use was associated with lower risk of incident cancer, while train use was additionally associated with a reduced risk of all-cause mortality and CVD mortality.

10.2 Limitations

10.2.1 Scope

Individual chapters of this thesis contain a discussion of the limitations of the data and methods used therein, in this section I will focus on more general limitations. The potential impacts of public transport on health and wellbeing are broad and this thesis has focused on only some of these. The majority of the empirical work in this thesis was focused on potential physical activity impacts, with the exception of the ONS-LS analyses, which used cancer and mortality as outcomes. This means that some impacts of public transport have not been included, for example, co-benefits such as air pollution, climate change implications, road traffic collisions, and wellbeing more widely. Research into associations of commuting and wellbeing have presented a mixed picture with strong potential confounding by socio-economic position.[135] The association between commute time and wellbeing outcomes also differed by commute mode, for example, among bus commuters, long commute times were more strongly associated with reduced job satisfaction and mental health than among commuters using other modes, while long rail commutes were associated with lower strain than shorter rail commutes.[135] In this thesis socio-economic position was used as an umbrella term for several measures of its constituent dimensions, in addition to composite measures of social deprivation. This was in part to enable the use of consistent terminology when referring to the differing variables which were available in the different datasets used in this thesis. Although different dimensions of socio-economic position, such as occupational class, status and material circumstances may differ in their health associations, further investigation of these differences was not within the scope of this thesis.[369]

Switching from private car to public transport use is associated with a reduction in the emission of atmospheric pollutants, subsequent improvement to air quality would lead to gains for population health.[370, 371] In addition to these population benefits, a literature review found that individuals travelling by car in Europe were most consistently exposed to higher levels of pollutants (particulate matter of size less than 2.5µm , black carbon , ultrafine particles of size less than 0.1µm and carbon monoxide) than users of other modes.[121] Those who walk appear to have the lowest exposure to pollutants, with cyclist and bus users between these two.[121] Conversely, research from the USA found that driving was associated with lower levels of exposure to particulate matter of less than 2.5µm than users of other modes, suggesting that context may be an important factor and that further investigation is necessary.[360] Although wellbeing and air pollution resulting from travel mode choice may contribute to some of the findings of Chapter 9, specifically the mortality and cancer outcomes, more detailed examination of these associations is outside the scope of this thesis.

Transport was responsible for 27% of UK greenhouse gas emission in 2017 having remained stable since 2016, and having fallen only 2% since 1990.[372] This compares with the energy and agriculture sectors which have reduced emission by 60% and 16% respectively since 1990.[372] As such, the proportion of UK greenhouse gas emission from the transport sector are growing.[372] Climate change is estimated to cause 250,000 deaths per year between 2030 and 2050 due to causes from undernutrition and heat exposure.[127-129] Public transport use leads to lower greenhouse gas emissions per mile travelled than car use, and therefore a population shift from car use to public transport use would lead to reduced reduce greenhouse gas emissions, even without improvement to vehicle efficiency.[125, 373]

Another mechanism through which public transport use can impact health is through road traffic collisions, which are a significant global cause of death, with over 1.3 million deaths in 2015.[130] A study comparing modes in the USA showed that fatalities per billion miles 2000-2009 were 7.28 for

drivers or passengers of a car or light truck.[131] This compared with 0.43 fatalities per billion passenger miles on a train, 0.24 on a light-rail system and 0.11 as a passenger on a bus [131], with similar statistics available for the UK.[374] The substantially lower mortality rates in public transport users compared with car use indicates further population health benefits from substitution of car journeys with public transport journeys.

Another mechanism through which public transport might influence health are through noise pollution. However, the effects of traffic noise are difficult to separate from other exposures, such as air pollution, therefore definitive conclusions are difficult.[375] However, noise is known to adversely affect cardiovascular health and therefore this remains an understudied mechanism through which transport affects health.[375, 376]

Chapters 7 and 8 investigated physical activity as a result of public transport use, rather than specific markers of disease status. However, low physical activity has established associations with increased risk of several important health outcomes, including a strong association with mortality.[152, 153, 219] In addition, the examination of the free bus pass in Chapter 8 used bus use as an outcome, which was itself then examined as an exposure, with respect to physical activity, mortality and cancer outcomes. The use of intermediate outcomes has limitations, such as unobserved factors influencing the association between the exposure and the ultimate outcomes and the influence of compensatory processes, such as reducing other physical activity or increasing calorific intake in response to increased active travel. However, this is a common approach where data shortcomings do not allow a single data source to be used to examine each step of a causal pathway. The systematic review in Chapter 5 revealed a scarcity of longitudinal evaluation of the association between public transport and cardio-metabolic outcomes, despite the growing evidence with intermediate outcomes. Following the identification of this gap in the literature, the analyses

presented in Chapter 10 were carried out, which evaluated commute mode with incident cancer and mortality outcomes.

The use of different data sources in this thesis meant that very detailed data on journeys were available for the chapters using NTS but not those using the ONS-LS. Chapters using NTS data were able to examine each constituent stage of each journey, in addition to the overall journey. Analyses of ONS-LS data used usual commute mode as an exposure, this fails to capture journeys for other purposes and journeys which use multiple modes, both within the same day or across different days. However, census data has seldom been employed to study transport mode and health, some analyses have been carried out but were limited to comparing 10-year relative risks and subsequently struggled for statistical power, they were also carried out before data from the 2011 Census were available.[377] Analysing commute mode as the exposure allows for a focus on working age people, who constitute a large and important section of the population at 65% of all people in England and Wales [68] These also constitute an important group with respect to cardio-metabolic risk factors, with the proportion overweight or obese increasing through the life course before beginning to fall in older age, peaks are seen in ages 65-74 in men and 75-84 in women.[281] This occurs amidst a decline in physical activity in those aged 35 and above in both sexes.[144] Those of working age are therefore a critically important target to increase physical activity and reduce adiposity. Those of working age also incur indirect costs of ill-health, over and above direct health care costs, in the form of reduced employment productivity.[378]

10.2.2 Data

This thesis focused on routine data, which is not collected to answer specific research questions, unlike primary collected data, and therefore some potentially important confounding factors were omitted. NTS data was collected for transport purposes and the Census is conducted to plan service

provision, therefore neither contain any data on diet, smoking or other physical activity, such as going to the gym. Leisure-time physical activity is known to differ between users of different transport modes [181], however, there is also some research into the health effects of transport modes in which leisure physical activity has little impact.[172, 261] The cross-sectional nature of NTS data also meant that it was not possible to evaluate individual levels factors associated with changes in travel behaviour. The 10-year intervals between data collection in the ONS-LS led to uncertainty about the stability of measures over time and the exact timing of any changes. Alternative data which might have been used to address the questions of this thesis include UK Biobank, ELSA and UKHLS. The latter two of these studies have smaller sample sizes than those used in this thesis, which would have led to difficulty disaggregating users of buses and trains. In addition, the length of follow-up is smaller than in the ONS-LS, which would have potentially led to low statistical power for detecting differences between groups. UK Biobank is large dataset but it is not representative of the source population, exhibiting evidence of the healthy volunteer effect, where those who chose to participate are healthier than those who do not.[379]

Self-reported walking, cycling and public transport use are measured in this thesis either by survey question or travel diary. While these methods can be employed at relatively low cost on large groups, there are some potential limitations, such as inaccurate recall, which might lead to recall bias if recall differs systematically between groups, e.g. if bus journeys were less well remembered than train journeys.[380] Social desirability bias may lead people to exaggerate active travel levels, if they perceive that this reflects well on them.[381] In addition, survey questions with numeric responses often cluster on round numbers, such as multiples of five or ten, this might affect estimates of journey duration or numbers of journeys.[382] Travel diary data has also been shown to underestimate the number of journeys, especially walking journeys, and to overestimate the length of recorded journeys.[204]

In recent years there has been an increasing effort to develop methods to objectively measure these behaviours, for example using pedometers, GPS, accelerometers and cameras. One example is the use of body worn cameras to more accurately record journeys, their mode and time taken.[204, 383] Although this method may not yet be useful in large scale studies, due to the time taken to analyse and interpret the pictures, it can be used to explore inaccuracies and biases in the existing diary data. Other methods have attempted to use GPS to measure travel behaviour, this can be used by studies of discrete infrastructure development, e.g. a new light-rail line or walkable neighbourhood, where the entry of participants into a circumscribed area can be used to designate them as users of the infrastructure.[188] The use of accelerometers to measure physical activity can address many of the limitations of self-reported measures but when physical activity is measured using both methods they provided differing estimates of physical activity levels.[211] The applicability of recommendations and health associations based on self-reported physical activity to levels measured objectively are not currently known. Methods have also been developed which use objective data from GPS and accelerometers with machine learning to develop an algorithm capable of predicting travel mode and destinations.[384, 385] The exact approach varies but can incorporate feedback and correction by participants to improve the prediction.[384] NTS in England conducted a consultation on introducing GPS data collection, which included a pilot of potential options but recommended retaining current data collection methods.[386] Increased technological innovation in data collection and processing presents opportunities for future studies of travel patterns and physical activity.

Where possible the analyses in this thesis have differentiated between users of light-rail and users of trains. Light-rail was defined as London Underground, in addition to eight other urban rail systems across England (two of which are also in London – the Dockland Light Railway and London Tramlink). This was the only distinction made in the available data and comparisons between the users of train and light-rail did reveal some differences, which to some extent justifies the use of this

categorisation. However, urban and suburban train services are often comparable with light-rail in terms of distance, frequency and journey times, making the distinction less certain.[387] For example, a journey from East Didsbury, in the southern suburbs into central Manchester could be taken by Metrolink (light-rail) or the suburban train service. The absence of a clear distinction between urban and regional train services in England, which are often provided by the same operator, makes any other categorisation impossible. It is also worth noting however, that some people commute long distances by train and would regularly use regional or express services to access work, therefore the distinction would always be arbitrary.

10.3 Comparison with existing literature

10.3.1 Systematic review

A change in BMI of -0.30kg/m^2 (-0.47, -0.14) associated with initiating public transport is a modest but clinically relevant effect on adiposity. These are smaller adiposity changes than have been seen with walking, which was associated with a BMI change of -0.53 kg/m^2 (-0.72, -0.35) in a systematic review of randomised controlled trials, although there was some evidence for publication bias in this analysis.[276] That walking was associated with greater adiposity benefits than public transport appears likely if public transport journeys contain less walking than walking journeys, which seems plausible. Walk commuting has also been found to be associated with a reduced risk of CVD and all-cause mortality, in addition to incident and fatal cancer [174, 175, 178], which suggests that public transport use might also have associations with these outcomes, albeit weaker than those seen with walking.

10.3.2 Public transport use and physical activity

Analyses of the travel patterns of England residents showed that 33% of the population used public transport at least once in the diary week, with 25% reporting some bus use in this period. Light-rail use was 7% and train use was 11%, with many individuals using multiple public transport modes. These figures are very similar to official figures released by the DfT calculated using the same NTS data.[43] Data on the characteristics of public transport users is concordant with findings elsewhere, in terms of ethnicity and differences between London and other areas of England.[47] However, data in this thesis are more detailed and give a greater understanding of the characteristics associated with public transport use as they are presented both unadjusted and mutually adjusted for selected potential confounders, such as population density and car access.

The estimated 21 minutes per day of physical activity accumulated in the course of public transport journeys is the first estimate of its kind for England but is consonant with those from other countries. A wide range of minutes of physical activity were reported by a review of this association (7-33 minutes per day), although many studies were of small and selective populations.[184] An included study which examined public transport users in the USA found that they accumulated a median of 19 minutes per day, with little difference between bus and train users.[184, 248] The overall estimate is similar to the finding in this thesis, however, I found a substantial difference between the 28 minutes seen for train users and the 16 minutes seen with bus users.[248] This difference could be due to people being willing to walk further to reach a train station than a bus stop, which might be necessary, as train stations are generally less densely located than bus stops.[317, 318]

10.3.3 Free older person's bus pass

The findings that the free bus pass was associated with higher levels of bus and active travel is consistent with existing short-term evidence but adds evidence that these associations persist over the longer term. This indicates that the policy has maintained its associations, with little increase or decrease in association sizes seen. Therefore, although bus subsidies and mileage have reduced over the period since the free bus pass was introduced, take-up remains high and bus pass possession continues to be associated with active and bus travel.[24] This is consistent with previous research which found that the free bus pass was associated with greater bus use and greater active travel.[334, 388] Research using data from ELSA found that possession of a free bus pass was associated with higher bus use, lower adiposity and greater gait speed, with these findings more robust among women.[81, 82]

In addition to higher bus use and active travel, some research has examined the wellbeing associations of the free bus pass, in line with the stated aim of the policy to guarantee financial security into older age and to alleviate social exclusion.[83, 84] 75% of bus pass holders reported that having a bus pass had increased their quality of life, with this higher among older bus pass holders.[389] Qualitative evaluation of bus pass holders has found that possession of a free bus pass eased feelings of social exclusion and encouraged a sense of belonging [86] and that when bus travel was free, older people used the bus as a social space.[389] Other researchers have found that possession of a free bus pass was associated with reduced depressive symptoms and feelings of loneliness among older adults, although no association was found with social isolation.[85]

10.3.4 ONS-Longitudinal Study analyses of commute mode

An official statistical release from the ONS using data from the 2011 England and Wales Census found that the share of commutes by different modes were similar to that found in this thesis.[272]

The official statistics show 64% commuted by sedentary modes, 16% by public transport and 14% by either walking or cycling, compared with the thesis findings of 66% by sedentary modes, 19% by public transport and 16% by walking or cycling.[272] Differences were likely to be because the official figures included those commuting by 'other' modes and those working from home, both of which were excluded from the analyses in this thesis. ONS data are also restricted to the 2011 Census, whereas this thesis combined data from 1991, 2001 and 2011, based on which was the participant's baseline year.[272]

The analyses in this thesis were the first to examine public transport use specifically and mortality and cancer outcomes, therefore direct comparisons are not possible. Some studies using UK Biobank data have examined groups which included public transport users, in addition to users of other modes. The first of these examined mixed mode commuters, where mixed mode was categorised into those which included walking and those which included cycling.[181] This study found that mixed mode commuting which included cycling was associated with a reduced risk of all-cause mortality, cancer incidence and cancer mortality, while mixed mode commuting which included walking did not have any heath associations.[181] The second study grouped all non-car transport modes together and found that these were associated with reduced risk of fatal and incident CVD.[182]

A meta-analysis of 18 prospective studies (14 walking studies and seven cycling studies) found that walking and cycling for any purpose was associated with an 11% and 10% reduction in all-cause mortality respectively, with the greatest benefits seen among those moving from little or no active transport, to some.[174] These associations differed from those of this thesis, being smaller than the 20% lower risk seen in cycle commuters and larger than the statistically non-significant 3% lower risk seen in walk commuters. This might be because the meta-analysis calculated the risk associated with accumulating 11.25MET-hours per week of walking or cycling, a value selected to correspond to

global recommendation of 150 minutes per week of moderate intensity physical activity.[141] However, the median distances for walk and cycle commuters in the 2011 ONS-LS, which was used in this thesis, were 0.8km and 2.9km respectively, which results in 8km of walking or 29km of cycling a week, based on two-way commuting five days-a-week. Assuming an average walk speed of 4.8km/hour (3 miles/hour) and an average cycle speed of 17.7km/hour (11 miles/hour), walking commuters were likely to accumulate about 5.8MET-hours per week on average, while cycle commuters were likely accumulate 11.1MET-hours.[139, 319] This indicates that the meta-analysis assumed higher physical activity levels among walk commuters than seen in this analysis but about the same levels of physical activity among cycle commuters.

A 2018 systematic review and meta-analyses by Dinu et al. examined the impact of walk and cycle commuting on a range of outcomes.[178] When examined separately, cycle commuting was associated with risk reductions of 24% for all-cause mortality, 46% for CVD incidence and a 25% for cancer mortality, with no associations seen with CVD mortality or breast cancer incidence.[178] Walk commuting was associated with a 27% reduction in risk of CVD incidence, with no association seen with all-cause and CVD mortality and incident and fatal cancer. In each case, Dinu et al. found greater risk reductions than seen in Chapter 9, however, this might be because many of their included studies categorised the minutes spent walking and cycling and compared the most active group with the least active group, ignoring the data from participants who were not at either extreme. This review also conducted analyses of a combined measure of walking and cycling commutes, which allowed the inclusion of those measuring walking and cycling separately, in addition to studies which examined only a combined measure. The combined measure was associated with an 8% reduction in all-cause mortality risk and a 9% reduction in CVD incidence risk, with no association seen with CVD morality, cancer mortality and breast cancer incidence.[178] These findings are broadly compatible with the findings of Chapter 9, given that they would be expected to be between the estimates for walk commuters and cycle commuters, which is the case

for most outcomes. Another meta-analysis by Hamer et al. examined commute mode, finding that a combined measure of walking and cycling was associated with an 11% reduced risk of CVD (fatal and non-fatal), with these finding stronger among women than men.[171] Again this sits between the findings in this chapter for walk commuters and those for cycle commuters when examining CVD mortality. A final systematic review by Oja et al. found that cycle commuting was associated with reduced risk of incident and fatal cancer, although meta-analyses were not conducted.[179]

10.4 Implications

Transport is an important social determinant of health in its own right and has impacts on other determinants.[336] This includes transport's importance for maintaining social networks and for accessing healthcare, the loss of which are important contributors to health inequalities.[227, 336] In this context, it is understandable that transport has a prominent role in the Sustainable Development Goals (SDGs), number 11 of which aims to 'create safe, inclusive, resilient and sustainable cities, including through affordable, accessible and expanded public transport systems'.[55] Public transport's potential contribution to improving air quality, reducing carbon emissions, and facilitating economic activity through reduced congestion and improved connectivity, addresses several other SDGs.[55, 72, 390]

Policies promoting public transport may also have physical activity benefits as a result of walking and cycling to access public transport. This may be particularly important to those for whom walking or cycling an entire journey is not possible and those who may not participate in sport or other leisure time physical activity. This is because those who benefit greatest from increasing physical activity are those who are most sedentary in society, when they move from doing little or no physical activity to doing some.[153, 154] Although transport is only one domain of physical activity, people that participate in active travel often accumulate greater levels of total physical activity than those using

sedentary transport modes.[171, 277, 337, 391] In England levels of active travel of been decreasing for at least the last 20 years, which is seen in trends over times in Chapter 8.[17, 147]

When examining the health impacts of transport physical activity, it is important to consider any impact this might have on other physical activity domains, including leisure physical activity. For example, any benefits from walking as part of transport might be negated if an individual then does not visit the gym. There is some evidence from a meta-analysis of research into the effects of new public transport infrastructure which suggests that increases in transport physical activity are more than compensated for by reductions in total physical activity.[194, 196] However, the included studies had varied findings, indicating that this might be a context specific phenomenon. Other evidence also indicates that objective measures of physical activity are lower among public transport users than car users.[392] However, there is also observational evidence that suggests that increased transport walking is associated with an increase in total physical activity, i.e. the increases in physical activity are not compensated for with reduction in other physical activity.[277, 391, 393] Indeed some evidence indicates that moving to less active travel modes is associated with reduced leisure physical activity.[180] It is also the case that the cardiovascular health benefits of active travel are independent of other domains of physical activity.[171] Indeed, the findings of Chapter 5 that initiating public transport use was associated with reduced adiposity would indicate that transport physical activity changes were not cancelled out. It is important that further research is directed at the impacts of public transport and active travel more generally on other domains of physical activity and total physical activity. The use of objective physical activity measurement is important here as there is a suggestion that these are discordant with self-reported findings.[392] If there are attributes of transport interventions which lead to reduced compensation, this would be important for policy makers to plan future interventions.

The amount of physical activity accumulated by public transport users is comparable with the levels achieved by existing physical activity interventions. A 2001 meta-analysis compared interventions to increase physical activity among healthy adults, including exercise prescription and mass media campaigns, and found a mean increase of 15 minutes a week.[394] A separate systematic review, looking specifically at interventions to increase walking for transport, found that the most effective intervention led to a 10 minutes a day increase.[235, 237] This was a workplace intervention involving an information booklet and some tailored advice.[237] Transport policies are promoted as an important way to scale up physical activity but there is limited evidence for the effectiveness of using transport systems to increase physical activity.[395, 396] Some research comes from the evaluation of a new guided busway in Cambridgeshire.[397] The busway is separate from the existing road network and has an accompanying path for pedestrians and cyclists. Living in close proximity to the new busway was associated with an increase in active commuting.[397] It is not clear, however, how much of this was associated with the public transport and how much was associated with the adjacent segregated path.

New public transport infrastructure is often associated with the redevelopment of the surrounding area. This was the case with the construction of light-rail infrastructure alongside new walkable streets in the US, which was associated with an increase of four minutes of objectively measured MVPA.[188, 398] It is uncertain whether the modest effect size reflects a small impact or whether it was due to the restriction to MVPA, rather than self-reported walking. Improving the wider built environment during public transport construction makes evaluating the impacts of public transport in isolation problematic. However, the potential synergies between different aspects of a development might make disentangling these effects undesirable.

Chapter 5 of this thesis found that initiating public transport use was associated with a reduction in BMI of 0.30kg/m^2. Although this is a fairly modest reduction in adiposity, it translates to a mean

weight loss of 0.9kg in men and 0.8kg in women in the population of England.[279] This would be a clinically significant reduction in adiposity and is comparable with, or greater than, that seen with many individually focused interventions.[280, 281] Reducing BMI is beneficial to the health of all but the most underweight (which comprise a very small proportion of the population in high-income countries like the UK), a small reduction in BMI in a large number of individuals would therefore lead to a large reduction in population risk of several important causes of morbidity and mortality.[241, 399, 400]

The patterning of public transport use means that policy which affects the use or availability of public transport will have socio-economic implications and indeed, the absence of any intervention should also be seen to have implications. Rail spending comprised £13.7bn of the total transport spending of £23bn in 2017/18, while being responsible for 3% of journeys and 10% of total distance travelled.[12, 13] Total government spending on buses is more difficult to calculate as road building and maintenance is of benefit to all road traffic, including buses but also cars. However, buses are likely to attract only a small share of the remaining transport spend and it is likely that this fraction is shrinking due to substantial cuts to bus subsidies in England since 2010.[401] These cuts have seen a substantial reduction in the number of local authority subsidised bus miles, accompanied by a very slight increase in commercial bus miles.[24] Bus travel is responsible for 7% of total journeys and 5% of total distance, more than double the number of journeys as train travel, but half the distance.[12, 13]

A substantial proportion of rail spending in recent years in England has been directed towards large capital investment programmes primarily, Crossrail, an East-West metro line across London, and High Speed 2, a new intercity rail connection between London and some Northern cities via Birmingham.[56] It is possible that new and future rail infrastructure will attract a less socio-economically advantaged ridership than existing train services, however, even if this is not the case,

if they are successful in displacing car journeys this might be advantageous for all, due to reduced congestion, carbon emissions and pollution which would result.[126, 370] Car use currently consists 64% of journeys and 78% of total distance travelled in England and is more likely among the most socio-economically advantaged and least likely among the more socio-economically disadvantaged.[12, 13, 52] By displacing car journeys, increased rail use may contribute to a built environment which is more navigable on foot, facilitating the use of local buses.[402] However, for this to be possible, there needs to be a dense and efficient bus network for people to make use of, this requires buses to receive an equitable share of transport budgets.

By improving the accessibility, affordability and availability of public transport, transport policy could be used to encourage public transport use.[403, 404] Public transport use in England has been shown to be greater in areas with better provision of public transport, such as London.[14] Increasing the proportion of the population who travel by public transport, and the number who meet physical activity recommendations through this public transport travel, will require input from city planning and transport professionals. For people to switch from car to public transport use, having an available alternative is important, although this is unlikely to be sufficient to change the behaviour of all car users.[405, 406] Accessible public transport systems are proposed as a key intervention to improve health through city planning, yielding benefits due to physical activity, air and noise pollution.[407] Current guidelines in the UK are in line with these recommendations, suggesting that physical activity can be incorporated into long journeys by encouraging public transport use, especially where it occurs in conjunction with active forms of travel.[408-412]

Research on financial incentives for using public transport have shown some evidence of efficacy, although there is some uncertainty about whether this is at the expense of car travel, walking or cycling.[403] A systematic review of financial incentive to promote active travel found that while they might have the potential to play a greater role in increasing active travel, there is a need for

more higher quality studies, with better controls.[403] In addition to two studies of free bus passes which have been discussed above, the review included two additional studies which examined public transport subsidies. One study of recent migrants to the Stuttgart area of Germany found that those receiving the intervention of travel advice and a small financial incentive (a one-day free ticket) had greater public transport use at follow-up, approximately 12 weeks after the move.[413] The other study, looking at an employer sponsored transit pass, found it to be associated with meeting physical activity recommendations, although differences between those who received the pass and those that did not might explain some of these differences.[414]

In 2050, a predicted 66% of the global population are expected to live in urban areas, in Europe this is predicted to be 80% by 2030 [415, 416], therefore planning public transport systems to accommodate this trend is essential.[417] When conurbations grow through unplanned urban sprawl, this can result in unhealthy and environmentally damaging conditions.[418, 419] Urban sprawl can lead to journeys which are too long to be walked or cycled but by improving urban design to include high density, mixed development with rapid, efficient and well planned public transport systems, more sustainable transport can be facilitated.[420]

With complex multi-causal problems such as obesity related ill-health, single interventions are likely to be insufficient, what is necessary is the reshaping of interconnected factors by addressing multiple inputs.[421] This is consistent with a population approach in which small changes for the individual are accumulated across the population and result in large population health improvements.[241] The accumulation of these kind of small changes which act at a population level may be more effective at achieving sustained behaviour change in populations than by attempting to affect large changes in diet and energy expenditure in targeted individuals.[422]

In addition to promoting public transport use, additional inputs which might be addressed include those which disincentivise car use in order to encourage more active modes. An example of this kind of intervention is a levy on workplace car parking spaces, such as the one introduced by Nottingham City Council in 2012.[423, 424] Evaluation of this policy found that the levy reduced congestion and that this occurred through two mechanisms, employers reduced parking space availability to reduce their liability and they also passed the charge on to employees, which disincentivised car commuting. Rather that charging for parking, the Greater London Authority levies a congestion charges on drivers who enter an area central London. This policy was implemented in 2003 and led to a substantial reduction in congestion in the designated zone.[423-425] However, if attempts at behaviour change are seen as an attack on car drivers and on the autonomy they experience in car use, they may resist change and oppose any such interventions.[426, 427]

10.5 Inequalities

Health inequalities are a recognised problem in public policy and despite several high profile reports on their extent and impact, they appear to be widening.[227-229, 428] To address this, it has been suggested that all proposed policies should have their potential impact on health inequalities evaluated, regardless of whether the aim of the policy is health related or directed at other sectors, e.g., housing or transport.[227, 228] Policies which lead to a uniform improvement in risk exposure across the population are likely to reduce absolute health inequalities, although not necessarily relative inequalities.[238] In order to reduce relative inequality, in addition to absolute inequality, policies should disproportionately improve the risk exposure among those who suffer higher risk, such as the socio-economically disadvantaged.[238]

Encouraging public transport use among those who do not participate in exercise or sport may be an effective way to target the most sedentary in society who would benefit most from increasing their

physical activity.[153] Women in England are less likely to meet physical activity recommendations than men, 2016 estimates suggest that 66% of men and 58% of women are physically inactive.[144] This thesis also found that women were more likely to use public transport in the diary week than men and that this was driven predominantly by bus use.

Some minority ethnic groups also have lower physical activity levels than the general population. In England, women of all minority ethnicities and men of South Asian ethnicity are less likely to be physically active, taking into account leisure-time exercise, domestic tasks and walking.[223, 224] The General Household Survey found that participation in sport, games or physical activity is lower in some minority ethnic groups, including Black African, Black Caribbean, Indian and Pakistani groups.[225] Again the analyses in this thesis show that public transport use is already relatively common in some minority ethnic groups, for example those of Black ethnicities, with these differences driven primarily by bus use. Some of the ethnic differences presented in this thesis are related to the geospatial patterning of ethnic minorities within England and how this relates to public transport provision. Minority ethnic groups are more prevalent in large cities, and especially London. It is these larger municipalities, which are more population dense and have better provision of public transport services. However, it remains the case that minority ethnic groups have poorer health outcomes than Whites and if public transport policy can be used to address these inequalities, it should be considered an important option.[93]

Available data also finds that physical activity is heavily patterned across socio-economic position, data from 2012 show that the proportion of adults in England meeting physical activity guidelines is lower in households with lower income. It falls from 76% in men and 63% of women in the highest income quintile, to 55% of men and 47% of women in the lowest income quintile.[234] Chapter 6 showed that lower income and household occupation status were associated with greater public transport use, although this was influenced by other factors, while bus use specifically was more

common among the less socio-economically advantaged after accounting for other factors. If encouraging bus use has a disproportionate effect on these groups, this is likely to have an inequality reducing effect.

The relationship between different modes of transport and their users is linked with the areas in which different groups are likely to reside. Bus journeys in England are typically used for short distances, with most buses stopping regularly, which makes long distance travel slow.[26, 53] Distances travelled to work are greater among those who earn larger salaries, compared with lower earners, with trade-offs seen between financial rewards and satisfaction, which in part drives the socio-economic differences.[135] There are also differences between the types of areas which are generally served by different modes, for example, train use has a relatively greater use in urban fringe or suburban areas, while buses are more commonly found in higher density, inner-city areas, with light-rail sitting between these two.[14, 295, 296] The residents of the suburbs tend to be more socio-economically advantaged than the traditionally less affluent inner city areas, therefore some of the difference in mode use is geospatial in nature.[297, 298]

The ethnic differences found in Chapter 8 may have been partially driven by the geospatial distribution of ethnic groups in England, with the majority of the ethnic minority participants living in more densely populated areas which are likely to be better served by public transport.[14, 295, 296] While the extent of this is not known, available data does suggest that provision of services may be behind any health inequality reducing effects seen. Alongside enabling increased access to services and social networks, policies promoting active forms of travel may confer physical health benefits from increasing levels of transport-associated physical activity. While active travel constitutes just one domain of total physical activity, evidence suggests that those who use active travel modes have higher levels of total physical activity than those who do not [171, 277, 337, 391].

Universal benefits are those which are not based on financial means and are thus available to all, irrespective of wealth or ability to pay. The free bus pass examined in Chapter 8 is universal in this sense, although it is restricted on the basis of age; all persons who meet the age requirement are entitled to a free bus pass. When considering potential changes to existing free bus pass provision, a policy review by the Northern Ireland Assembly concluded that reducing provision was liable to have a negative impact on social exclusion.[429] The government has recently amended legislation to enable the bus pass to continue in its current form for the foreseeable future and remain a universal benefit.[79] This is despite calls to remove or means-test the free bus pass in order to target benefits at those in greatest need.[65] Take-up of entitlements is often lower when applicants must prove their financial eligibility [91], with potential explanations including perceived ineligibility, difficulty in the application process and a reluctance to disclose financial information.[430] Reluctance to apply for means tested benefits disproportionately effects poorer older people, which might undermine efforts to target the most vulnerable with means testing.[91] Furthermore, there is evidence that some of the benefits seen in bus pass holders emanates from the very fact that it is a universal benefit, something that the holder had earned and which gives them a sense of belonging.[86]

Encouraging bus use among an older population is in line with the WHO's framework for Active Aging, which proposes increasing physical activity levels by targeting non-health actors.[431] Older people are an important target for interventions of this kind as many will eventually cease driving, through their own choice or otherwise. Driving cessation in an older population can lead to an inability to access essential services and pastimes, it is also associated with depression and declines in physical and social functioning.[432-436] Encouraging older people to use the bus before they cease driving can be helpful towards a gradual transition, which means that any negative perceptions associated with cessation are reduced and ensures ongoing mobility among those who would be otherwise unable to travel.[437, 438]

10.6 Unanswered questions and future research

The systematic review presented in Chapter 5 found that there was very little research examining the association between public transport and cardio-metabolic outcomes other than adiposity. Chapter 9 has contributed to this by examining the association between public transport and all-cause and CVD mortality, however, research is required using alternative data sources and examining other populations in different contexts. Additional cardio-metabolic outcomes which might be examined with respect to public transport include, type 2 diabetes and incident CVD, while hip fractures and emergency department attendances might give an indication of general health and mobility of older individuals. Potentially useful data for such research might be Hospital Episode Statistics (HES), which contains details of hospital visits, their causes and outcomes, alternatively, a source of primary care data in the UK is the Clinical Practice Research Datalink (CPRD) which is likely to have better data for chronic outcomes, such as type 2 diabetes. These could potentially provide detailed outcomes data, however, they would need to be linked to a suitable exposure data source, which to my knowledge has not yet been carried out.

Greater evaluation of the physical activity and health benefits of new infrastructure is required in order to establish what impacts can be expected and how these can be optimised. GIS data captures a measure of access to public transport and offers an important potential avenue of future research. The impact of different measures of public transport access should be evaluated, for example, density of public transport stops, distance to public transport stops and number of different modes available. The distances people are willing to travel to access public transport is also poorly understood and is known to differ by mode, therefore the distances over which public transport accessibility are studied might have substantial impact.[317] In addition to the finding on the associations of bus use, the systematic review also indicated the need for greater study of the association between bus stop proximity and adiposity. The two currently available studies have

discordant finding which might be attributable to several differences between the studies, for example, one was conducted in China and one in the USA. Additional research from these, and other contexts, are required to establish the importance of this exposure and the causes of the differences seen in the currently available data.

More generally, the health impacts of physical activity are still an area of research which requires greater study. The current recommendations of 150 minutes of MVPA per week is somewhat arbitrary.[311] There is a large body of evidence for a health benefit associated with this level of physical activity, however, it is uncertain whether this is the ideal level for health benefits, for example compared with 140 or 160 minutes.[310, 311] Evidence reviews to inform updating physical activity recommendations concede that 150 minutes remains justified because of a lack of evidence for an alternative, rather than due to strong evidence that it is the most suitable.[310, 311] Additionally, many existing physical activity recommendations suggest that physical activity should be accumulated in bouts of at least 10 minutes.[140, 141] Evidence from studies using accelerometers, which are more able to accurately capture short durations of physical activity, have shown that short bouts of physical activity carry equivalent benefits to that seen with longer bouts.[311, 314, 439, 440] In light of this, future changes to recommendations are likely to consider removing the restriction to bouts of 10 minutes or more.[310, 311]

Qualitative research could compliment the quantitative findings of this thesis, for example, by exploring what leads to changes in travel behaviour and what factors contribute to preventing behaviour change. Although research into users of different modes gives insight into mode choices, further exploration of attitudes to new infrastructure should be considered when evaluating new public transport and active travel interventions.[426, 427] Research of this kind could enable future interventions to be tailored to maximise their impact on travel behaviours. Qualitative data from older people could add to existing research on the free bus pass [134, 389], providing vital

contextual data on the changing impacts of free bus pass, for example, the impact of the changing age of eligibility and how cuts to bus services might effects attitudes to the policy.

Increasing numbers of people in England report working from home, between 1998 and 2014 the number increased from 2.9 million to 4.2 million, an increase from 11.1% of workers to 13.9%.[441] Working from home is more common among those in more highly skilled occupations, which is reflected in higher earnings reported by those that work from home compared with workers who did not.[441] Those that work from home will not be accumulating any active travel during commutes, perhaps being even more sedentary than car commuters. However, working from home potentially frees time up for activities which have health benefits, for example, going to the gym, it also allows home-workers to avoid certain downsides to commuting, including delays, traffic jams and bad weather. Further research is required to investigate these effects further, although this falls outwith the scope of this thesis.

The most effective strategies to encourage public transport use are not fully understood and additional research is required to identify these. A greater understanding of the way financial incentives could be used to encourage public transport is needed if this approach is to be applied to alternative groups or settings. Longitudinal evidence of the active travel impact of the bus pass would be valuable, in addition it might be possible to evaluate discounted rail travel. Railcards entitle holders to a one-third discount on rail travel in Great Britain and are available for several groups, including younger and older people, the forerunner of the current 18-25 Railcard was initially released in 1974.[442] An examination of whether reducing the cost of train travel is effective at increasing its use and whether this has any implications for the active travel of those who take-up railcards would be an interesting adjunct to the existing findings for bus travel. Additionally, if local authorities were encouraged to implement local policies to incentivise public transport use, these could be evaluated to establish a wider evidence base for incentives to change

transport behaviour and their health impacts. Current guidance suggests that priority should be given to pedestrian, cyclists and public transport users when local authorities consider transport and built environment issues.[408, 443, 444] In addition to reducing the financial barriers to public transport use, improving the efficiency of public transport has been shown to increase use.[53] Transport for London report that reductions in bus use are highly responsive to reductions in average bus speed, in the short term at least.[53] To this end, providing efficient timely public transport with minimal cost to the individual might be expected to deliver increases in public transport use. Especially if combined with a model of road user charging which disincentivises car use by increasing the marginal cost of car journeys.[403]

Further research is required to evaluate the health impacts of new technologies across many sectors, many of which will involve changes to the way people travel. Perhaps the most obvious of these is the development of connected and autonomous vehicles, although the extent to which these will transform the transport network is contested.[114] Some predictions suggest fleets of autonomous vehicles will carry travellers to their destinations and remove the need for individually owned vehicles, while others propose a situation where vehicles are improved by the addition of autonomous features, but where human drivers are still required.[114] The potential health effects of autonomous vehicles should be considered during the development of the regulatory framework in which they will operate, and once this has been finalised, robust evaluation will be necessary to establish the health impacts. The large growth in the use of ride-hailing apps seen in some urban areas in recent years could have profound impacts on travel behaviour and it is important that this is studied, both with traditional methods such as travel surveys but also potentially using data from the firms providing these services. Although it might appear that ride-hailing apps would compete with public transport, there is at least some evidence that they work synergistically with public transport and facilitate multimodal journeys.[445]

10.7 Conclusion

This thesis has found that public transport use is more common among those of minority ethnicity and the socio-economically disadvantaged, compared with White people and the more socio-economically advantaged. Public transport use is associated with physically active behaviour and public transport users benefit from improved health in the form of reduced adiposity and lower risk of cancer incidence. Given the health effects seen among public transport users and the findings that public transport use is more common among some potentially vulnerable groups, encouraging public transport use in order to improve health and reduce inequalities might be an effective and equitable health improvement strategy.

References

1. Patterson, R., Webb, E., Hone, T., Millett, C., and Laverty, A.A. *Associations of public transport use with cardio-metabolic health: A systematic review and meta-analysis.* American Journal of Epidemiology, 2019 (*in press)*. http://dx.doi.org/10.1093/aje/kwz012
2. Patterson, R., Webb, E., Millett, C., and Laverty, A.A. *Physical activity accrued as part of public transport use in England.* Journal of Public Health, 2018. **fdy099**. https://doi.org/10.1093/pubmed/fdy099
3. Patterson, R., Webb, E., Mindell, J.S., Millett, C., and Laverty, A.A. *Ethnic group differences in impacts of free bus passes in England: A national study.* Journal of Transport & Health, 2018. **11**: p. 1-14. https://doi.org/10.1016/j.jth.2018.09.005
4. Laverty, A., Webb, E., Patterson, R., Mindell, J., and Millett, C. *Health benefits of providing free bus travel to older people in England - end of project report*. 2018.
5. Oxford English Dictionary. *"public, adj. and n."*. [Accessed on: 29 November, 2018]; Available from: http://www.oed.com/view/Entry/154052?redirectedFrom=public+transport.
6. Department for Transport *Table NTS0303: Average number of trips (trip rates) by main mode: England, 1995/97 to 2016*. 2016. Available from: https://www.gov.uk/government/statistical-data-sets/nts03-modal-comparisons.
7. Department for Transport *Table TSGB0102: Passenger journeys on public transport vehicles: annual from 1950*. 2017. Available from: https://www.gov.uk/government/statistical-data-sets/tsgb01-modal-comparisons#table-tsgb0102.
8. Butcher, L. *Briefing paper CBP 6521: Passenger rail services in England*. 2018. House of Commons Library: London, UK. Available from: https://researchbriefings.parliament.uk/ResearchBriefing/Summary/SN06521.
9. Departmenr for Transport *Table LRT0101: Passenger journeys on light rail and trams by system: England - annual from 1983/84*. 2018. Available from: https://www.gov.uk/government/statistical-data-sets/light-rail-and-tram-statistics-lrt.
10. Merriam-Webster. *light-rail*. [Accessed on: 20 January, 2019]; Available from: https://www.merriam-webster.com/dictionary/light-rail.
11. Department for Transport. *NTS Statistical Tables*. 2016 12 April, 2016 [Accessed on: 12 April, 2016]; Available from: https://www.gov.uk/government/collections/national-travel-survey-statistics.
12. Department for Transport *Table NTS0301: Mode share - average number of trips: England, 2015*. 2016. Available from: https://www.gov.uk/government/statistical-data-sets/nts03-modal-comparisons.
13. Department for Transport *Table NTS0302: Mode share - average distance travelled: England, 2015*. 2016. Available from: https://www.gov.uk/government/statistical-data-sets/nts03-modal-comparisons.
14. Department for Transport *Table NTS9903: Average number of trips (trip rates) by main mode, region and Rural-Urban Classification: England, 2016/17*. 2018. Available from: https://www.gov.uk/government/statistical-data-sets/nts03-modal-comparisons#mode-by-region.
15. Department for Transport *Table TSGB0101: Passenger transport, by mode: annual from 1952*. 2016. Available from: https://www.gov.uk/government/statistical-data-sets/tsgb01-modal-comparisons#table-tsgb0102.
16. Department for Transport *Table NTS0101: Trips, distance travelled and time taken: England, 1972/73 to 2016*. 2016. Available from: https://www.gov.uk/government/statistical-data-sets/nts01-average-number-of-trips-made-and-distance-travelled.

17. Department for Transport *Table NTS0305: Average distance travelled by mode: England, 1995/97 to 2016*. 2016. Available from: https://www.gov.uk/government/statistical-data-sets/nts03-modal-comparisons.
18. Department for Transport *National Travel Survey: England 2017 Statistical Release*. 2018. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/729521/national-travel-survey-2017.pdf.
19. Department for Transport *Table BUS0103: Passenger journeys on local bus services by metropolitan area status and country per head of population2: Great Britain, annual from 1991/92*. 2018. Available from: https://www.gov.uk/government/statistical-data-sets/bus01-local-bus-passenger-journeys#table-bus0103.
20. Butcher, L. *Buses: deregulation in the 1980s*. 2010. House of Commons Library: London, UK. Available from: https://researchbriefings.files.parliament.uk/documents/SN01534/SN01534.pdf.
21. Department for Transport *Table BUS0108: Passenger journeys on local bus services by region per head of population: Great Britain, annual from 1991/92*. 2018. Available from: https://www.gov.uk/government/statistical-data-sets/bus01-local-bus-passenger-journeys#table-bus0103.
22. Mackett, R.L. *The health implications of inequalities in travel.* Journal of Transport & Health, 2014. **1**(3): p. 202-209. http://doi.org/10.1016/j.jth.2014.07.002
23. Campaign for better transport *Buses in Crisis: A report on bus funding across England and Wales 2010 - 2016*. 2016: London, UK. Available from: https://bettertransport.org.uk/sites/default/files/research-files/buses-in-crisis-2015.pdf.
24. Department for Transport *Table BUS0205a: Vehicle miles on local bus services by metropolitan area status and country, and service type: Great Britain, annual from 1987/88*. 2018. Available from: https://www.gov.uk/government/statistical-data-sets/bus02-vehicle-distance-travelled.
25. Department for Transport *Annual bus statistics year ending march 2015*. 2015. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/485296/annual-bus-statistics-year-ending-march-2015.pdf.
26. Department for Transport *Table NTS0308: Average number of trips by trip length and main mode: England, 2017*. 2018. Available from: https://www.gov.uk/government/statistical-data-sets/nts03-modal-comparisons.
27. Transport for London *London Travel Demand Survey - Workbook 2016/17*. 2018. Available from: https://tfl.gov.uk/corporate/about-tfl/how-we-work/planning-for-the-future/consultations-and-surveys/london-travel-demand-survey.
28. Department for Transport *Table LRT9901a [miles] London Underground statistics, annual from 2000/01*. 2018. Available from: https://www.gov.uk/government/statistical-data-sets/light-rail-and-tram-statistics-lrt.
29. Department for Transport *Table LRT0109: Passenger journeys per head on light rail and trams by system: England - annual from 2004/05*. 2018. Available from: https://www.gov.uk/government/statistical-data-sets/light-rail-and-tram-statistics-lrt.
30. Department for Transport *Table LRT0203: Route kilometres open for passenger traffic on light rail and trams by system1: England - annual from 1995/96*. 2018. Available from: https://www.gov.uk/government/statistical-data-sets/light-rail-and-tram-statistics-lrt.
31. United Nations *The World's Cities in 2016*. 2016. Available from: http://www.un.org/en/development/desa/population/publications/pdf/urbanization/the_worlds_cities_in_2016_data_booklet.pdf.

32. PWC *The Sharing Economy - consumer intelligence series* 2015. Available from: https://www.pwc.com/us/en/technology/publications/assets/pwc-consumer-intelligence-series-the-sharing-economy.pdf.
33. McGuckin, N. and Fucci, A. *Summary of travel trends - 2017 National Household Travel Survey*. 2018. U.S. Department of Transportation. Available from: https://nhts.ornl.gov/assets/2017_nhts_summary_travel_trends.pdf.
34. Krovi, R. and Barnes, C. *Chapter 3 - Work-related Travel Patterns of People of Colour*, in *Travel Patterns of People of Color*, Battelle, Editor. 2000. U.S. Department of Transport Federal Highway Administration: Columbus, Ohio. Available from: https://www.fhwa.dot.gov/ohim/trvpatns.pdf.
35. Chu, Z., Polzin, S.E., Rey, J.R., and Hill, E.T. *Chapter 6 - Mode Choice by People of Color for Non-Work Travel*, in *Travel Patterns of People of Color*, Battelle, Editor. 2000. U.S. Department of Transport Federal Highway Administration: Columbus, Ohio. Available from: https://www.fhwa.dot.gov/ohim/trvpatns.pdf.
36. Ahem, A., Weyman, G., Redelbach, M., Schulz, A., Akkermans, L., Vannacci, L., . . . van Grinsver, A. *Analysis of National Travel Statistics in Europe*. 2013. European Commission: Luxembourg. Available from: http://publications.jrc.ec.europa.eu/repository/bitstream/JRC83304/tch-d2.1_final.pdf.
37. Strandell, H. and Wolff, P. *The EU in the world - 2018 Edition*. 2018. European Union: Luxembourg. Available from: https://ec.europa.eu/eurostat/documents/3217494/9066251/KS-EX-18-001-EN-N.pdf/64b85130-5de2-4c9b-aa5a-8881bf6ca59b.
38. Deng, T. and Nelson, J.D. *Recent Developments in Bus Rapid Transit: A Review of the Literature.* Transport Reviews, 2011. **31**(1): p. 69-96. http://doi.org/10.1080/01441647.2010.492455
39. Hensher, D.A. and Golob, T.F. *Bus rapid transit systems: a comparative assessment.* Transportation, 2008. **35**(4): p. 501-518. http://doi.org/10.1007/s11116-008-9163-y
40. Mobereola, D. *Lagos Bus Rapid Transit: Africa's first BRT scheme*. 2009. The World Bank. Available from: https://siteresources.worldbank.org/EXTAFRSUBSAHTRA/Resources/DP09-Lagos-BRT.pdf.
41. Department for Transport *Table NTS0601: Average number of trips (trip rates) by age, gender and main mode: England, 2017*. 2018. Available from: https://www.gov.uk/government/statistical-data-sets/nts03-modal-comparisons#mode-by-age-and-gender.
42. Department for Transport *Table NTS0605: Average distance travelled by age, gender and mode: England, 2016*. 2017. Available from: https://www.gov.uk/government/statistical-data-sets/nts03-modal-comparisons#mode-by-age-and-gender.
43. Department for Transport *National travel survey Mode use, 2005 - 2015: A view into a travel week*. 2015. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/577825/mode-use-2015-a-view-into-a-travel-week.pdf.
44. Department for Transport *Table LRT0401: Share of light rail and tram stages, distance and time by age: England, 2009/16*. 2017. Available from: https://www.gov.uk/government/statistical-data-sets/light-rail-and-tram-statistics-lrt.
45. Department for Transport *Table NTS0611: Average number of trips (trip rates) by age, gender and purpose: England, 2017*. 2018. Available from: https://www.gov.uk/government/statistical-data-sets/nts04-purpose-of-trips.
46. Department for Transport *Table NTS0707: Adult personal car access and trip rates, by ethnic group: England, 2002 - 2017*. 2017. Available from: https://www.gov.uk/government/statistical-data-sets/nts07-car-ownership-and-access.

47. Laverty, A.A., Mindell, J.S., Webb, E.A., and Millett, C. *Active travel to work and cardiovascular risk factors in the United Kingdom.* Am J Prev Med, 2013. **45**(3): p. 282-8. http://dx.doi.org/10.1016/j.amepre.2013.04.012
48. Transport for London *Travel in London, Supplementary Report: London Travel Demand Survey (LTDS)*. 2011. Available from: https://www.clocs.org.uk/wp-content/uploads/2014/05/london-travel-demand-survey-2011.pdf.
49. Department for Transport. *Ethnicity facts and Figures: Travel by distance, trips, type of transport and purpose*. 2017 [Accessed on: 5 June, 2018]; Available from: https://www.ethnicity-facts-figures.service.gov.uk/culture-and-community/transport/travel-by-distance-trips-type-of-transport-and-purpose/latest.
50. Office for National Statistics. *Nomis Official Labour Market Statistics: KS201EW - Ethnic group*. 2011 [Accessed on: 15 January 2019]; Available from: https://www.nomisweb.co.uk/query/construct/submit.asp?forward=yes&menuopt=201&subcomp=.
51. Department for Transport *Table NTS0707: Adult personal car access and trip rates, by ethnic group: England, 2002 - 2017*. 2018. Available from: https://www.gov.uk/government/statistical-data-sets/nts07-car-ownership-and-access.
52. Department for Transport *Table NTS0705: Travel by household income quintile and main mode / mode: England, 2017*. 2018. Available from: https://www.gov.uk/government/statistical-data-sets/nts07-car-ownership-and-access.
53. Transport for London *Travel in London - Report 10*. 2017. Available from: http://content.tfl.gov.uk/travel-in-london-report-10.pdf.
54. Dahlgren, G. and Whitehead, M. *European strategies for tackling social inequities in health: Levelling up part 2*. 2006. WHO. Available from: http://www.euro.who.int/__data/assets/pdf_file/0018/103824/E89384.pdf.
55. World Health Organization. *Sustainable Development Goals*. 2015 [Accessed on: 8 March, 2018]; Available from: http://www.un.org/sustainabledevelopment/sustainable-development-goals/.
56. HM Treasury *Public Expenditure Statistical Analyses 2018*. 2018. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/726871/PESA_2018_Accessible.pdf.
57. Rutherford, T. *Briefing paper 8130: Transport spending by region*. 2018. House of Commons Library: London, UK. Available from: https://researchbriefings.parliament.uk/ResearchBriefing/Summary/CBP-8130.
58. Butcher, L., Meakin, A., and Rutherford, T. *Briefing paper 7177: Transport 2015*. 2015. House of Commons Library: London, UK. Available from: https://researchbriefings.parliament.uk/ResearchBriefing/Summary/CBP-7177.
59. Department for Transport *Table NTS0205: Household car availability: England, 1951 to 2017*. 2018. Available from: https://www.gov.uk/government/statistical-data-sets/nts02-driving-licence-holders#table-nts0205.
60. Butcher, L. and Rutherford, T. *Briefing paper CBP07545: Bus Services Act 2017 Briefing Paper*. 2017. House of Commons Library: London, UK. Available from: https://researchbriefings.parliament.uk/ResearchBriefing/Summary/CBP-7545.
61. Peat, J., Grey, I., Hoehn, T., Holmes, K., and Waterson, M. *Local bus services market investigation: A report on the supply of local bus services in the UK (excluding Northern Ireland and London)*. 2011. Competition Commision. Available from: http://webarchive.nationalarchives.gov.uk/20140403001219/http://www.competition-commission.org.uk/assets/competitioncommission/docs/pdf/inquiry/ref2010/localbus/pdf/00_sections_1_15.pdf.

62. Butcher, L. *Buses: grants and subsidies*. 2013. House of Commons Library: London, UK. Available from: https://researchbriefings.parliament.uk/ResearchBriefing/Summary/SN01522#fullreport.
63. Department for Transport *Bus Subsidy Reform Consultation Analysis* 2013. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/233060/consultation-analysis.pdf.
64. Department for Transport *Table BUS0811a: Net current expenditure on concessionary travel2 by metropolitan area status: England, annual from 2000-013*. 2017. Available from: https://www.gov.uk/government/statistical-data-sets/bus08-concessionary-travel.
65. Butcher, L. *Briefing paper SN01499: Concessionary bus fares*. 2015. House of Commons Library: London, UK. Available from: https://www.gov.uk/apply-for-elderly-person-bus-pass.
66. Department for Transport *Table BUS0405: Local bus fares index (at current prices) by metropolitan area status and country: Great Britain*. 2018. Available from: https://www.gov.uk/government/statistical-data-sets/bus04-costs-fares-and-revenue.
67. Office for National Statistics. *Population density tables*. 2015 [Accessed on: 26 October, 2018]; Available from: https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/datasets/populationdensitytables.
68. Office for National Statistics. *Nomis Official Labour Market Statistics*. 2011 [Accessed on: 1 March, 2016]; Available from: https://www.nomisweb.co.uk/census/2011/DC2101EW/view/2092957699?rows=c_ethpuk11&cols=c_age.
69. Dalton, A.M., Jones, A.P., Panter, J.R., and Ogilvie, D. *Neighbourhood, Route and Workplace-Related Environmental Characteristics Predict Adults' Mode of Travel to Work.* PLOS ONE, 2013. **8**(6): p. e67575. http://doi.org/10.1371/journal.pone.0067575
70. Lu, Y., Sun, G., Sarkar, C., Gou, Z., and Xiao, Y. *Commuting Mode Choice in a High-Density City: Do Land-Use Density and Diversity Matter in Hong Kong?* International Journal of Environmental Research and Public Health, 2018. **15**(5): p. 920. https://doi.org/10.3390/ijerph15050920
71. Zimmerman, S. and Fang, K. *Public Transport Service Optimization and System Integration*. 2015. World Bank. Available from: https://openknowledge.worldbank.org/bitstream/handle/10986/23489/Public0transpo0d0system0integration.pdf?sequence=1&isAllowed=y.
72. Department for Transport *The Bus Services Bill: An Overview*. 2016. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/558349/the-bus-services-bill-an-overview.pdf.
73. Transport for Greater Manchester. *The future of bus services: Bus reform*. 2017 [Accessed on: 19 April, 2018]; Available from: https://www.tfgm.com/future-travel/bus-reform.
74. GOV.UK. *State Pension age timetables* [Accessed on: 29 February, 2016]; Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/310231/spa-timetable.pdf.
75. Transport Scotland. *Concessionary travel for people aged 60+ or with a disability*. [Accessed on: 12 April, 2016]; Available from: http://www.transport.gov.scot/public-transport/concessionary-travel-people-aged-60-or-disability.
76. Welsh Government. *Concessionary travel*. [Accessed on: 12 April, 2016]; Available from: http://gov.wales/topics/transport/public/concessionary/?lang=en.
77. Nidirect. *60+/Senior SmartPass*. [Accessed on: 12 April, 2016]; Available from: https://www.nidirect.gov.uk/articles/60senior-smartpass.
78. Department for Transport *Evaluation of concessionary bus travel the impacts of the free bus pass*. 2016. Available from:

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/669076/evaluation-of-concessionary-bus-travel.pdf.

79. Department for Transport. *Free bus passes for older and disabled people protected for the future*. 2018 [Accessed on: 13 January, 2019]; Available from: https://www.gov.uk/government/news/free-bus-passes-for-older-and-disabled-people-protected-for-the-future.
80. Coronini-Cronberg, S., Millett, C., Laverty, A.A., and Webb, E. *The impact of a free older persons' bus pass on active travel and regular walking in England.* Am J Public Health, 2012. **102**(11): p. 2141-8. http://dx.doi.org/10.2105/AJPH.2012.300946
81. Webb, E., Netuveli, G., and Millett, C. *Free bus passes, use of public transport and obesity among older people in England.* J Epidemiol Community Health, 2012. **66**(2): p. 176-80. http://dx.doi.org/10.1136/jech.2011.133165
82. Webb, E., Laverty, A., Mindell, J., and Millett, C. *Free Bus Travel and Physical Activity, Gait Speed, and Adiposity in the English Longitudinal Study of Ageing.* Am J Public Health, 2016. **106**(1): p. 136-141. http://dx.doi.org/10.2105/AJPH.2015.302907
83. HM Treasury *Budget 2006*. 2006. The Stationery Office: London, UK. Available from: https://www.gov.uk/government/publications/red-book-2006-budget.
84. HM Treasury *2005 Budget*. 2005. The Stationary Office: London, UK. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/251094/372.pdf.
85. Reinhard, E., Courtin, E., van Lenthe, F.J., and Avendano, M. *Public transport policy, social engagement and mental health in older age: a quasi-experimental evaluation of free bus passes in England.* Journal of Epidemiology and Community Health, 2018. https://doi.org/10.1136/jech-2017-210038
86. Jones, A., Goodman, A., Roberts, H., Steinbach, R., and Green, J. *Entitlement to concessionary public transport and wellbeing: a qualitative study of young people and older citizens in London, UK.* Soc Sci Med, 2013. **91**: p. 202-9. https://doi.org/10.1016/j.socscimed.2012.11.040
87. Rye, T. and Mykura, W. *Concessionary bus fares for older people in Scotland - are they achieving their objectives?* Journal of Transport Geography, 2009. **17**(6): p. 451-456. http://doi.org/10.1016/j.jtrangeo.2008.08.003
88. Merry, L. *Finding the cash for Dilnot's proposals: scrap free travel and winter fuel payments, says SMF*. 2011 [Accessed on: 12 April, 2016]; Available from: http://www.smf.co.uk/finding-the-cash-for-dilnots-proposals-scrap-free-travel-and-winter-fuel-payments-says-smf/.
89. The Economist. *The Granny State*. 2015 [Accessed on: 12 April, 2016]; Available from: http://www.economist.com/news/leaders/21645192-britain-should-stop-subsidising-old-and-rich-expense-young-and-poor-granny.
90. Oxera *Subsidising buses: How to get the best from taxpayers' money. Report prepared for the LGA*. 2009. Available from: http://www.oxera.com/Oxera/media/Oxera/Subsidising-buses-report-August-2009.pdf?ext=.pdf.
91. Comptroller and Auditor General *Means Testing*. 2011. National Audit Office: London, UK. Available from: https://www.nao.org.uk/wp-content/uploads/2011/09/10121464.pdf.
92. Department for Work and Pensions *Income Related Benefits: Estimates of Take-up in 2009-10*. 2012. Available from: https://www.gov.uk/government/statistics/income-related-benefits-estimates-of-take-up.
93. Nazroo, J. *Ethnicity, class and health*. 2001. London, UK: Policy Studies Institute. Available from: http://www.psi.org.uk/pdf/EthnicityClassAndHealth.pdf.
94. Butcher, L. *Briefing paper CBP 1343: Railway passenger franchises*. 2018. House of Commons Library: London, UK. Available from: https://researchbriefings.parliament.uk/ResearchBriefing/Summary/SN01343.

95. Office of Rail and Road. *Index showing average change in price of rail fares by ticket type-Table 1.8*. 2015 [Accessed on: 26 October, 2016]; Available from: http://dataportal.orr.gov.uk/displayreport/html/html/ee32b90d-1f28-4963-88b4-0dff62950b77.
96. Office of Rail and Road. *GB rail industry financial information 2014/15*. 2016 [Accessed on: 25 October, 2016]; Available from: http://orr.gov.uk/statistics/published-stats/gb-rail-industry-financial-information.
97. Office of Rail and Road *UK rail industry financial information 2016-17*. 2018. Available from: http://orr.gov.uk/__data/assets/pdf_file/0006/26439/uk-rail-industry-financial-information-2016-17.pdf.
98. Dempsey, N. *Briefing paper SN06384: Railways: fares statistics*. 2018. House of Commons Library: London, UK. Available from: https://researchbriefings.files.parliament.uk/documents/SN06384/SN06384.pdf.
99. The Labour Party *For the many no the few: The Labour Party Manefesto 2017*. 2017. Available from: https://labour.org.uk/wp-content/uploads/2017/10/labour-manifesto-2017.pdf.
100. Competition and Markets Authority *Competition in passenger rail services in Great Britain*. 2016. Available from: http://webarchive.nationalarchives.gov.uk/20170519082326/https://www.gov.uk/cma-cases/passenger-rail-services-competition-policy-project.
101. *Statement from the Mayor of London*. 2016 [Accessed on: 17 October, 2018]; Available from: https://www.london.gov.uk/press-releases/mayoral/statement-from-the-mayor-of-london.
102. *In a written statement to the House Chris Grayling gave an update on rail transport (HC Deb 6 December 2016, c 322WS)*.
103. Shaw, N. *The future shape and financing of Network Rail (The Shaw report)*. 2016. Department for Transport. Available from: http://webarchive.nationalarchives.gov.uk/20170514130725/https://www.gov.uk/government/publications/shaw-report-final-report-and-recommendations.
104. Urban Transport Group *Rail Devolution Works*. 2016: Leeds, UK. Available from: http://www.urbantransportgroup.org/system/files/general-docs/UTG%20%E2%80%93%20Rail%20Devolution%20Works.pdf.
105. Steer Davies Gleave *Crossrail 2 Consultation Analysis*. 2016. Available from: https://consultations.tfl.gov.uk/crossrail2/october2015/user_uploads/crossrail2autumn2015consultation.pdf.
106. National Infrastructure Commission *High Speed North*. 2016. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/507791/High_Speed_North.pdf.
107. Department for Transport *High Speed Two: East and West The next steps to Crewe and beyond*. 2015. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/480712/hs2-east-and-west.pdf.
108. Transport, D.f. *Connecting people: a strategic vision for rail*. 2017. Controller of Her Majesty's Stationery. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/663124/rail-vision-web.pdf.
109. Linton, C. and Bray, J. *Taxi! Issues and options for city region taxi and private hire vehicle policy*. 2017. The Urban Transport Group. Available from: http://www.urbantransportgroup.org/resources/types/reports/taxi-issues-and-options-city-region-taxi-and-private-hire-vehicle-policy.
110. Department for Transport *Statistical release: Taxi and private hire vehicle statisitics: England 2017*. 2017. Available from:

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/642759/taxi-private-hire-vehicles-2017.pdf.
111. Transports for London. *TfL exploring whether a new 'demand responsive' TfL bus service could complement existing bus network*. 2018 [Accessed on: 23 Octboer, 2018]; Available from: https://tfl.gov.uk/info-for/media/press-releases/2018/march/tfl-exploring-whether-a-new-demand-responsive-tfl-bus-service-could-complement-existing-bus-network.
112. Oxford Bus Company. *Pickmeup from the Oxford Bus Company*. [Accessed on: 23 October, 2018]; Available from: https://pickmeup.oxfordbus.co.uk/.
113. Citymapper. *Smart Ride by Citymapper*. [Accessed on: 23 October, 2018]; Available from: https://citymapper.com/smartride.
114. Clarke, J. and Butcher, L. *Briefing paper CBP 7965: Connected and autonomous road vehicles*. 2017. House of Commons Library: London, UK. Available from: https://researchbriefings.parliament.uk/ResearchBriefing/Summary/CBP-7965.
115. House of Lords Science and Technology Select Committee *Connected and Autonomous Vehicles: The future?* 2017. House of Lords: London, UK. Available from: https://publications.parliament.uk/pa/ld201617/ldselect/ldsctech/115/115.pdf.
116. Musselwhite, C. and Haddad, H. *Older people's travel and mobility needs: a reflection of a hierarchical model 10 years on.* Quality in Ageing and Older Adults, 2018. **19**(2): p. 87-105. http://doi.org/10.1108/QAOA-12-2017-0054
117. Department for Transport *Research on the Impacts of Connected and Autonomous Vehicles (CAVs) on Traffic Flow*. 2016. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/530091/impacts-of-connected-and-autonomous-vehicles-on-traffic-flow-summary-report.pdf.
118. Bates, J. and Leibling, D. *Spaced out: perspectives on parking policy*. 2012. RAC Foundation. Available from: https://www.racfoundation.org/wp-content/uploads/2017/11/spaced_out-bates_leibling-jul12.pdf.
119. Harford, T. *Crosstown traffic*, in *The undercover economist*. 2006. Abacus: London, UK.
120. Badstuber, N. *Here's why fewer Londoners are taking the tube – and why it poses a threat to the TfL's finances*. 2018 [Accessed on: 24 October, 2018]; Available from: https://www.citymetric.com/transport/here-s-why-fewer-londoners-are-taking-tube-and-why-it-poses-threat-tfl-s-finances-3925.
121. de Nazelle, A., Bode, O., and Orjuela, J.P. *Comparison of air pollution exposures in active vs. passive travel modes in European cities: A quantitative review.* Environment International, 2017. **99**: p. 151-160. https://doi.org/10.1016/j.envint.2016.12.023
122. Park, E.S. and Sener, I.N. *Impact of light rail transit on traffic-related pollution and stroke mortality.* International Journal of Public Health, 2017. **62**(7): p. 721-728. http://doi.org/10.1007/s00038-017-0967-4
123. Beevers, S., Carslaw, D., Williams, M., Dajnak, D., Stewart, G., Kelly, F., and Fussell, J. *Traffic management strategies for emissions reduction: recent experience in London.* Energy and Emission Control Technologies, 2016. http://doi.org/10.2147/eect.S69858
124. World Health Organization *Health effects of transport-related air pollution*. 2005. Available from: http://www.euro.who.int/__data/assets/pdf_file/0006/74715/E86650.pdf.
125. Kwan, S.C., Tainio, M., Woodcock, J., Sutan, R., and Hashim, J.H. *The carbon savings and health co-benefits from the introduction of mass rapid transit system in Greater Kuala Lumpur, Malaysia.* Journal of Transport & Health, 2017. **6**: p. 187-200. https://doi.org/10.1016/j.jth.2017.06.006
126. Wall, G., Olaniyan, B., Woods, L., and Musselwhite, C. *Encouraging sustainable modal shift—An evaluation of the Portsmouth Big Green Commuter Challenge.* Case Studies on Transport Policy, 2017. **5**(1): p. 105-111. https://doi.org/10.1016/j.cstp.2016.11.006

127. Woodcock, J., Banister, D., Edwards, P., Prentice, A.M., and Roberts, I. *Energy and transport.* The Lancet, 2007. **370**(9592): p. 1078-1088. http://doi.org/10.1016/S0140-6736(07)61254-9
128. Woodcock, J., Edwards, P., Tonne, C., Armstrong, B.G., Ashiru, O., Banister, D., . . . Roberts, I. *Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport.* Lancet, 2009. **374**(9705): p. 1930-43. http://doi.org/10.1016/S0140-6736(09)61714-1
129. World Health Organisation *Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s*, Simon Hales, et al., Editors. 2014: Geneva, Switzerland. Available from: https://www.climatecaseireland.ie/wp-content/uploads/2018/04/9789241507691_eng.pdf.
130. GBD 2015 Mortality and Causes of Death Collaborators *Global, regional, and national life expectancy, all-cause mortality, and cause-specifi c mortality for 249 causes of death, 1980–2015: a systematic analysis for the Global Burden of Disease Study 2015.* Lancet, 2016. **388**: p. 1459-1544. http://doi.org/10.1016/S0140-6736(16)31012-1
131. Savage, I. *Comparing the fatality risks in United States transportation across modes and over time.* Research in Transportation Economics, 2013. **43**(1): p. 9-22. https://doi.org/10.1016/j.retrec.2012.12.011
132. Martin, A., Goryakin, Y., and Suhrcke, M. *Does active commuting improve psychological wellbeing? Longitudinal evidence from eighteen waves of the British Household Panel Survey.* Prev Med, 2014. **69**: p. 296-303. http://doi.org/10.1016/j.ypmed.2014.08.023
133. Office for National Statistics *Commuting and personal wellbeing 2014*. 2014. Available from: https://webarchive.nationalarchives.gov.uk/20160107224314/http://www.ons.gov.uk/ons/dcp171766_351954.pdf.
134. Andrews, G., Parkhurst, G., Susilo, Y.O., and Shaw, J. *The grey escape: investigating older people's use of the free bus pass.* Transportation Planning and Technology, 2012. **35**(1): p. 3-15. http://doi.org/10.1080/03081060.2012.635413
135. Chatterjee, K., Clark, B., Martin, A., and Davis, A. *The Commuting and Wellbeing Study: Understanding the Impact of Commuting on People's Lives.* 2017. UWE Briustol, UK. Available from: https://travelbehaviour.files.wordpress.com/2017/10/caw-summaryreport-onlineedition.pdf.
136. Green, J., Jones, A., and Roberts, H. *More than A to B: the role of free bus travel for the mobility and wellbeing of older citizens in London.* Ageing & Society, 2014. **34**(03): p. 472-494. http://doi.org/10.1017/S0144686X12001110
137. Mackett, R. *Impact of Concessionary Bus Travel on the Well-Being of Older and Disabled People.* Transportation Research Record, 2013. **2352**(1): p. 114-119. http://doi.org/10.3141/2352-13
138. World Health Organization. *Physical Activity*. [Accessed on: 19 October, 2016]; Available from: http://www.who.int/topics/physical_activity/en/.
139. Ainsworth, B.E., Haskell, W.L., Herrmann, S.D., Meckes, N., Bassett, D.R., Jr., Tudor-Locke, C., . . . Leon, A.S. *2011 Compendium of Physical Activities: a second update of codes and MET values.* Med Sci Sports Exerc, 2011. **43**(8): p. 1575-81. http://doi.org/10.1249/MSS.0b013e31821ece12
140. Chief Medical Office *Physical activity guidelines for older Adults (65+ Years)*. 2011. Department of Health, : London, UK. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/213741/dh_128146.pdf.
141. World Health Organization *Global Recommendations on Physical Activity for Health*. 2010: Geneva, Switzerland. Available from: http://apps.who.int/iris/bitstream/10665/44399/1/9789241599979_eng.pdf.
142. Tremblay, M.S., Carson, V., Chaput, J.P., Connor Gorber, S., Dinh, T., Duggan, M., . . . Zehr, L. *Canadian 24-Hour Movement Guidelines for Children and Youth: An Integration of Physical*

Activity, Sedentary Behaviour, and Sleep. Appl Physiol Nutr Metab, 2016. **41**(6 Suppl 3): p. S311-27. http://doi.org/10.1139/apnm-2016-0151

143. Canadian Society for Exercise Physiology. *Canadian 24-Hour Movement Guidelines: An Integration of Physical Activity, Sedentary Behaviour, and Sleep*. 2016 [Accessed on: 26 October, 2018]; Available from: http://csepguidelines.ca/.
144. Scholes, S. *Health Survey for England 2016 - Physical activity in adults*. 2017. Health and Social Care Information Centre. Available from: https://files.digital.nhs.uk/publication/m/3/hse16-adult-phy-act.pdf.
145. Guthold, R., Stevens, G.A., Riley, L.M., and Bull, F.C. *Worldwide trends in insufficient physical activity from 2001 to 2016: a pooled analysis of 358 population-based surveys with 1.9 million participants.* The Lancet Global Health, 2018. http://doi.org/10.1016/S2214-109X(18)30357-7
146. Cawley, J. *An economic framework for understanding physical activity and eating behaviors.* American Journal of Preventive Medicine, 2004. **27**(3, Supplement): p. 117-125. http://dx.doi.org/10.1016/j.amepre.2004.06.012
147. Stamatakis, E., Ekelund, U., and Wareham, N.J. *Temporal trends in physical activity in England: The Health Survey for England 1991 to 2004.* Preventive Medicine, 2007. **45**(6): p. 416-423. http://dx.doi.org/10.1016/j.ypmed.2006.12.014
148. Brownson, R.C., Boehmer, T.K., and Luke, D.A. *Declining rates of physical activity in the United States: what are the contributors?* Annu Rev Public Health, 2005. **26**: p. 421-43. http://doi.org/10.1146/annurev.publhealth.26.021304.144437
149. Knuth, A.G. and Hallal, P.C. *Temporal Trends in Physical Activity: A Systematic Review.* Journal of Physical Activity and Health, 2009. **6**(5): p. 548-559. http://doi.org/10.1123/jpah.6.5.548
150. Lanningham-Foster, L., Nysse, L.J., and Levine, J.A. *Labor saved, calories lost: the energetic impact of domestic labor-saving devices.* Obes Res, 2003. **11**(10): p. 1178-81. http://doi.org/10.1038/oby.2003.162
151. Hamilton, M.T., Healy, G.N., Dunstan, D.W., Zderic, T.W., and Owen, N. *Too Little Exercise and Too Much Sitting: Inactivity Physiology and the Need for New Recommendations on Sedentary Behavior.* Curr Cardiovasc Risk Rep, 2008. **2**(4): p. 292-298. http://doi.org/10.1007/s12170-008-0054-8
152. Warburton, D.E., Charlesworth, S., Ivey, A., Nettlefold, L., and Bredin, S.S. *A systematic review of the evidence for Canada's Physical Activity Guidelines for Adults.* IJBNPA, 2010. **7**(39). https://doi.org/10.1186/1479-5868-7-39
153. Woodcock, J., Franco, O.H., Orsini, N., and Roberts, I. *Non-vigorous physical activity and all-cause mortality: systematic review and meta-analysis of cohort studies.* Int J Epidemiol, 2011. **40**(1): p. 121-38. http://doi.org/10.1093/ije/dyq104
154. Smith, A.D., Crippa, A., Woodcock, J., and Brage, S. *Physical activity and incident type 2 diabetes mellitus: a systematic review and dose-response meta-analysis of prospective cohort studies.* Diabetologia, 2016. **59**(12): p. 2527-2545. http://doi.org/10.1007/s00125-016-4079-0
155. Ezzati, M., Hoorn, S.V., Lopez, A.D., Danaei, G., Rodgers, A., Mathers, C.D., and Murray, C.J.L. *Comparative Quantification of Mortality and Burden of Disease Attributable to Selected Risk Factors*, in *Global Burden of Disease and Risk Factors*, A.D. Lopez, et al., Editors. 2006: Washington, DC. Available from: http://www.ncbi.nlm.nih.gov/books/NBK11813.
156. Swift, D.L., McGee, J.E., Earnest, C.P., Carlisle, E., Nygard, M., and Johannsen, N.M. *The Effects of Exercise and Physical Activity on Weight Loss and Maintenance.* Progress in Cardiovascular Diseases, 2018. **61**(2): p. 206-213. https://doi.org/10.1016/j.pcad.2018.07.014

157. Wareham, N.J., van Sluijs, E.M., and Ekelund, U. *Physical activity and obesity prevention: a review of the current evidence.* Proceedings of the Nutrition Society, 2005. **64**(2): p. 229-247. http://doi.org/10.1079/PNS2005423
158. Bhatnagar, P., Wickramasinghe, K., Wilkins, E., and Townsend, N. *Trends in the epidemiology of cardiovascular disease in the UK.* Heart, 2016. **102**(24): p. 1945-1952. http://doi.org/10.1136/heartjnl-2016-309573
159. Public Health England. *Chapter 3: trends in morbidity and risk factors*. Health profile for England. 2018 [Accessed on: 24 October, 2018]; Available from: https://www.gov.uk/government/publications/health-profile-for-england-2018/chapter-3-trends-in-morbidity-and-risk-factors#risk-factors-associated-with-morbidity.
160. Institute for Health Metrics and Evaluation (IHME) *Global Burden of Disease Study 2016 (GBD 2016) Results*. 2016: Seattle, Washington. Available from: http://ihmeuw.org/4jn5.
161. Public Health England. *About obesity: UK and Ireland prevalence and trends*. 2014 [Accessed on: 1 April, 2016]; Available from: https://www.noo.org.uk/NOO_about_obesity/adult_obesity/UK_prevalence_and_trends.
162. Sharma, M., Nazareth, I., and Petersen, I. *Trends in incidence, prevalence and prescribing in type 2 diabetes mellitus between 2000 and 2013 in primary care: a retrospective cohort study.* BMJ Open, 2016. **6**(1): p. e010210. http://doi.org/10.1136/bmjopen-2015-010210
163. Hex, N., Bartlett, C., Wright, D., Taylor, M., and Varley, D. *Estimating the current and future costs of Type 1 and Type 2 diabetes in the UK, including direct health costs and indirect societal and productivity costs.* Diabet Med, 2012. **29**(7): p. 855-62. http://doi.org/10.1111/j.1464-5491.2012.03698.x
164. Kyu, H.H., Bachman, V.F., Alexander, L.T., Mumford, J.E., Afshin, A., Estep, K., . . . Forouzanfar, M.H. *Physical activity and risk of breast cancer, colon cancer, diabetes, ischemic heart disease, and ischemic stroke events: systematic review and dose-response meta-analysis for the Global Burden of Disease Study 2013.* BMJ, 2016. **354**. http://doi.org/10.1136/bmj.i3857
165. Office for National Statistics. *Cancer registration statistics, England: 2016*. 2018 [Accessed on: 23 October, 2018]; Available from: https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/conditionsanddiseases/bulletins/cancerregistrationstatisticsengland/final2016#breast-prostate-lung-and-colorectal-cancers-continue-to-be-the-most-common.
166. Cancer Research UK. *Cancer statistics for the UK*. 2018 [Accessed on: 23 October, 2018]; Available from: https://www.cancerresearchuk.org/health-professional/cancer-statistics-for-the-uk.
167. Lee, I.M., Shiroma, E.J., Lobelo, F., Puska, P., Blair, S.N., and Katzmarzyk, P.T. *Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy.* The Lancet, 2012. **380**(9838): p. 219-229. http://dx.doi.org/10.1016/S0140-6736(12)61031-9
168. Lim, S.S., Vos, T., Flaxman, A.D., Danaei, G., Shibuya, K., Adair-Rohani, H., . . . Ezzati, M. *A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010.* The Lancet, 2012. **380**(9859): p. 2224-2260. http://dx.doi.org/10.1016/S0140-6736(12)61766-8
169. Wen, C.P., Wai, J.P.M., Tsai, M.K., Yang, Y.C., Cheng, T.Y.D., Lee, M.-C., . . . Wu, X. *Minimum amount of physical activity for reduced mortality and extended life expectancy: a prospective cohort study.* Lancet, 2011. **378**. http://doi.org/10.1016/s0140-6736(11)60749-6
170. Public Health England. *Chapter 2: trends in mortality*. Health profile for England: 2018. 2018 [Accessed on: 23 October, 2018]; Available from: https://www.gov.uk/government/publications/health-profile-for-england-2018/chapter-2-trends-in-mortality.

171. Hamer, M. and Chida, Y. *Active commuting and cardiovascular risk: a meta-analytic review.* Prev Med, 2008. **46**(1): p. 9-13. https://doi.org/10.1016/j.ypmed.2007.03.006
172. Flint, E., Cummins, S., and Sacker, A. *Associations between active commuting, body fat, and body mass index: population based, cross sectional study in the United Kingdom.* BMJ, 2014. **349**: p. g4887. http://dx.doi.org/10.1136/bmj.g4887
173. Ogilvie, D., Mitchell, R., Mutrie, N., Petticrew, M., and Platt, S. *Personal and environmental correlates of active travel and physical activity in a deprived urban population.* Int J Behav Nutr Phys Act, 2008. **5**: p. 43. http://doi.org/10.1186/1479-5868-5-43
174. Kelly, P., Kahlmeier, S., Gotschi, T., Orsini, N., Richards, J., Roberts, N., . . . Foster, C. *Systematic review and meta-analysis of reduction in all-cause mortality from walking and cycling and shape of dose response relationship.* International Journal of Behavioral Nutrition and Physical Activity, 2014. **11**(132). http://doi.org/10.1186/s12966-014-0132-x
175. Hamer, M. and Chida, Y. *Walking and primary prevention: a meta-analysis of prospective cohort studies.* Br J Sports Med, 2008. **42**(4): p. 238-43. http://doi.org/10.1136/bjsm.2007.039974
176. Dons, E., Rojas-Rueda, D., Anaya-Boig, E., Avila-Palencia, I., Brand, C., Cole-Hunter, T., . . . Götschi, T. *Transport mode choice and body mass index: Cross-sectional and longitudinal evidence from a European-wide study.* Environment International, 2018. **119**: p. 109-116. https://doi.org/10.1016/j.envint.2018.06.023
177. Riiser, A., Solbraa, A., Jenum, A.K., Birkeland, K.I., and Andersen, L.B. *Cycling and walking for transport and their associations with diabetes and risk factors for cardiovascular disease.* Journal of Transport & Health, 2018. **11**: p. 193-201. https://doi.org/10.1016/j.jth.2018.09.002
178. Dinu, M., Pagliai, G., Macchi, C., and Sofi, F. *Active Commuting and Multiple Health Outcomes: A Systematic Review and Meta-Analysis.* Sports Medicine, 2018. http://doi.org/10.1007/s40279-018-1023-0
179. Oja, P., Titze, S., Bauman, A., de Geus, B., Krenn, P., Reger-Nash, B., and Kohlberger, T. *Health benefits of cycling: a systematic review.* Scand J Med Sci Sports, 2011. **21**(4): p. 496-509. http://doi.org/10.1111/j.1600-0838.2011.01299.x
180. Flint, E. and Cummins, S. *Active commuting and obesity in mid-life: cross-sectional, observational evidence from UK Biobank.* The Lancet Diabetes & Endocrinology, 2016. **4**(5): p. 420-435. http://dx.doi.org/10.1016/s2213-8587(16)00053-x
181. Celis-Morales, C.A., Lyall, D.M., Welsh, P., Anderson, J., Steell, L., Guo, Y., . . . Gill, J.M.R. *Association between active commuting and incident cardiovascular disease, cancer, and mortality: prospective cohort study.* BMJ, 2017. **357**. http://doi.org/10.1136/bmj.j1456
182. Panter, J., Mytton, O., Sharp, S., Brage, S., Cummins, S., Laverty, A.A., . . . Ogilvie, D. *Using alternatives to the car and risk of all-cause, cardiovascular and cancer mortality.* Heart, 2018. http://dx.doi.org/10.1136/heartjnl-2017-312699
183. Wen, L.M., Rissel, C., and Fu, H. *The Effect of Active Transport, Transport Systems, and Urban Design on Population Health.* Journal of Environmental and Public Health, 2013. **2013**: p. 3. http://doi.org/10.1155/2013/457159
184. Rissel, C., Curac, N., Greenaway, M., and Bauman, A. *Physical Activity Associated with Public Transport Use—A Review and Modelling of Potential Benefits.* International Journal of Environmental Research and Public Health, 2012. **9**(7): p. 2454-2478. http://doi.org/10.3390/ijerph9072454
185. Evans, A.W. and Addison, J.D. *Interactions between rail and road safety in Great Britain.* Accident Analysis & Prevention, 2009. **41**(1): p. 48-56. http://dx.doi.org/10.1016/j.aap.2008.09.001
186. Davis, M.G., Fox, K.R., Hillsdon, M., Coulson, J.C., Sharp, D.J., Stathi, A., and Thompson, J.L. *Getting out and about in older adults: the nature of daily trips and their association with*

objectively assessed physical activity. International Journal of Behavioral Nutrition and Physical Activity, 2011. **8**(1): p. 1-9. http://doi.org/10.1186/1479-5868-8-116

187. Batista Ferrer, H., Cooper, A., and Audrey, S. *Associations of mode of travel to work with physical activity, and individual, interpersonal, organisational, and environmental characteristics.* Journal of Transport & Health, 2018. **9**: p. 45-55. https://doi.org/10.1016/j.jth.2018.01.009
188. Brown, B.B., Tharp, D., Smith, K.R., and Jensen, W.A. *Objectively measured active travel and uses of activity-friendly neighborhood resources: Does change in use relate to change in physical activity and BMI?* Preventive Medicine Reports, 2017. **8**: p. 60-66. http://dx.doi.org/10.1016/j.pmedr.2017.08.004
189. Chaix, B., Kestens, Y., Duncan, S., Merrien, C., Thierry, B., Pannier, B., . . . Méline, J. *Active transportation and public transportation use to achieve physical activity recommendations? A combined GPS, accelerometer, and mobility survey study.* International Journal of Behavioral Nutrition and Physical Activity, 2014. **11**(1): p. 124. http://doi.org/10.1186/s12966-014-0124-x
190. Costa, S., Ogilvie, D., Dalton, A., Westgate, K., Brage, S., and Panter, J. *Quantifying the physical activity energy expenditure of commuters using a combination of global positioning system and combined heart rate and movement sensors.* Preventive Medicine, 2015. **81**: p. 339-344. https://doi.org/10.1016/j.ypmed.2015.09.022
191. Miller, H.J., Tribby, C.P., Brown, B.B., Smith, K.R., Werner, C.M., Wolf, J., . . . Oliveira, M.G.S. *Public transit generates new physical activity: Evidence from individual GPS and accelerometer data before and after light rail construction in a neighborhood of Salt Lake City, Utah, USA.* Health & Place, 2015. **36**: p. 8-17. https://doi.org/10.1016/j.healthplace.2015.08.005
192. Saelens, B.E., Moudon, A.V., Kang, B., Hurvitz, P.M., and Zhou, C. *Relation Between Higher Physical Activity and Public Transit Use.* American Journal of Public Health, 2014. **104**(5): p. 854-859. http://doi.org/10.2105/ajph.2013.301696
193. Voss, C., Sims-Gould, J., Ashe, M.C., McKay, H.A., Pugh, C., and Winters, M. *Public transit use and physical activity in community-dwelling older adults: Combining GPS and accelerometry to assess transportation-related physical activity.* Journal of Transport & Health, 2016. **3**(2): p. 191-199. http://dx.doi.org/10.1016/j.jth.2016.02.011
194. Hirsch, J.A., DeVries, D.N., Brauer, M., Frank, L.D., and Winters, M. *Impact of new rapid transit on physical activity: A meta-analysis.* Preventive Medicine Reports, 2018. **10**: p. 184-190. https://doi.org/10.1016/j.pmedr.2018.03.008
195. Xiao, C., Goryakin, Y., and Cecchini, M. *Physical Activity Levels and New Public Transit: A Systematic Review and Meta-analysis.* American Journal of Preventive Medicine, 2019. **56**(3): p. 464-473. https://doi.org/10.1016/j.amepre.2018.10.022
196. Hirsch, J.A., DeVries, D.N., Brauer, M., Frank, L.D., and Winters, M. *Corrigendum to "Impact of new rapid transit on physical activity: A meta-analysis" Preventive Medicine Reports 10 (2018) 184–190.* Preventive Medicine Reports, 2018. **11**: p. 312-313. https://doi.org/10.1016/j.pmedr.2018.08.011
197. Rundle, A., Diez Roux, A.V., Free, L.M., Miller, D., Neckerman, K.M., and Weiss, C.C. *The urban built environment and obesity in New York City: a multilevel analysis.* Am J Health Promot, 2007. **21**(4 Suppl): p. 326-34. https://doi.org/10.4278%2F0890-1171-21.4s.326
198. Lovasi, G.S., Neckerman, K.M., Quinn, J.W., Weiss, C.C., and Rundle, A. *Effect of individual or neighborhood disadvantage on the association between neighborhood walkability and body mass index.* Am J Public Health, 2009. **99**(2): p. 279-84. http://doi.org/10.2105/ajph.2008.138230
199. Abu-Omar, K. and Rutten, A. *Relation of leisure time, occupational, domestic, and commuting physical activity to health indicators in Europe.* Prev Med, 2008. **47**(3): p. 319-23. http://doi.org/10.1016/j.ypmed.2008.03.012

200. Tudor-Locke, C., Bittman, M., Merom, D., and Bauman, A. *Patterns of walking for transport and exercise: a novel application of time use data.* Int J Behav Nutr Phys Act, 2005. **2**: p. 5. http://doi.org/10.1186/1479-5868-2-5

201. Stopher, P.R. and Greaves, S.P. *Household travel surveys: Where are we going?* Transportation Research Part A: Policy and Practice, 2007. **41**(5): p. 367-381. https://doi.org/10.1016/j.tra.2006.09.005

202. Morris, S., Humphrey, A., Byron, C., Templeton, I., and Hurn, J. *National Travel Survey 2014 - Technical Report*. 2015. The Department for Transport. Available from: https://www.gov.uk/government/statistics/national-travel-survey-2014.

203. Kang, B., Moudon, A.V., Hurvitz, P.M., Reichley, L., and Saelens, B.E. *Walking objectively measured: classifying accelerometer data with GPS and travel diaries.* Med Sci Sports Exerc, 2013. **45**(7): p. 1419-28. http://doi.org/10.1249/MSS.0b013e318285f202

204. Kelly, P., Doherty, A., Mizdrak, A., Marshall, S., Kerr, J., Legge, A., . . . Foster, C. *High group level validity but high random error of a self-report travel diary, as assessed by wearable cameras.* Journal of Transport & Health, 2014. **1**(3): p. 190-201. http://dx.doi.org/10.1016/j.jth.2014.04.003

205. Wijndaele, K., Westgate, K., Stephens, S.K., Blair, S.N., Bull, F.C., Chastin, S.F., . . . Healy, G.N. *Utilization and Harmonization of Adult Accelerometry Data: Review and Expert Consensus.* Med Sci Sports Exerc, 2015. http://doi.org/10.1249/MSS.0000000000000661

206. Tremblay, M.S., Colley, R.C., Saunders, T.J., Healy, G.N., and Owen, N. *Physiological and health implications of a sedentary lifestyle.* Applied Physiology, Nutrition, & Metabolism = Physiologie Appliquee, Nutrition et Metabolisme, 2010. **35**(6): p. 725-40. https://doi.org/10.1139/H10-079

207. Troiano, R.P., Berrigan, D., Dodd, K.W., Masse, L.C., Tilert, T., and McDowell, M. *Physical activity in the United States measured by accelerometer.* Med Sci Sports Exerc, 2008. **40**. http://doi.org/10.1249/mss.0b013e31815a51b3

208. Kozey-Keadle, S., Libertine, A., Lyden, K., Staudenmayer, J., and Freedson, P.S. *Validation of wearable monitors for assessing sedentary behavior.* Med Sci Sports Exerc, 2011. **43**(8): p. 1561-7. http://doi.org/10.1249/MSS.0b013e31820ce174

209. Atkin, A.J., Gorely, T., Clemes, S.A., Yates, T., Edwardson, C., Brage, S., . . . Biddle, S.J. *Methods of Measurement in epidemiology: sedentary Behaviour.* Int J Epidemiol, 2012. **41**(5): p. 1460-71. https://doi.org/10.1093/ije/dys118

210. Ham, S.A., Reis, J.P., Strath, S.J., Dubose, K.D., and Ainsworth, B.E. *Discrepancies between methods of identifying objectively determined physical activity.* Medicine and science in sports and exercise, 2007. **39**(1): p. 52-58. http://doi.org/10.1249/01.mss.0000235886.17229.42

211. Aresu, M., Becares, L., Brage, S., Chaudhury, M., Doyle-Francis, M., Esliger, D., . . . Wardle, H. *Health survey for England 2008 - Volume 1 Physical activity and fitness*, R. Craig, J. Mindell, and V. Hirani, Editors. 2009. The NHS Information Centre for health and social care: London, UK. Available from: http://www.hscic.gov.uk/catalogue/PUB00430/heal-surv-phys-acti-fitn-eng-2008-rep-v2.pdf.

212. Davis, M.G., Fox, K.R., Hillsdon, M., Sharp, D.J., Coulson, J.C., and Thompson, J.L. *Objectively measured physical activity in a diverse sample of older urban UK adults.* Med Sci Sports Exerc, 2011. **43**(4): p. 647-54. http://doi.org/10.1249/MSS.0b013e3181f36196

213. Institute of Medicine (US) Committee on Preventing the Global Epidemic of Cardiovascular Disease: Meeting the Challenges in Developing Countries *Chapter 2 - Epidemiology of Cardiovascular Disease*, in *Promoting Cardiovascular Health in the Developing World: A Critical Challenge to Achieve Global Health*, V. Fuster and B. Kelly, Editors. 2010. National Academies Press (US): Washington, DC. Available from: https://www.ncbi.nlm.nih.gov/books/NBK45688/.

214. Health Survey for England via PHE data and analysis tools *Patterns and trends in adult obesity*. 2017. Available from: https://app.box.com/s/og3q86aqejc99okxe9xyvpfvo21xai21/file/256370456621.
215. Conolly, A. and Saunders, C. *Health Survey for England 2016: Adult overweight and obesity*. 2017. Health and Social Care Information Centre. Available from: https://files.digital.nhs.uk/publication/m/6/hse2016-adult-obe.pdf.
216. Di Angelantonio, E., Bhupathiraju, S.N., Wormser, D., Gao, P., Kaptoge, S., de Gonzalez, A.B., . . . Hu, F.B. *Body-mass index and all-cause mortality: individual-participant-data meta-analysis of 239 prospective studies in four continents.* The Lancet, 2016. **388**(10046): p. 776-786. https://doi.org/10.1016/S0140-6736(16)30175-1
217. NatCen Social Research *Health Survey for England 2016: Adult health trends*. 2017. Health and Social Care Information Centre. Available from: https://files.digital.nhs.uk/publication/m/0/hse2016-adult-trends.pdf.
218. Khamis, R.Y., Ammari, T., and Mikhail, G.W. *Gender differences in coronary heart disease.* Heart, 2016. **102**(14): p. 1142-1149. http://doi.org/10.1136/heartjnl-2014-306463
219. Paterson, D.H. and Warburton, D.E. *Physical activity and functional limitations in older adults: a systematic review related to Canada's Physical Activity Guidelines.* Int J Behav Nutr Phys Act, 2010. **7**: p. 38. http://dx.doi.org/10.1186/1479-5868-7-38
220. OECD *Obesity and the Economics of Prevention: Fit not Fat*. 2014. Available from: https://www.oecd.org/unitedkingdom/Obesity-Update-2014-ENGLAND.pdf.
221. Yusuf, S., Reddy, S., Ôunpuu, S., and Anand, S. *Global burden of cardiovascular diseases part II: variations in cardiovascular disease by specific ethnic groups and geographic regions and prevention strategies.* Circulation, 2001. **104**(23): p. 2855-2864. https://doi.org/10.1161/hc4701.099488
222. Bhopal, R., Bansal, N., Fischbacher, C., Brown, H., and Capewell, S. *Ethnic variations in the incidence and mortality of stroke in the Scottish Health and Ethnicity Linkage Study of 4.65 million people.* European Journal of Preventive Cardiology, 2012. **19**(6): p. 1503-1508. http://doi.org/10.1177/1741826711423217
223. Williams, E.D., Stamatakis, E., Chandola, T., and Hamer, M. *Assessment of physical activity levels in South Asians in the UK: findings from the Health Survey for England.* Journal of Epidemiology and Community Health, 2010. http://doi.org/10.1136/jech.2009.102509
224. Higgins, V. and Dale, A. *Ethnic Differences in Physical Activity and obesity*, in *Ethnicity and integration: Understanding population trends and processes - Volume 3*, J. Stillwell and M. van Ham, Editors. 2010. Springer: London, UK. Available from: https://lemosandcrane.co.uk/resources/University%20of%20Manchester%20-%20Ethnic%20differences%20in%20physical%20activity%20and%20obesity.pdf.
225. Fox, K.R. and Richards, L. *Results from the sport and leisure module of the 2002 General Household Survey*. 2002. HMSO. Available from: http://hydeparkandwoodhouseonline.com/wp-content/uploads/2010/09/General-Household-Survey-2002.pdf.
226. Bryan, S.N., Tremblay, M.S., Perez, C.E., Ardern, C.I., and Katzmarzyk, P.T. *Physical activity and ethnicity: evidence from the Canadian Community Health Survey.* Can J Public Health, 2006. **97**(4): p. 271-6. http://dx.doi.org/10.17269/cjph.97.746
227. Marmot, M., Atkinson, T., Bell, J., Black, C., Broadfoot, P., and Cumberlege, J. *Fair Society Healthy Lives - The Marmot Review*. 2010: London, UK. Available from: http://www.instituteofhealthequity.org/resources-reports/fair-society-healthy-lives-the-marmot-review.
228. Acheson, D. *Independent Inquiry into Inequalities in Health Report*. 1998. The Stationery Office,. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/265503/ih.pdf.

229. Townsend, P., Davidson, N., Black, D.S., and Whitehead, M. *Inequalities in health : the Black report*. Health divide. 1992. London, UK: Penguin.
230. National Obesity Observatory *Adult Obesity and Socioeconomic Status*. 2012. Available from: http://www.noo.org.uk/uploads/doc/vid_16966_AdultSocioeconSep2012.pdf.
231. Goyal, A., Bhatt, D.L., Steg, P.G., Gersh, B.J., Alberts, M.J., Ohman, E.M., . . . Reduction of Atherothrombosis for Continued Health Registry, I. *Attained educational level and incident atherothrombotic events in low- and middle-income compared with high-income countries.* Circulation, 2010. **122**(12): p. 1167-75. http://doi.org/10.1161/CIRCULATIONAHA.109.919274
232. Connolly, V., Unwin, N., Sherriff, P., Bilous, R., and Kelly, W. *Diabetes prevalence and socioeconomic status: a population based study showing increased prevalence of type 2 diabetes mellitus in deprived areas.* Journal of Epidemiology and Community Health, 2000. **54**(3): p. 173-177. http://doi.org/10.1136/jech.54.3.173
233. Rabi, D.M., Edwards, A.L., Southern, D.A., Svenson, L.W., Sargious, P.M., Norton, P., . . . Ghali, W.A. *Association of socio-economic status with diabetes prevalence and utilization of diabetes care services.* BMC Health Serv Res, 2006. **6**: p. 124. http://doi.org/10.1186/1472-6963-6-124
234. Scholes, S. and Mindell, J. *Chapter 2 - Physical activity in adults*, in *Health Survey for England 2012. Volume 1: Health, social care and lifestyles.*, R. Craig and J. Mindell, Editors. 2013. Health and Social Care Information Centre: Leeds, UK. Available from: http://content.digital.nhs.uk/catalogue/PUB13218/HSE2012-Ch2-Phys-act-adults.pdf.
235. Ogilvie, D., Foster, C.E., Rothnie, H., Cavill, N., Hamilton, V., Fitzsimons, C.F., . . . Scottish Physical Activity Research, C. *Interventions to promote walking: systematic review.* BMJ, 2007. **334**(7605): p. 1204. http://doi.org/10.1136/bmj.39198.722720.BE
236. Pereira, M.A., Kriska, A.M., Day, R.D., Cauley, J.A., LaPorte, R.E., and Kuller, L.H. *A randomized walking trial in postmenopausal women: Effects on physical activity and health 10 years later.* Archives of Internal Medicine, 1998. **158**(15): p. 1695-1701. http://doi.org/10.1001/archinte.158.15.1695
237. Mutrie, N., Carney, C., Blamey, A., Crawford, F., Aitchison, T., and Whitelaw, A. *"Walk in to Work Out": a randomised controlled trial of a self help intervention to promote active commuting.* Journal of Epidemiology and Community Health, 2002. **56**(6): p. 407-412. http://doi.org/10.1136/jech.56.6.407
238. Capewell, S. and Graham, H. *Will Cardiovascular Disease Prevention Widen Health Inequalities?* PLoS Med, 2010. **7**(8): p. e1000320. http://doi.org/10.1371/journal.pmed.1000320
239. Oxford English Dictionary. *"agency, n."*. [Accessed on: 26 February, 2019]; Available from: http://www.oed.com/view/Entry/3851?redirectedFrom=agency.
240. Adams, J., Mytton, O., White, M., and Monsivais, P. *Why Are Some Population Interventions for Diet and Obesity More Equitable and Effective Than Others? The Role of Individual Agency.* PLoS Med, 2016. **13**(4): p. e1001990. https://doi.org/10.1371/journal.pmed.1001990
241. Rose, G. *Sick individuals and sick populations.* International Journal of Epidemiology, 2001. **30**(3): p. 427-432. http://doi.org/10.1093/ije/30.3.427
242. Foster, C., Kelly, P., Reid, H.A.B., Roberts, N., Murtagh, E.M., Humphreys, D.K., . . . Milton, K. *What works to promote walking at the population level? A systematic review.* Br J Sports Med, 2018. **52**(12): p. 807-812. http://doi.org/10.1136/bjsports-2017-098953
243. Department of Health *Committee of Inquiry into the Future Development of the Public Health Function*. 1998. The Stationery Office. Available from: https://www.gov.uk/government/publications/independent-inquiry-into-inequalities-in-health-report.

244. World Health Organization *Progressing the sustainable development goals through health in all policies: case studies from around the world*. 2017. Available from: https://www.who.int/social_determinants/publications/progressing-sdg-case-studies-2017.pdf.
245. Roth, G.A., Abate, D., Abate, K.H., Abay, S.M., Abbafati, C., Abbasi, N., . . . Murray, C.J.L. *Global, regional, and national age-sex-specific mortality for 282 causes of death in 195 countries and territories, 1980–2017: a systematic analysis for the Global Burden of Disease Study 2017.* The Lancet, 2018. **392**(10159): p. 1736-1788. https://doi.org/10.1016/S0140-6736(18)32203-7
246. Robertson, R., Robertson, A., Jepson, R., and Maxwell, M. *Walking for depression or depressive symptoms: a systematic review and meta-analysis.* Mental Health and Physical Activity, 2012. **5**(1): p. 66-75. http://doi.org/10.1016/j.mhpa.2012.03.002
247. Murphy, M.H., Nevill, A.M., Murtagh, E.M., and Holder, R.L. *The effect of walking on fitness, fatness and resting blood pressure: a meta-analysis of randomised, controlled trials.* Prev Med, 2007. **44**(5): p. 377-85. http://doi.org/10.1016/j.ypmed.2006.12.008
248. Besser, L.M. and Dannenberg, A.L. *Walking to public transit: steps to help meet physical activity recommendations.* Am J Prev Med, 2005. **29**(4): p. 273-80. http://dx.doi.org/10.1016/j.amepre.2005.06.010
249. Hagstromer, M., Oja, P., and Sjostrom, M. *Physical activity and inactivity in an adult population assessed by accelerometry.* Med Sci Sports Exerc, 2007. **39**(9): p. 1502-8. http://doi.org/10.1249/mss.0b013e3180a76de5
250. Sedgwick, P. *Cross sectional studies: advantages and disadvantages.* BMJ : British Medical Journal, 2014. **348**. http://doi.org/10.1136/bmj.g2276
251. Wells, G.A., Shea, B., O'Connell, D., Peterson, J., Welch, V., Losos, M., and Tugwell, P. *The Newcastle-Ottawa Scale (NOS) for assessing the quality of non-randomised studies in meta-analyses.* 2000. Available from: http://www.ohri.ca/programs/clinical_epidemiology/oxford.asp.
252. Higgins, JPT. Green, S. (editors) *Cochrane handbook for systematic reviews of interventions. Version 5.1.0 [Updated March 2011]*. The Cochrane Collaboration, 2011. Available from: www.handbook.cochrane.org.
253. Juni, P., Witschi, A., Bloch, R., and Egger, M. *The hazards of scoring the quality of clinical trials for meta-analysis.* JAMA, 1999. **282**(11): p. 1054-60. http://doi.org/10.1001/jama.282.11.1054
254. DerSimonian, R. and Laird, N. *Meta-analysis in clinical trials.* Control Clin Trials, 1986. **7**(3): p. 177-88. https://doi.org/10.1016/0197-2456(86)90046-2
255. Higgins, J.P. and Thompson, S.G. *Quantifying heterogeneity in a meta-analysis.* Stat Med, 2002. **21**(11): p. 1539-58. http://doi.org/10.1002/sim.1186
256. Sterne, J.A.C., Sutton, A.J., Ioannidis, J.P.A., Terrin, N., Jones, D.R., Lau, J., . . . Higgins, J.P.T. *Recommendations for examining and interpreting funnel plot asymmetry in meta-analyses of randomised controlled trials.* BMJ, 2011. **343**. http://doi.org/10.1136/bmj.d4002
257. Brown, B.B. and Werner, C.M. *Before and After a New Light Rail Stop: Resident Attitudes, Travel Behavior, and Obesity.* Journal of the American Planning Association, 2008. **75**(1): p. 5-12. http://doi.org/10.1080/01944360802458013
258. Chen, C. and Menifield, C.E. *An ecological study on means of transportation to work and obesity: Evidence from U.S. states.* Transport Policy, 2017. **59**: p. 174-180. http://dx.doi.org/10.1016/j.tranpol.2017.07.017
259. Hirsch, J.A., Moore, K.A., Barrientos-Gutierrez, T., Brines, S.J., Zagorski, M.A., Rodriguez, D.A., and Diez Roux, A.V. *Built environment change and change in BMI and waist circumference: Multi-ethnic Study of Atherosclerosis.* Obesity, 2014. **22**(11): p. 2450-7. http://dx.doi.org/10.1002/oby.20873

260. MacDonald, J.M., Stokes, R.J., Cohen, D.A., Kofner, A., and Ridgeway, G.K. *The effect of light rail transit on body mass index and physical activity.* Am J Prev Med, 2010. **39**(2): p. 105-12. http://doi.org/10.1016/j.amepre.2010.03.016
261. Flint, E., Webb, E., and Cummins, S. *Change in commute mode and body-mass index: prospective, longitudinal evidence from UK Biobank.* The Lancet Public Health, 2016. **1**(2): p. e46-e55. http://doi.org/10.1016/S2468-2667(16)30006-8
262. Martin, A., Panter, J., Suhrcke, M., and Ogilvie, D. *Impact of changes in mode of travel to work on changes in body mass index: evidence from the British Household Panel Survey.* J Epidemiol Community Health, 2015. **69**(8): p. 753-61. http://doi.org/10.1136/jech-2014-205211
263. Sun, B., Yan, H., and Zhang, T. *Built environmental impacts on individual mode choice and BMI: Evidence from China.* Journal of Transport Geography, 2017. **63**: p. 11-21. http://doi.org/10.1016/j.jtrangeo.2017.07.004
264. Gosse, M.A. *How accurate is self-reported BMI?* Nutrition Bulletin, 2014. **39**(1): p. 105-114. http://doi.org/10.1111/nbu.12075
265. World Health Organization *The ICD-10 classification of mental and behavioural disorders: Clinical descriptions and diagnostic guidelines.* . 1992. World Health Organisation: Geneva, Switzerland. Available from: https://www.who.int/classifications/icd/en/bluebook.pdf.
266. Higgins, J.P., Thompson, S.G., Deeks, J.J., and Altman, D.G. *Measuring inconsistency in meta-analyses.* BMJ, 2003. **327**(7414): p. 557-60. http://doi.org/10.1136/bmj.327.7414.557
267. Le Vine, S., Wu, C., and Polak, J. *A nationwide study of factors associated with household car ownership in China.* IATSS Research, 2018. **42**(3): p. 128-137. https://doi.org/10.1016/j.iatssr.2017.10.001
268. Panter, J., Griffin, S., Dalton, A.M., and Ogilvie, D. *Patterns and predictors of changes in active commuting over 12 months.* Prev Med, 2013. **57**(6): p. 776-84. http://doi.org/10.1016/j.ypmed.2013.07.020
269. Brenner, H. and Loomis, D. *Varied Forms of Bias Due to Nondifferential Error in Measuring Exposure.* Epidemiology, 1994. **5**(5): p. 510-517.
270. Ogden, C.L., Carroll, M.D., Kit, B.K., and Flegal, K.M. *Prevalence of childhood and adult obesity in the united states, 2011-2012.* JAMA, 2014. **311**(8): p. 806-814. http://doi.org/10.1001/jama.2014.732
271. Adams, M.A., Frank, L.D., Schipperijn, J., Smith, G., Chapman, J., Christiansen, L.B., . . . Sallis, J.F. *International variation in neighborhood walkability, transit, and recreation environments using geographic information systems: the IPEN adult study.* Int J Health Geogr, 2014. **13**: p. 43. http://doi.org/10.1186/1476-072x-13-43
272. Gower, T.L. *2011 Census Analysis - Method of Travel to Work in England and Wales Report*. 2013. Office for National Statisitcs. Available from: http://webarchive.nationalarchives.gov.uk/20160105160709/http://www.ons.gov.uk/ons/dcp171766_299766.pdf.
273. McKenzie, B. and Rapine, M. *Commuting in the United States: 2009, American Community Survey Reports, ACS-15.* 2009. U.S. Census Bureau: Washington D.C. Available from: https://www2.census.gov/library/publications/2011/acs/acs-15.pdf.
274. Barr, A., Bentley, R., Simpson, J.A., Scheurer, J., Owen, N., Dunstan, D., . . . Kavanagh, A. *Associations of public transport accessibility with walking, obesity, metabolic syndrome and diabetes.* Journal of Transport & Health, 2016. **3**(2): p. 141-153. http://dx.doi.org/10.1016/j.jth.2016.01.006
275. Hess, D.B. and Russell, J.K. *Influence of built environment and transportation access on body mass index of older adults: Survey results from Erie County, New York.* Transport Policy, 2012. **20**(0): p. 128-137. https://doi.org/10.1016/j.tranpol.2012.01.010
276. Murtagh, E.M., Nichols, L., Mohammed, M.A., Holder, R., Nevill, A.M., and Murphy, M.H. *The effect of walking on risk factors for cardiovascular disease: An updated systematic review*

and meta-analysis of randomised control trials. Preventive Medicine, 2015. **72**: p. 34-43. https://doi.org/10.1016/j.ypmed.2014.12.041

277. Foley, L., Panter, J., Heinen, E., Prins, R., and Ogilvie, D. *Changes in active commuting and changes in physical activity in adults: a cohort study.* International Journal of Behavioral Nutrition and Physical Activity, 2015. **12**(1): p. 161. http://doi.org/10.1186/s12966-015-0323-0
278. Saunders, L.E., Green, J.M., Petticrew, M.P., Steinbach, R., and Roberts, H. *What are the health benefits of active travel? A systematic review of trials and cohort studies.* PLoS One, 2013. **8**(8): p. e69912. http://doi.org/10.1371/journal.pone.0069912
279. NatCen Social Research and University College London, Department of Epidemiology and Public Health. *Health Survey for England, 2012 [data collection]*. 2014. UK Data Service. SN 7480. http://doi.org/10.5255/UKDA-SN-7480-1
280. Stephens, S.K., Cobiac, L.J., and Veerman, J.L. *Improving diet and physical activity to reduce population prevalence of overweight and obesity: an overview of current evidence.* Prev Med, 2014. **62**: p. 167-78. http://doi.org/10.1016/j.ypmed.2014.02.008
281. Moody, A. *Chapter 10 - Adult anthropometric measures, overweight and obesity*, in *Health Survey for England 2012. Volume 1: Health, social care and lifestyles.*, R. Craig and J. Mindell, Editors. 2012. Health and Social Care Information Centre: Leeds, UK. Available from: http://digital.nhs.uk/catalogue/PUB13218.
282. Masters, R.K., Reither, E.N., Powers, D.A., Yang, Y.C., Burger, A.E., and Link, B.G. *The Impact of Obesity on US Mortality Levels: The Importance of Age and Cohort Factors in Population Estimates.* American Journal of Public Health, 2013. **103**(10): p. 1895-1901. http://doi.org/10.2105/ajph.2013.301379
283. Bastien, M., Poirier, P., Lemieux, I., and Després, J.-P. *Overview of Epidemiology and Contribution of Obesity to Cardiovascular Disease.* Progress in Cardiovascular Diseases, 2014. **56**(4): p. 369-381. https://doi.org/10.1016/j.pcad.2013.10.016
284. Abdullah, A., Peeters, A., de Courten, M., and Stoelwinder, J. *The magnitude of association between overweight and obesity and the risk of diabetes: a meta-analysis of prospective cohort studies.* Diabetes Res Clin Pract, 2010. **89**(3): p. 309-19. http://doi.org/10.1016/j.diabres.2010.04.012
285. Langerudi, M.F., Abolfazl, M., and Sriraj, P.S. *Health and transportation: Small scale area association.* Journal of Transport & Health, 2015. **2**(2): p. 127-134. http://dx.doi.org/10.1016/j.jth.2014.08.005
286. Office for National Statistics. *Annual Survey of Hours and Earnings: 2017 provisional and 2016 revised results*. 2017 [Accessed on: 7 January, 2019]; Available from: https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/earningsandworkinghours/bulletins/annualsurveyofhoursandearnings/2017provisionaland2016revisedresults#regional-earnings.
287. data.gov.uk. *National public transport access nodes (NaPTAN)*. 2014 [Accessed on: 28 October, 2018]; Available from: https://data.gov.uk/dataset/ff93ffc1-6656-47d8-9155-85ea0b8f2251/national-public-transport-access-nodes-naptan.
288. Department for Transport. *National Travel Survey, 2002-2014: Special Licence Access. [data collection]. 4th Edition. UK Data Service. SN 7553*. 2016. http://doi.org/10.5255/UKDA-SN-7553-4
289. Department for Transport *National Travel Survey - Data Extract User Guide, 1995-2014*. 2015. Available from: https://doc.ukdataservice.ac.uk/doc/6108/mrdoc/pdf/6108_user_guide_1995-2014.pdf.
290. Mindell, J.S., Giampaoli, S., Goesswald, A., Kamtsiuris, P., Mann, C., Männistö, S., . . . on behalf of the H. E.S. Response Rate Group. *Sample selection, recruitment and participation rates in health examination surveys in Europe – experience from seven national surveys.* BMC

Medical Research Methodology, 2015. **15**(1): p. 78. http://dx.doi.org/10.1186/s12874-015-0072-4
291. StataCorp LP *Introduction*, in *Stata survey data reference manual - release 13*. 2013. Stata Press: College Station, Texas. Available from: https://www.stata.com/manuals13/svy.pdf.
292. Practical Examplars and Survey Analysis (PEAS). *Clustering and PSU's (Primary Sampling Units)*. 2006 [Accessed on: 2 October, 2018]; Available from: http://www.restore.ac.uk/PEAS/clustering.php#intro.
293. StataCorp LLC *Multiple-stage designs and with replacement sampling*, in *Stata survey data reference manual - release 15*. 2017. Stata Press: College Station, Texas. p. 189-190. Available from: https://www.stata.com/manuals/svy.pdf.
294. Office for National Statistics *Commuting to work, changes to travel to work areas: 2001 to 2011*. 2015. Available from: https://www.ons.gov.uk/employmentandlabourmarket/peopleinwork/employmentandemployeetypes/articles/commutingtoworkchangestotraveltoworkareas/2001to2011.
295. Office for National Statistics *Population estimates for the UK, England and Wales, Scotland and Northern Ireland: mid-2017*. 2018. Available from: https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/bulletins/annualmidyearpopulationestimates/mid2017.
296. Office for National Statistics *Standard Area Measurements (2016) for Administrative Areas in the United Kingdom*. 2018. Available from: https://ons.maps.arcgis.com/home/item.html?id=a79de233ad254a6d9f76298e666abb2b.
297. Office for National Statistics *Towns and cities analysis, England and Wales, March 2016*. 2016. Available from: https://www.ons.gov.uk/peoplepopulationandcommunity/housing/articles/townsandcitiesanalysisenglandandwalesmarch2016/2016-03-18.
298. INEQ-CITIES Project. *London: Socio-Economic Indicators*. 2012 [Accessed on: 7 January, 2019]; Available from: https://www.ucl.ac.uk/ineqcities/atlas/cities/london/london-sei.
299. Office for National Statistics. *2011 Census Analysis - Distance Travelled to Work*. 2014 [Accessed on: 16 February, 2017]; Available from: http://webarchive.nationalarchives.gov.uk/20160105160709/http://www.ons.gov.uk/ons/dcp171776_357812.pdf.
300. Department for Transport *Table NTS0409: Average number of trips (trip rates) by purpose and main mode: England, 2017*. 2018. Available from: https://www.gov.uk/government/statistical-data-sets/nts03-modal-comparisons.
301. Ng, S.W. and Popkin, B.M. *Time use and physical activity: a shift away from movement across the globe.* Obesity Reviews, 2012. **13**(8): p. 659-680. http://doi.org/10.1111/j.1467-789X.2011.00982.x
302. Straker, L. and Mathiassen, S.E. *Increased physical work loads in modern work – a necessity for better health and performance?* Ergonomics, 2009. **52**(10): p. 1215-1225. http://doi.org/10.1080/00140130903039101
303. Boone-Heinonen, J., Evenson, K.R., Taber, D.R., and Gordon-Larsen, P. *Walking for prevention of cardiovascular disease in men and women: a systematic review of observational studies.* Obes Rev, 2009. **10**(2): p. 204-17. http://doi.org/10.1111/j.1467-789X.2008.00533.x
304. Hu, G., Jousilahti, P., Borodulin, K., Barengo, N.C., Lakka, T.A., Nissinen, A., and Tuomilehto, J. *Occupational, commuting and leisure-time physical activity in relation to coronary heart disease among middle-aged Finnish men and women.* Atherosclerosis, 2007. **194**(2): p. 490-497. https://doi.org/10.1016/j.atherosclerosis.2006.08.051
305. Barengo, N.I.C., Hu, G., Lakka, T.A., Pekkarinen, H., Nissinen, A., and Tuomilehto, J. *Low physical activity as a predictor for total and cardiovascular disease mortality in middle-aged*

men and women in Finland. European Heart Journal, 2004. **25**(24): p. 2204-2211. http://doi.org/10.1016/j.ehj.2004.10.009

306. Williams, R. *Using the margins command to estimate and interpret adjusted predictions and marginal effects.* Stata Journal, 2012. **12**(2): p. 308-331. http://doi.org/10.1177/1536867X1201200209
307. Kirkwood, B. and Sterne, J. *Essential Medical Statistics*. 2nd ed. 2013. Oxford, UK: Blackwell Science.
308. Lepanjuuri, K., Cornick, P., Byron, C., Templeton, I., and Hurn, J. *Appendix T NTS short walks experiment findings in: National Travel Survey 2016 Technical report*. 2017. The Department for Transport. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/632910/nts-technical-report-2016.pdf.
309. Physical Activity Guidelines Advisory Committee *Physical Activity Guidelines for Americans*. 2008. Department of Health and Human Services: Washington D.C. Available from: http://health.gov/paguidelines/guidelines/.
310. Weggemans, R.M., Backx, F.J.G., Borghouts, L., Chinapaw, M., Hopman, M.T.E., Koster, A., . . . Committee Dutch Physical Activity, G. *The 2017 Dutch Physical Activity Guidelines.* Int J Behav Nutr Phys Act, 2018. **15**(1): p. 58. http://www.doi.org/10.1186/s12966-018-0661-9
311. Murphy, M.H., Broom, D.R., Gill, J.M.R., Gray, C.M., Jones, A., Steele, J., . . . van Zanten, J.V. *Expert Working Group Working Paper - Adults Working Group - UK physical activity guidelines: Draft review and recommendations for adults (aged 19-64 years)*. 2018. University of Bristol. Available from: http://www.bristol.ac.uk/media-library/sites/sps/documents/cmo/adults-technical-report.pdf.
312. Bull, F.C. and the Expert Working Groups, *Technical Report - Physical Activity Guidelines in the UK: Review and Recommendations*. 2010. School of Sport, Exercise and Health Sciences, Loughborough University. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/213743/dh_128255.pdf.
313. Physical Activity Guidelines Advisory Committee *Physical Activity Guidelines Advisory Committee Report*. 2008. U.S. Department of Health and Human Services: Washington DC.
314. Jefferis, B.J., Parsons, T.J., Sartini, C., Ash, S., Lennon, L.T., Wannamethee, S.G., . . . Whincup, P.H. *Does duration of physical activity bouts matter for adiposity and metabolic syndrome? A cross-sectional study of older British men.* International Journal of Behavioral Nutrition & Physical Activity, 2016. **13**(1): p. 36. http://doi.org/10.1186/s12966-016-0361-2
315. Hupin, D., Roche, F., Gremeaux, V., Chatard, J.C., Oriol, M., Gaspoz, J.M., . . . Edouard, P. *Even a low-dose of moderate-to-vigorous physical activity reduces mortality by 22% in adults aged >/=60 years: a systematic review and meta-analysis.* Br J Sports Med, 2015. **49**(19): p. 1262-7. 10.1136/bjsports-2014-094306
316. Granger, E., Di Nardo, F., Harrison, A., Patterson, L., Holmes, R., and Verma, A. *A systematic review of the relationship of physical activity and health status in adolescents.* European Journal of Public Health, 2017. **27**(suppl_2): p. 100-106. 10.1093/eurpub/ckw187
317. Daniels, R. and Mulley, C. *Explaining walking distance to public transport: The dominance of public transport supply.* Journal of Transport and Land Use, 2013. **6**(2): p. 5. http://doi.org/10.5198/jtlu.v6i2.308
318. O'Sullivan, S. and Morrall, J. *Walking Distances to and from Light-Rail Transit Stations.* Transportation Research Record, 1996. **1538**: p. 19-26. http://dx.doi.org/10.3141/1538-03
319. Ainsworth, B.E., Haskell, W.L., Herrmann, S.D., Meckes, N., R., B.J.D., Tudor-Locke, C., . . . Leon, A.S. *The Compendium of Physical Activities Tracking Guide*. [Accessed on: 16 February, 2017]; Available from: https://sites.google.com/site/compendiumofphysicalactivities/home.

320. Office for National Statistics. *England population mid-year estimate*. 2018 [Accessed on: 1 November, 2018]; Available from: https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/timeseries/enpop/pop.
321. Department for Transport *Table NTS0620: Take-up of concessionary travel schemes by gender: England, 1998/00 to 2017*. 2017. Available from: https://www.gov.uk/government/statistical-data-sets/nts06-age-gender-and-modal-breakdown.
322. Madood, T., Berthoud, R., Lakey, J., Nazroo, J., Smith, P., Virdee, S., and Beishon, S. *The Fourth National Survey of Ethnic Minorities: Ethnic Minorities in Britain - Diversity and Disadvantage*. 1997. Policy Studies Institute. Available from: http://www.psi.org.uk/pdf/Ethnic%20Minorities%20In%20Britain_large_file.pdf.
323. Piachaud, D., Nazroo, J., Jennie Popay, and Bennett, F. *Social Inclusion and Social Mobility: Task Group Report*. 2009. Institute of Health Inequality. Available from: http://www.instituteofhealthequity.org/resources-reports/social-inclusion-and-social-mobility-task-group-report.
324. El-Sayed, A.M., Scarborough, P., and Galea, S. *Ethnic inequalities in obesity among children and adults in the UK: a systematic review of the literature.* Obes Rev, 2011. **12**(5): p. e516-34. http://dx.doi.org/10.1111/j.1467-789X.2010.00829.x
325. Golob, T.T. and Meurs, H. *Biases in response over time in a seven-day travel diary.* Transportation, 1986. **13**(2): p. 163-181. https://doi.org/10.1007/bf00165546
326. Edwards, R.D. *Public transit, obesity, and medical costs: assessing the magnitudes.* Prev Med, 2008. **46**(1): p. 14-21. https://doi.org/10.1016/j.ypmed.2007.10.004
327. Bassett, D. *Measurement of daily walking distance-questionnaire versus pedometer.* Med Sci Sports Exerc, 2000. **32**(5): p. 1018-1023.
328. Dunlop, D.D., Semanik, P., Song, J., Manheim, L.M., Shih, V., and Chang, R.W. *Risk factors for functional decline in older adults with arthritis.* 2005. **52**(4): p. 1274-1282. 10.1002/art.20968
329. Clark, D.O. *The effect of walking on lower body disability among older blacks and whites.* American journal of public health, 1996. **86**(1): p. 57-61.
330. Long, J.S. and Freese, J. *Regression Models for Categorical Dependent Variables Using Stata*. 2nd ed. 2005. College Station, Texas: Stata Press. 349-414.
331. StataCorp LLC *zinb — Zero-inflated negative binomial regression*, in *Stata Base Reference Manual*. 2017. Stata Press: College Station, Texas. Available from: https://www.stata.com/manuals13/rzinb.pdf.
332. Nomis - official labour market statistics. *QS102EW - Population density*. 2013 [Accessed on: 5 November, 2018]; Available from: https://www.nomisweb.co.uk/census/2011/qs102ew.
333. Cooke, S. and Behrens, R. *Correlation or cause? The limitations of population density as an indicator for public transport viability in the context of a rapidly growing developing city.* Transportation Research Procedia, 2017. **25**: p. 3003-3016. https://doi.org/10.1016/j.trpro.2017.05.229
334. Kelly, E. *A ticket to Ride: Does Free Bus Travel Promote Active Ageing?* 2011. University College London & Institute for Fiscal Studies. London.: London, UK. Available from: https://www.economics.utoronto.ca/index.php/index/research/downloadSeminarPaper/4163.
335. Edwards, P., Steinbach, R., Green, J., Petticrew, M., Goodman, A., Jones, A., . . . Wilkinson, P. *Health impacts of free bus travel for young people: evaluation of a natural experiment in London.* J Epidemiol Community Health, 2013. **67**(8): p. 641-7. http://doi.org/10.1136/jech-2012-202156
336. Secretary's Advisory Committee on National Health Promotion and Disease Prevention Objectives for 2020 *Healthy People 2020: An Opportunity to Address Societal Determinants*

of Health in the U.S. 2010. Available from: https://www.healthypeople.gov/sites/default/files/SocietalDeterminantsHealth.pdf.
337. Wanner, M., Gotschi, T., Martin-Diener, E., Kahlmeier, S., and Martin, B.W. *Active transport, physical activity, and body weight in adults: a systematic review.* Am J Prev Med, 2012. **42**(5): p. 493-502. https://doi.org/10.1016/j.amepre.2012.01.030
338. Xu, H., Wen, L.M., and Rissel, C. *The Relationships Between Active Transport to Work or School and Cardiovascular Health or Body Weight: A Systematic Review.* Asia-Pacific Journal of Public Health, 2013. **25**(4): p. 298-315. http://doi.org/10.1177/1010539513482965
339. Hamer, M., Batty, G.D., Stamatakis, E., and Kivimaki, M. *Comparison of risk factors for fatal stroke and ischemic heart disease: A prospective follow up of the health survey for England.* Atherosclerosis, 2011. **219**(2): p. 807-810. https://doi.org/10.1016/j.atherosclerosis.2011.08.016
340. Collins, R. *What makes UK Biobank special?* Lancet, 2012. **379**(9822): p. 1173-4. https://doi.org/10.1016/s0140-6736(12)60404-8
341. Office for National Statistics. *What is a census*. [Accessed on: 6 November, 2018]; Available from: https://www.ons.gov.uk/census/2011census/howourcensusworks/aboutcensuses/whatisacensus.
342. Office for National Statistics *Counting the homeless in the United Kingdom census - Note by the Office for National Statistics*. 2009. United Nations - Economic and Social Reseach Council: Geneva, Switzerland. Available from: https://unstats.un.org/unsd/censuskb20/Attachments/2009GBR_ECE_Homeless-GUIDee7c9eb0c2b24e5d8ceb10cfff8423f4.pdf.
343. Lynch, K., Leib, S., Warren, J., Rogers, N., and Buxton, J. *Longitudinal Study 2001 - 2011: Completeness of census linkage*. 2015. Centre for Longitudinal Study Information and User Support. Available from: http://www.ucl.ac.uk/celsius/resources/ls-series.
344. Office for National Statistics. *Deaths of Longitudinal Study members*. [Accessed on: 12 November, 2018]; Available from: http://webarchive.nationalarchives.gov.uk/20130525174132/http://www.ons.gov.uk/ons/about-ons/who-we-are/services/longitudinal-study/data-quality/event-sampling-and-linkage/deaths-of-ls-members/index.html.
345. Soler, E.P. and Ruiz, V.C. *Epidemiology and risk factors of cerebral ischemia and ischemic heart diseases: similarities and differences.* Current cardiology reviews, 2010. **6**(3): p. 138-149. https://doi.org/10.2174/157340310791658785
346. Chaturvedi, N. *Ethnic differences in cardiovascular disease.* Heart (British Cardiac Society), 2003. **89**(6): p. 681-686. http://dx.doi.org/10.1136/heart.89.6.681
347. Gelband, H. *Cancer*. 2015. Washington DC, USA: World Bank.
348. Young, A.M., Hobbs, R.M.R.C.G.P., and Kerr, D.J. *ABC of colorectal cancer*. 2nd ed. 2011. Chichester, UK: Wiley-Blackwell.
349. Vermeulen, M.A., Slaets, L., Cardoso, F., Giordano, S.H., Tryfonidis, K., van Diest, P.J., . . . van Deurzen, C.H.M. *Pathological characterisation of male breast cancer: Results of the EORTC 10085/TBCRC/BIG/NABCG International Male Breast Cancer Program.* Eur J Cancer, 2017. **82**: p. 219-227. http://doi.org/10.1016/j.ejca.2017.01.034
350. Norman, P. and Boyle, P. *Are health inequalities between differently deprived areas evident at different ages? A longitudinal study of census records in England and Wales, 1991–2001.* Health & Place, 2014. **26**: p. 88-93. https://doi.org/10.1016/j.healthplace.2013.12.010
351. Boyle, P., Norman, P., and Rees, P. *Changing places. Do changes in the relative deprivation of areas influence limiting long-term illness and mortality among non-migrant people living in non-deprived households?* Social Science & Medicine, 2004. **58**(12): p. 2459-2471. https://doi.org/10.1016/j.socscimed.2003.09.011

352. Norman, P., Boyle, P., and Rees, P. *Selective migration, health and deprivation: a longitudinal analysis.* Social Science & Medicine, 2005. **60**(12): p. 2755-2771. https://doi.org/10.1016/j.socscimed.2004.11.008
353. Office for National Statistics *Statistical bulletin: 2011 Census: Population and Household Estimates for Small Areas in England and Wales, March 2011*. 2012. Available from: https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/bulletins/2011censuspopulationandhouseholdestimatesforsmallareasinenglandandwales/2012-11-23.
354. Allison, P.D. *Event history and survival analysis*. Second edition ed. Quantitative applications in the social sciences. 2014. London, UK: SAGE publications, Inc.
355. Kleinbaum, D.G. *Survival analysis : a self-learning text*. 2nd ed, ed. M. Klein. 2005. New York, New York: Springer.
356. Cleves, M.A., Gould, W.W., and Marchenko, Y.V. *An introduction to survival analysis using Stata*. 3rd ed. 2010. College Station, Texas: Stata Press.
357. Duke-Williams, O. *Long-Term Stability in Active Modes of Travel to Work*. in *International Conference on Transport & Health*. 2016. San Jose, California. Available from: https://icth.confex.com/icth/2016/meetingapp.cgi/Paper/1630.
358. Psaltopoulou, T., Hatzis, G., Papageorgiou, N., Androulakis, E., Briasoulis, A., and Tousoulis, D. *Socioeconomic status and risk factors for cardiovascular disease: Impact of dietary mediators.* Hellenic J Cardiol, 2017. **58**(1): p. 32-42. http://doi.org/10.1016/j.hjc.2017.01.022
359. Hajat, A., Hsia, C., and O'Neill, M.S.J.C.E.H.R. *Socioeconomic Disparities and Air Pollution Exposure: a Global Review.* 2015. **2**(4): p. 440-450. http://doi.org/10.1007/s40572-015-0069-5
360. Chaney, R.A., Sloan, C.D., Cooper, V.C., Robinson, D.R., Hendrickson, N.R., McCord, T.A., and Johnston, J.D. *Personal exposure to fine particulate air pollution while commuting: An examination of six transport modes on an urban arterial roadway.* PLOS ONE, 2017. **12**(11): p. e0188053. https://doi.org/10.1371/journal.pone.0188053
361. Apparicio, P., Gelb, J., Carrier, M., Mathieu, M.-È., and Kingham, S. *Exposure to noise and air pollution by mode of transportation during rush hours in Montreal.* Journal of Transport Geography, 2018. **70**: p. 182-192. https://doi.org/10.1016/j.jtrangeo.2018.06.007
362. Brock, A., Griffiths, C., and Rooney, C. *The effect of the introduction of ICD-10 on cancer mortality trends in England and Wales*, in *Health Statistics Quarterly*. 2004. p. 7-17. Available from: http://www.celsius.lshtm.ac.uk/modules/mortality/ICD10-1.pdf.
363. Office for National Statistics *Statistical bulletin: Cancer Registration Statistics, England: 2013*. 2015. Available from: https://www.ons.gov.uk/peoplepopulationandcommunity/healthandsocialcare/conditionsanddiseases/bulletins/cancerregistrationstatisticsengland/2015-07-10#data-quality.
364. Bauman, A.E., Grunseit, A.C., Rangul, V., and Heitmann, B.L. *Physical activity, obesity and mortality: does pattern of physical activity have stronger epidemiological associations?* BMC Public Health, 2017. **17**(1): p. 788. https://doi.org/10.1186/s12889-017-4806-6
365. Autenrieth, C.S., Baumert, J., Baumeister, S.E., Fischer, B., Peters, A., Doring, A., and Thorand, B. *Association between domains of physical activity and all-cause, cardiovascular and cancer mortality.* Eur J Epidemiol, 2011. **26**(2): p. 91-9. https://doi.org/10.1007/s10654-010-9517-6
366. Coleman, M.P. *Trends in breast cancer incidence, survival, and mortality.* The Lancet, 2000. **356**(9229): p. 590-591. http://doi.org/10.1016/S0140-6736(00)02593-9
367. Peto, R., Boreham, J., Clarke, M., Davies, C., and Beral, V. *UK and USA breast cancer deaths down 25% in year 2000 at ages 20–69 years.* The Lancet, 2000. **355**(9217): p. 1822. http://doi.org/10.1016/S0140-6736(00)02277-7

368. World Health Organization. *Premature NCD deaths*. 2018 [Accessed on: 18 December, 2018]; Available from: https://www.who.int/gho/ncd/mortality_morbidity/ncd_premature_text/en/.
369. Bartley, M., Sacker, A., Firth, D., and Fitzpatrick, R. *Understanding social variation in cardiovascular risk factors in women and men: the advantage of theoretically based measures.* Social Science & Medicine, 1999. **49**(6): p. 831-845. https://doi.org/10.1016/S0277-9536(99)00192-6
370. Beaudoin, J., Farzin, Y.H., and Lin Lawell, C.Y.C. *Public transit investment and sustainable transportation: A review of studies of transit's impact on traffic congestion and air quality.* Research in Transportation Economics, 2015. **52**: p. 15-22. https://doi.org/10.1016/j.retrec.2015.10.004
371. Nawrot, T.S., Perez, L., Künzli, N., Munters, E., and Nemery, B. *Public health importance of triggers of myocardial infarction: a comparative risk assessment.* The Lancet, 2011. **377**(9767): p. 732-740. https://doi.org/10.1016/S0140-6736(10)62296-9
372. Department for Business, Energy & Industrial Strategy, *2017 UK Greenhouse Gas Emissions* 2019. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/776083/2017_Final_emissions_statistics_one_page_summary.pdf.
373. U.S. Department of Transportation Federal Transit Administration *Public Transportation's Role in Responding to Climate Change*. 2010. Available from: https://www.transit.dot.gov/sites/fta.dot.gov/files/docs/PublicTransportationsRoleInRespondingToClimateChange2010.pdf.
374. Department for Transport *Table RAS53: Passenger casualty rates for different modes of travel*. 2016. Available from: https://www.gov.uk/government/statistical-data-sets/ras53-modal-comparisons.
375. Mueller, N., Rojas-Rueda, D., Cole-Hunter, T., de Nazelle, A., Dons, E., Gerike, R., . . . Nieuwenhuijsen, M. *Health impact assessment of active transportation: A systematic review.* Preventive Medicine, 2015. **76**: p. 103-114. https://doi.org/10.1016/j.ypmed.2015.04.010
376. Dzhambov, A. *Long-term noise exposure and the risk for type 2 diabetes: A meta-analysis.* 2015. **17**(74): p. 23-33. http://doi.org/10.4103/1463-1741.149571
377. Crosby, L. and Grundy, E. *Historical changes to the social distribution of active commuting in England and Wales 1971–2001, and its effect on health and mortality: LSHTM MSc in Demography and Health thesis, candidate no. 100750.* . 2011.
378. Seuring, T., Archangelidi, O., and Suhrcke, M. *The Economic Costs of Type 2 Diabetes: A Global Systematic Review.* PharmacoEconomics, 2015. **33**(8): p. 811-831. https://doi.org/10.1007/s40273-015-0268-9
379. Fry, A., Littlejohns, T.J., Sudlow, C., Doherty, N., Adamska, L., Sprosen, T., . . . Allen, N.E. *Comparison of Sociodemographic and Health-Related Characteristics of UK Biobank Participants With Those of the General Population.* American Journal of Epidemiology, 2017. **186**(9): p. 1026-1034. http://doi.org/10.1093/aje/kwx246
380. Coughlin, S.S. *Recall bias in epidemiologic studies.* Journal of Clinical Epidemiology, 1990. **43**(1): p. 87-91. https://doi.org/10.1016/0895-4356(90)90060-3
381. Fisher, R.J. *Social Desirability Bias and the Validity of Indirect Questioning.* Journal of Consumer Research, 1993. **20**(2): p. 303-315. http://doi.org/10.1086/209351
382. Holbrook, A.L., Anand, S., Johnson, T.P., Cho, Y.I.K., Shavitt, S., Chávez, N., and Weiner, S. *Response Heaping in Interviewer-Administered SurveysIs It Really a Form of Satisficing?* Public Opinion Quarterly, 2014. **78**(3): p. 591-633. http://doi.org/10.1093/poq/nfu017
383. Kelly, P., Doherty, A., Berry, E., Hodges, S., Batterham, A.M., and Foster, C. *Can we use digital life-log images to investigate active and sedentary travel behaviour? Results from a pilot study.* International Journal of Behavioral Nutrition and Physical Activity, 2011. **8**(1): p. 1-9. http://doi.org/10.1186/1479-5868-8-44

384. Prelipcean, A.C., Gidófalvi, G., and Susilo, Y.O. *MEILI: A travel diary collection, annotation and automation system.* Computers, Environment and Urban Systems, 2018. **70**: p. 24-34. https://doi.org/10.1016/j.compenvurbsys.2018.01.011
385. Procter, D.S., Page, A.S., Cooper, A.R., Nightingale, C.M., Ram, B., Rudnicka, A.R., . . . Owen, C.G. *An open-source tool to identify active travel from hip-worn accelerometer, GPS and GIS data.* International Journal of Behavioral Nutrition and Physical Activity, 2018. **15**(1): p. 91. http://doi.org/10.1186/s12966-018-0724-y
386. Department for Transport *Public consultation on the future design of the National Travel Survey*. 2012. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/230560/NTSconsultationSummaryofresponses.pdf.
387. Badstuber, N. *Orange Invades: All Change for London's New Overground Lines*. 2015 [Accessed on: 9 January, 2019]; Available from: https://www.londonreconnections.com/2015/orange-invades-all-change-for-londons-new-overground-lines/.
388. Baker, S. and White, P. *Impacts of free concessionary travel: Case study of an English rural region.* Transport Policy, 2010. **17**(1): p. 20-26. http://doi.org/doi:10.1016/j.tranpol.2009.09.002
389. Andrews, G.P. *Just the ticket? Exploring the contribution of free bus fares policy to quality of later life*, in *Faculty of Environment & Technology*. 2012. University of the West of England, Bristol.
390. Chapman, L. *Transport and climate change: a review.* Journal of Transport Geography, 2007. **15**(5): p. 354-367. https://doi.org/10.1016/j.jtrangeo.2006.11.008
391. Foley, L., Dumuid, D., Atkin, A.J., Olds, T., and Ogilvie, D. *Patterns of health behaviour associated with active travel: a compositional data analysis.* Int J Behav Nutr Phys Act, 2018. **15**(1): p. 26. 10.1186/s12966-018-0662-8
392. Imamura, F., Wijndaele, K., Brage, S., White, T., Ogilvie, D., Woodcock, J., . . . Griffin, S.J. *Driving status, travel modes and accelerometer-assessed physical activity in younger, middle-aged and older adults: a prospective study of 90 810 UK Biobank participants.* 2019. 10.1093/ije/dyz065
393. Sahlqvist, S., Goodman, A., Cooper, A.R., Ogilvie, D., and iConnect consortium *Change in active travel and changes in recreational and total physical activity in adults: longitudinal findings from the iConnect study.* Int J Behav Nutr Phys Act, 2013. **10**: p. 28. http://doi.org/10.1186/1479-5868-10-28
394. Conn, V.S., Hafdahl, A.R., and Mehr, D.R. *Interventions to increase physical activity among healthy adults: meta-analysis of outcomes.* Am J Public Health, 2011. **101**(4): p. 751-8. http://doi.org/10.2105/AJPH.2010.194381
395. Global Advocacy for Physical Activity (GAPA) the Advocacy Council of the International Society for Physical Activity and Health (ISPAH) *NCD Prevention: Investments that Work for Physical Activity - A complementary document to The Toronto Charter for Physical Activity: A Global Call to Action* 2011. Available from: http://www.paha.org.uk/Resource/toronto-charter-for-physical-activity-a-global-call-for-action.
396. Reis, R.S., Salvo, D., Ogilvie, D., Lambert, E.V., Goenka, S., and Brownson, R.C. *Scaling up physical activity interventions worldwide: stepping up to larger and smarter approaches to get people moving.* The Lancet, 2016. **388**(10051): p. 1337-1348. http://doi.org/10.1016/S0140-6736(16)30728-0
397. Ogilvie, D., Panter, J., Guell, C., Jones, A., Mackett, R., and Griffin, S. *Health impacts of the Cambridgeshire Guided Busway: a natural experimental study.* Public Health Res, 2016. **4**(1). http://doi.org/10.3310/phr04010
398. Brown, B.B., Werner, C.M., Tribby, C.P., Miller, H.J., and Smith, K.R. *Transit Use, Physical Activity, and Body Mass Index Changes: Objective Measures Associated With Complete Street*

Light-Rail Construction. American Journal of Public Health, 2015. **105**(7): p. 1468-1474. http://doi.org/10.2105/Ajph.2015.302561

399. Prospective Studies, C. *Body-mass index and cause-specific mortality in 900 000 adults: collaborative analyses of 57 prospective studies.* The Lancet, 2009. **373**(9669): p. 1083-1096. https://doi.org/10.1016/S0140-6736(09)60318-4
400. Ezzati, M., Obermeyer, Z., Tzoulaki, I., Mayosi, B.M., Elliott, P., and Leon, D.A. *Contributions of risk factors and medical care to cardiovascular mortality trends.* Nature reviews. Cardiology, 2015. **12**(9): p. 508-530. http://doi.org/10.1038/nrcardio.2015.82
401. Department for Transport *Table BUS0502b: Estimated net support paid by central and local government (at 2016/17 prices2) for local bus services and concessionary travel by area type: England, annual from 1996/97*. 2018. Available from: https://www.gov.uk/government/statistical-data-sets/bus05-subsidies-and-concessions.
402. Jacobsen, P.L., Racioppi, F., and Rutter, H. *Who owns the roads? How motorised traffic discourages walking and bicycling.* Injury Prevention, 2009. **15**(6): p. 369-373. http://doi.org/10.1136/ip.2009.022566
403. Martin, A., Suhrcke, M., and Ogilvie, D. *Financial incentives to promote active travel: an evidence review and economic framework.* Am J Prev Med, 2012. **43**(6): p. e45-57. http://doi.org/10.1016/j.amepre.2012.09.001
404. National Institute for Health and Care Excellence. *Physical Activity and the Environment*. 2018 [Accessed on: 23 March, 2018]; Available from: https://www.nice.org.uk/guidance/ng90/chapter/Recommendations.
405. Jensen, M. *Passion and heart in transport — a sociological analysis on transport behaviour.* Transport Policy, 1999. **6**(1): p. 19-33. https://doi.org/10.1016/S0967-070X(98)00029-8
406. Beirão, G. and Sarsfield Cabral, J.A. *Understanding attitudes towards public transport and private car: A qualitative study.* Transport Policy, 2007. **14**(6): p. 478-489. https://doi.org/10.1016/j.tranpol.2007.04.009
407. Giles-Corti, B., Vernez-Moudon, A., Reis, R., Turrell, G., Dannenberg, A.L., Badland, H., . . . Owen, N. *City planning and population health: a global challenge.* The Lancet, 2016. **388**(10062): p. 2912-2924. http://doi.org/10.1016/s0140-6736(16)30066-6
408. NICE *Physical activity: walking and cycling*. 2012. Available from: https://www.nice.org.uk/guidance/ph41/resources/physical-activity-walking-and-cycling-pdf-1996352901061.
409. Public Health England *Working Together to Promote Active Travel A briefing for local authorities*. 2016. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/523460/Working_Together_to_Promote_Active_Travel_A_briefing_for_local_authorities.pdf.
410. National Physical Activity Plan Alliance *U.S. National Physical Activity Plan*. 2016. Available from: http://physicalactivityplan.org/docs/2016NPAP_Finalforwebsite.pdf.
411. Sustrans and Transport Scotland *Active Travel Strategy Guidance*. 2014. Available from: https://www.sustrans.org.uk/sites/default/files/images/files/scotland/policy/Active-Travel-Strategy-Guidance.pdf.
412. World Health Organization *Action Plan for implementation of the European Strategy for the Prevention and Control of Noncommunicable Diseases 2012–2016* 2012: Copenhagan, Denmark. Available from: http://www.euro.who.int/__data/assets/pdf_file/0019/170155/e96638.pdf?ua=1.
413. Bamberg, S. *Is a residential relocation a good opportunity to change people's travel behavior? Results from a theory-driven intervention study.* Environ Behav, 2006. **38**. https://doi.org/10.1177/0013916505285091
414. Lachapelle, U. and Frank, L.D. *Transit and health: mode of transport, employer-sponsored public transit pass programs, and physical activity.* J Public Health Policy, 2009. **30 Suppl 1**: p. S73-94. http://doi.org/10.1057/jphp.2008.52

415. Carmichael, L., Racioppi, F., Calvert, T., and Sinnett, D. *Environment and health for European cities in the 21st century: making a difference*. 2017. World Health Organization: Copenhagen, Denmark. Available from: http://www.euro.who.int/__data/assets/pdf_file/0020/341615/bookletdef.pdf?ua=1.
416. World Health Organization Regional Office for Europe *Towards More Physical Activity in Cities*. 2017. World Health Organization: Copenhagen, Denmark. Available from: http://www.euro.who.int/__data/assets/pdf_file/0018/353043/2017_WHO_Report_FINAL_WEB.pdf?ua=1.
417. United Nations, D.o.E.a.S.A., Population Division, *World Urbanization Prospects: The 2014 Revision, Highlights* 2014. Available from: https://esa.un.org/unpd/wup/publications/files/wup2014-highlights.Pdf.
418. McGranahan, G. and Satterthwaite, D. *Urbanisation concepts and trends. IIED Working Paper.* 2014. IIED: London, UK. Available from: http://pubs.iied.org/pdfs/10709IIED.pdf.
419. Ewing, R., Meakins, G., Hamidi, S., and Nelson, A.C. *Relationship between urban sprawl and physical activity, obesity, and morbidity - update and refinement.* Health Place, 2014. **26**: p. 118-26. http://doi.org/10.1016/j.healthplace.2013.12.008
420. Sallis, J.F., Cerin, E., Conway, T.L., Adams, M.A., Frank, L.D., Pratt, M., . . . Owen, N. *Physical activity in relation to urban environments in 14 cities worldwide: a cross-sectional study.* Lancet, 2016. http://doi.org/10.1016/s0140-6736(15)01284-2
421. Rutter, H., Savona, N., Glonti, K., Bibby, J., Cummins, S., Finegood, D.T., . . . White, M. *The need for a complex systems model of evidence for public health.* The Lancet, 2017. **390**(10112): p. 2602-2604. http://doi.org/10.1016/S0140-6736(17)31267-9
422. Hill, J.O. *Can a small-changes approach help address the obesity epidemic? A report of the Joint Task Force of the American Society for Nutrition, Institute of Food Technologists, and International Food Information Council.* Am J Clin Nutr, 2009. **89**(2): p. 477-84. http://dx.doi.org/10.3945/ajcn.2008.26566
423. Nottingham City Council. *Workplace parking levy*. 2017 [Accessed on: 14 November, 2018]; Available from: https://www.nottinghamcity.gov.uk/transport-parking-and-streets/parking-and-permits/workplace-parking-levy/.
424. Dale, S., Frost, M., Ison, S., Quddus, M., and Warren, M.P. *Evaluating the impact of a workplace parking levy on local traffic congestion: The case of Nottingham UK.* Transport Policy, 2017. **59**: p. 153-164. https://doi.org/10.1016/j.tranpol.2017.07.015
425. Broaddus, A., Browne, M., and Allen, J. *Sustainable Freight.* Transportation Research Record: Journal of the Transportation Research Board, 2015. **2478**(1): p. 1-11. http://doi.org/10.3141/2478-01
426. Thomas, G.O., Walker, I., and Musselwhite, C. *Grounded Theory analysis of commuters discussing a workplace carbon-reduction target: Autonomy, satisfaction, and willingness to change behaviour in drivers, pedestrians, bicyclists, motorcyclists, and bus users.* Transportation Research Part F: Traffic Psychology and Behaviour, 2014. **26**: p. 72-81. https://doi.org/10.1016/j.trf.2014.06.009
427. Hiscock, R., Macintyre, S., Kearns, A., and Ellaway, A. *Means of transport and ontological security: Do cars provide psycho-social benefits to their users?* Transportation Research Part D: Transport and Environment, 2002. **7**(2): p. 119-135. https://doi.org/10.1016/S1361-9209(01)00015-3
428. The Health Foundation. *Health Equity in England: The Marmot Review 10 Years On* 2018 [Accessed on: 18 January, 2019]; Available from: https://www.health.org.uk/news-and-comment/news/health-equity-in-england-the-marmot-review-10-years-on.
429. Department for Regional Development. *Policy review of the Northern Ireland concessionary fares scheme*. 2007: Belfast, Northern Ireland. Available from: https://www.assemblyresearchmatters.org/wp-content/uploads/2017/12/Policy-review-of-concessionary-fares.pdf.

430. Bunt, K., Adams, L., and Leo, C. *Understanding the relationship between the barriers and triggers to claiming Pension Credit*. 2006. Department for Work and Pensions: Leeds, UK. Available from: https://webarchive.nationalarchives.gov.uk/20130314011506/http://research.dwp.gov.uk/asd/asd5/rports2005-2006/rrep336.pdf.
431. World Health Organization *Active Ageing - A policy Framework*. 2002: Geneva, Switzerland. Available from: http://apps.who.int/iris/bitstream/10665/67215/1/WHO_NMH_NPH_02.8.pdf.
432. Marottoli, R.A., de Leon, C.F.M., Glass, T.A., Williams, C.S., Cooney, J.L.M., and Berkman, L.F. *Consequences of Driving Cessation Decreased Out-of-Home Activity Levels.* The Journals of Gerontology: Series B, 2000. **55**(6): p. S334-S340. https://doi.org/10.1093/geronb/55.6.S334
433. Taylor, B.D. and Tripodes, S. *The effects of driving cessation on the elderly with dementia and their caregivers.* Accident Analysis & Prevention, 2001. **33**(4): p. 519-528. https://doi.org/10.1016/S0001-4575(00)00065-8
434. Marottoli, R., A., Leon, C.F.M., Glass, T., A., Williams, C.S., Cooney, L.M., Berkman, L.F., and Tinetti, M.E. *Driving Cessation and Increased Depressive Symptoms: Prospective Evidence from the New Haven EPESE.* Journal of the American Geriatrics Society, 1997. **45**(2): p. 202-206. https://doi.org/10.1111/j.1532-5415.1997.tb04508.x
435. Edwards, J.D., Lunsman, M., Perkins, M., Rebok, G.W., and Roth, D.L. *Driving Cessation and Health Trajectories in Older Adults.* The Journals of Gerontology: Series A, 2009. **64A**(12): p. 1290-1295. https://doi.org/10.1093/gerona/glp114
436. Ragland, D.R., Satariano, W.A., and MacLeod, K.E. *Driving Cessation and Increased Depressive Symptoms.* The Journals of Gerontology: Series A, 2005. **60**(3): p. 399-403. https://doi.org/10.1093/gerona/60.3.399
437. Musselwhite, C.B. and Shergold, I. *Examining the process of driving cessation in later life.* European Journal of Ageing, 2013. **10**(2): p. 89-100. https://doi.org/10.1007/s10433-012-0252-6
438. Janke, M.K. *Age related disabilities that may impair driving and their assessment*. 1994. Research and Development Section, Division of Program and Policy Administration, California Department of Motor Vehicles. Available from: https://www.dmv.ca.gov/portal/wcm/connect/3fbabce2-511b-4ec5-9185-d98f566d56f1/S6-156.pdf?MOD=AJPERES&CONVERT_TO=url&CACHEID=3fbabce2-511b-4ec5-9185-d98f566d56f1.
439. Fan, J.X., Brown, B.B., Hanson, H., Kowaleski-Jones, L., Smith, K.R., and Zick, C.D. *Moderate to Vigorous Physical Activity and Weight Outcomes: Does Every Minute Count?* 2013. **28**(1): p. 41-49. http://doi.org/10.4278/ajhp.120606-QUAL-286
440. Loprinzi, P.D. and Cardinal, B.J. *Association between Biologic Outcomes and Objectively Measured Physical Activity Accumulated in ≥ 10-Minute Bouts and < 10-Minute Bouts.* 2013. **27**(3): p. 143-151. http://doi.org/10.4278/ajhp.110916-QUAN-348
441. Office for National Statistics *Record proportion of people in employment are home workers*. 2014. Available from: https://webarchive.nationalarchives.gov.uk/20160105210705/http://www.ons.gov.uk/ons/rel/lmac/characteristics-of-home-workers/2014/sty-home-workers.html.
442. NUS. *NUS sucesses*. [Accessed on: 9 January, 2019]; Available from: https://www.nus.org.uk/en/who-we-are/nus-successes/.
443. NICE *Physical activity: encouraging activity in the general population: Draft for consultation*. 2019. Available from: https://www.nice.org.uk/guidance/GID-QS10073/documents/194.
444. NICE *Physical activity and the environment*. 2018. Available from: https://www.nice.org.uk/guidance/ng90/resources/physical-activity-and-the-environment-pdf-1837748441797.

445. Zhang, Y. and Zhang, Y. *Exploring the Relationship between Ridesharing and Public Transit Use in the United States.* International Journal of Environmental Research and Public Health, 2018. **15**(8): p. 1763. http://doi.org/10.3390/ijerph15081763

Appendix A – Table and Figures

Appendix Table A-1: Search terms used in Medline (Ovid)

Travel Term

1. exp railroads/

2. ((Public adj transport*) OR commute OR commuting OR bus OR buses OR coach OR coaches OR train OR trains OR rail OR subway* OR metro OR tram OR trams OR underground OR (public adj transit) OR (mass adj transit) OR (active adj travel) OR (active adj transport)).mp

3. 1 or2

Outcome Terms

Diabetes

4. exp Diabetes Mellitus, Type 2/

5. (MODY or NIDDM or T2D*).mp.

6. (non insulin* depend* or noninsulin* depend* or noninsulin?depend* or non insulin?depend*).mp.

7. ((typ? 2 or typ? II or typ?2 or typ?II) adj2 diabet*).mp.

8. ((late or adult* or matur* or slow or stabl*) adj2 onset adj2 diabet*).mp.

9. or/4-8

10. exp Diabetes Insipidus/

11. diabet* insipidus.mp.

12. 10 or 11 (combines the two diabetes insipidus)

13. 9 not 12 (search for diabetes terms, not the insipidus terms)

Dysglycaemia

14. exp glucose intolerance/ or exp insulin resistance/ or exp blood glucose

15. ((glucose adj intoleran*) or (insulin adj resistan*) or (blood adj glucose) or (plasma adj glucose) or (metabolic adj syndrome) or glyc?emia).mp.

16. 14 or 15

Dyslipidemias

17. Exp dyslipidemias/ or exp triglycerides/ or exp cholesterol/ or exp lipoproteins/

18. (dyslipid?aemia* or tr?glyceride* or cholesterol* or hdl* or ldl* or lipoprotein* hyperlipid* or hyperlip?emia* or hypercholesterol* or hypercholester?emia* or hyperlipoprotein?emia* or hypertrigl?cerid?emia*).mp.

19. 20 or 21

Obesity

20. exp Obesity/ or exp overweight/ or exp body mass index/ or exp waist-hip ratio/ or exp Waist-height ratio/ or exp Waist circumference/ or exp Adipose tissue/

21. (obesity or overweight or (body adj mass adj index) or bmi or (body adj fat) or adiposity or (body adj weight)).mp

22. 20 or 21

Hypertension

23. exp Hypertension/ or exp Blood Pressure/

24. exp Hypertension/ or exp Blood Pressure/

25. ((blood adj pressure) or hypertens$).mp.

26. 23 or 24 or 25

Cardiovascular disease

27. cardiovascular diseases/ or exp heart diseases/ or exp vascular diseases/

28. cerebrovascular disorders/ or exp brain ischemia/ or exp carotid artery diseases/ or exp dementia, vascular/ or exp intracranial arterial diseases/ or exp "intracranial embolism and thrombosis"/ or exp intracranial hemorrhages/ or exp stroke/

29. (coronar$ adj2 (disease$ or event$)).mp.

30. (cerebrovasc$ or cardiovasc$ or angina$ or stroke or strokes).mp.

31. (myocardi$ adj2 (infarct$ or ischaemi$ or ischemi$)).mp.

32. (morbid$ adj3 (heart$ or coronar$ or ischaem$ or ischem$ or myocard$)).mp.

33. (vascular$ adj2 (peripheral$ or disease$)).mp.

34. (heart$ adj2 (disease$ or attack$)).mp.

35. 27 or 28 or 29 or 30 or 31 or 32 or 33 or 34

Mortality

36. Exp mortality/

37. (mortal* or death or fatal).mp

38. 36 or 37

39. 13 or 16 or 19 or 22 or 26 or 35 or 38

40. 3 and 39

41. limit 40 to (English language and humans)

Appendix Table A-2: Additional characteristics of included studies

Author (Year)	***Exposure***	***Comparator***	***Outcome definition***	***Sample selection***
Brown et al. (2008)	Whether rode TRAX light-rail in the 2 weeks prior to being interviewed at time 1 and time 2. Ridership groups: almost half the respondents were continuing riders (45.8%, n = 22; six had no car access) who reported riding TRAX in the previous two weeks at both Time 1 and Time 2. New riders were the 22.9% (n = 11; two had no car access) who reported riding TRAX only at Time 2, when the new, closer stop opened. A final 31.3% (n = 15; one had no car access) were classified as non-riders. This last group, included two respondents who had ridden TRAX at Time 1 but not at Time 2. Three respondents did not answer the TRAX ridership question.	Direct comparison is not made but non-rider obesity is presented alongside obesity among new and continuing riders.	Objectively measured obesity. Portable stadiometers were used to measure height and scales to measure weight, and calculated body mass index (weight in kilograms divided by height in meters squared). Adult obesity is a BMI >30.	Study notifications were to all residential addresses within one half mile of the new stop, then phoned or visited door-to-door to recruit individual participants and obtain signed consents, as many residents did not own phones. Someone answered the door at 215 of the 496 potentially eligible addresses. From these, 102 participants were recruited, of whom 100 provided accelerometer data for the first measurement period (Time 1). During the second measurement period (Time 2): , 51 of the 100 residents who had complete data at Time 1 were recruited to complete the survey; 47 of these wore the accelerometer again. The remaining did not participate for a variety of reasons: 38 had moved, 1 was too ill, and 10 refused to participate again. Eligible participants included adult Spanish- or English-speakers in the study area who could walk a few blocks.

Brown et al. (2017)	Any bus, light rail, or commuter rail trips, inside or outside the neighborhood, were included as transit travel; the city's light rail system was extended to the neighborhood in 2013. Transit use across two years resulted in four groups: never, continuing, former, and new riders.	Former and never users of public transit.	Objective change in BMI. Heights and weights were measured using calibrated scales and portable stadiometers, with BMI defined as kg/m^2	Adults were recruited in an area up to 2 km north and south of the complete street renovation area. Eligible adults from randomly sampled blocks included those who could walk a few blocks, spoke English or Spanish, were not pregnant, anticipated remaining in the neighbourhood for a year, gave informed consent, and provided at least 3 days of ≥10 h/day accelerometer wear along with GPS data. This study includes 536 adults with valid data who remained in the study in 2012 and 2013. There were 939 participants at time 1. By time 2, 403 participants were lost to follow-up: 283 participants moved, 77 did not have valid GPS data, 34 refused, and 9 became ineligible
Chen et al. (2017)	% of state workers commuting by public transportation (U.S. DOT State Transportation Statistics). Lagged 1 year.		1) % state adults whose Body Mass Index (BMI) scores are above 30 (self-reported) 2) % state adults whose Body Mass Index (BMI) scores are between 25 and 29.9 (self-reported) From the CDC data	All 50 states of USA
Flint et al. (2016)	At both time points, participants were asked "what types of transport do you use to get to and from work?" and were able to select one or more mode This was used to derive two binary variables indicating whether the respondent had experienced one of the following transitions between baseline and repeat assessment: transition from car commuting to active or public transport commuting or transition from active or public transport to car commuting.	Stable car users in change from car analysis Stable AT or PT users in change from AT or PT analysis	Objective change in BMI between baseline and follow-up was the primary outcome for study objectives 2 and 3. Anthropometric measurements were taken by trained staff. Height and weight, was used to derive BMI via the standard formula. Change in BMI was calculated for each individual by subtracting BMI at baseline from BMI at follow-up.	UK Biobank recruited adults aged 40–69 years to 22 regional assessment centres, via National Health Service (NHS) patient registers. The sample of individuals who were present at both baseline and follow-up was refined to include only participants with complete data for all analytic variables at both time points.

Hirsch et al. (2014)	Euclidean distance between participants' addresses and the nearest bus route. Data were obtained from local planning departments, city governments, and regional entities. Neighborhoods were defined as a buffer around participants' addresses. Primary results are reported for 1-mile buffers. Sensitivity analyses were run with 1/2-mile buffers; results were similar and are not presented.	Those who had unchanged distance to bus stop	Objective BMI (kg/m^2) was calculated from weight measured to the nearest 0.045 kg (0.1 lbs), and height measured to the nearest 0.1 cm. Time-varying WC (cm) was measured at the umbilicus to the nearest 1 cm.	The sample included participants from the Multi-Ethnic Study of Atherosclerosis (MESA), a study of 6,814 US adults aged 45-84 years without clinical cardiovascular disease at baseline. Participants were recruited from six study sites (Baltimore, MD; Chicago, IL; Forsyth County, NC; Los Angeles, CA; New York, NY; and St. Paul, MN). After a baseline examination, participants attended four additional follow-up examinations occurring at approximately 1.5-2 year intervals. Of the 6,814 participants recruited in MESA, 6,027 were accurately geocoded, completed at least one subsequent exam, and were not missing information on obesity outcomes or built environment for the exams they attended. Of these, 521 were missing information on covariates (most missing information on total calories consumed), leaving a final sample size of 5,506.

MacDonald et al. (2010)	Light-rail use was assessed during the follow-up (exposure) [following light-rail construction] interview through a question that asked respondents if they used light-rail to commute to work on a daily basis. A dichotomous indicator was created representing whether or not the respondent used LRT to commute to work.	Full time workers who did not use the LRT after it opened.	BMI was calculated in kg/m^2 using self-reported height and weight. Respondents with a BMI≥30 were coded as obese.	Data were collected on a sample of individuals living in Charlotte, NC near the site of the South Corridor Light Rail (LRT) line. Subjects were selected through phone sampling based on census tract addresses within a 1-mile radius of the LRT line before it started operating. The survey sample frame included household telephone numbers in the GENESYS database. A single adult member of each household was selected based on the individual with the most recent birthday. Approximately 839 adult household members were recruited to participate in a baseline survey before the opening (pre) of the LRT (45% response rate). A total of 498 respondents (60%) were re-interviewed after the LRT system became operational (post). Only subjects who maintained continuous residency in the catchment area were re-interviewed. The main observable cause of attrition from the baseline sample was for renters who moved out of the catchment area. The overall response rate at follow-up was 87%, with only 3% (n=20) refusals.
Martin et al. (2015)	Switching commute mode: Participants reported their usual main mode of travel to work at t0, t1 and t2. For each wave, participants were categorised as using active modes of travel ('walking' or 'cycling'), public transport ('bus/coach', or rail: 'train' or 'underground/ metro'), or private motor transport ('car or van', 'car/ van passenger' or 'motorcycle'). Participants who reported using 'other' modes of travel were excluded from analysis.	Those who continued with the same private motor transport. Those who continued with the same PT mode	Change in self-reported BMI between t0 and t2. BMI in each wave was calculated by dividing self-reported weight by the square of self-reported height. Where height differed between waves, baseline height was used.	The BHPS is a nationally representative sample of households. Self-reported height and weight were in only two waves: t0, n=15 791 and t2, n=15 392. Data from these two waves and an intermediate wave t1, were used in these analyses. The sample used in the analyses (n=4056) was selected from the original BHPS sample at t0 (n=15 791). Participants eligible for inclusion in the analyses were those aged over 18 years who reported socio-economic and health status characteristics and who reported their usual main mode of travel to work, height and weight at t0 and t2.

Park et al. (2017)	Proximity to LRT line. Different buffer zones used, 3, 5 and 10 miles.	Residents of areas of Houston remote from the new LRT line. Outside the 10 miles buffer and a separate comparator was a Northwest region control area.	Mortality data were obtained from the Texas Department of State Health Services Center for Health Statistics for 2002–2005. Data were extracted concerning the number of daily deaths due to stroke [World Health Organization's International Classification of Diseases, 10th revision (ICD-10) code I60–I69].	Mortality data were obtained and decedents whose residences at the time of death were near the LRT—whose information was extracted using the 3-, 5-, and 10-mile buffers surrounding the LRT— were selected as the LRT exposure group. Two control groups, unaffected by the intervention, the first of which was those whose residences at the time of death consisting of 67 census tracts that are distant from the LRT. The second group was those whose residences at the time of death were outside the 10-mile buffer area falling within Harris County.
Sun et al (2017)	Self-reported distance to the nearest bus stop (km)	Those who had unchanged distance to bus stop	Change in self-reported BMI: calculated by the height and weight respondents reported	Twenty five provincial administrative units which account for 95% of the Chinese population (excluding Hong Kong, Macao and Taiwan) are covered by the survey sample of CFPS. Two periods of data which were gathered in 2010 and 2012, respectively are available. Since data on the built environment is from 2010, data for BMI and other variables come from 2012. This study focuses on the urban sub-sample. Deleting missing data, the sample for final analysis contains 8028 individuals distributed among 259 sub-districts of 127 districts and counties.
Webb et al. (2012)	Data on usage of public transport have been collected at all four waves of ELSA. In the 2002 and 2004 waves, the question 'Do you use public transport. a lot, quite often, sometimes, rarely, or never?' was used, and in the 2006 and 2008 waves, the question was 'How often do you use public transport. every day or nearly every day, two or three times a week, once a week, two or three times a month, once a month or less or, never'. To ensure comparability across waves, binary variables were created, classifying individuals into users	Non-PT users	Body mass index (BMI), waist circumference, and total and central obesity. The 2004 and 2008 waves of ELSA included nurse visits to participants, from which measured height, weight and waist circumference are available, allowing BMI to be calculated for these years. Obesity was defined in two ways: as a BMI ≥30 kg/m^2 and as a waist circumference of ≥102 cm among men and ≥88 cm among women.	Data were drawn from ELSA, a nationally representative sample of over 50s living in England. The sample originally drew >11 000 people aged 50 years and older from the 1998, 1999 and 2001 Health Surveys for England, who were surveyed in 2002, with three further waves of data collection in 2004, 2006 and 2008.

	and non-(never) users of public transport at each time point.			

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Appendix Table A-3: Newcastle-Ottawa quality assessment scale: cohort studies

Note: A study can be awarded a maximum of one star for each numbered item within the Selection and Outcome categories. A maximum of two stars can be given for Comparability

Selection

1) Representativeness of the exposed cohort
   a) truly representative of the average ____Person____ (describe) in the community ✱
      BHPS & ELSA
   b) somewhat representative of the average ___Person_____ in the community ✱
      MESA & UK Biobank
   c) selected group of users eg nurses, volunteers
      Includes: those selected based on proximity to public transport and a study using only urban residents.
   d) no description of the derivation of the cohort

2) Selection of the non exposed cohort
   a) drawn from the same community as the exposed cohort ✱
   b) drawn from a different source
   c) no description of the derivation of the non exposed cohort

3) Ascertainment of exposure
   a) secure record (eg surgical records) ✱
   b) structured interview ✱
   c) written self report
   d) no description

4) Demonstration that outcome of interest was not present at start of study
   a) yes ✱
   b) no

Comparability

1) Comparability of cohorts on the basis of the design or analysis
   a) study controls for _Physical activity__ (select the most important factor) ✱
   b) study controls for any additional factor ✱
   (This criteria could be modified to indicate specific control for a second important factor.)

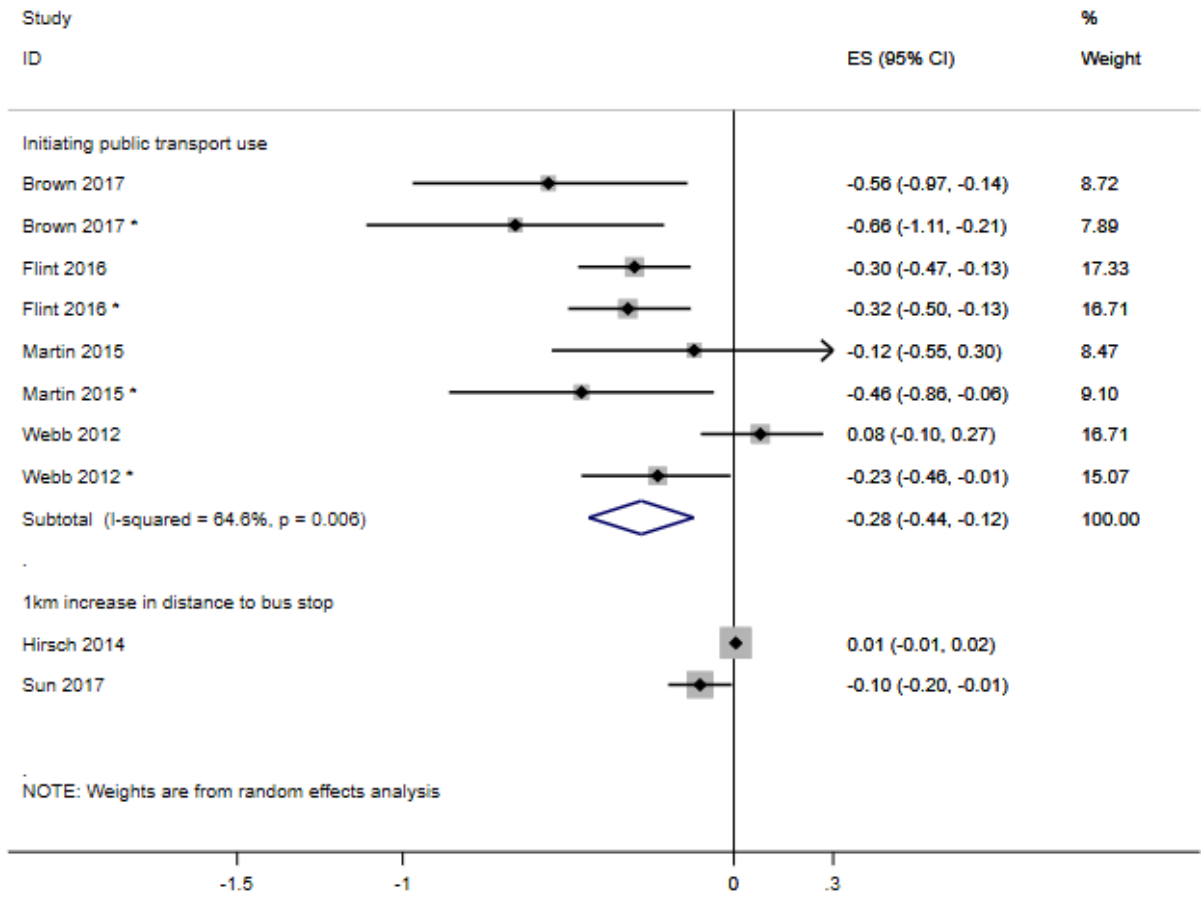
Outcome

1) Assessment of outcome
   a) independent blind assessment ✱
   b) record linkage ✱
   c) self report
   d) no description

2) Was follow-up long enough for outcomes to occur
   a) yes (select an adequate follow up period for outcome of interest) 6mo ✱
   b) no

3) Adequacy of follow up of cohorts
   a) complete follow up - all subjects accounted for ✱
   b) subjects lost to follow up unlikely to introduce bias - small number lost - > _50_ % follow up, or description provided of those lost) ✱
   c) follow up rate < 50% (select an adequate %) and no description of those lost
   d) no statement

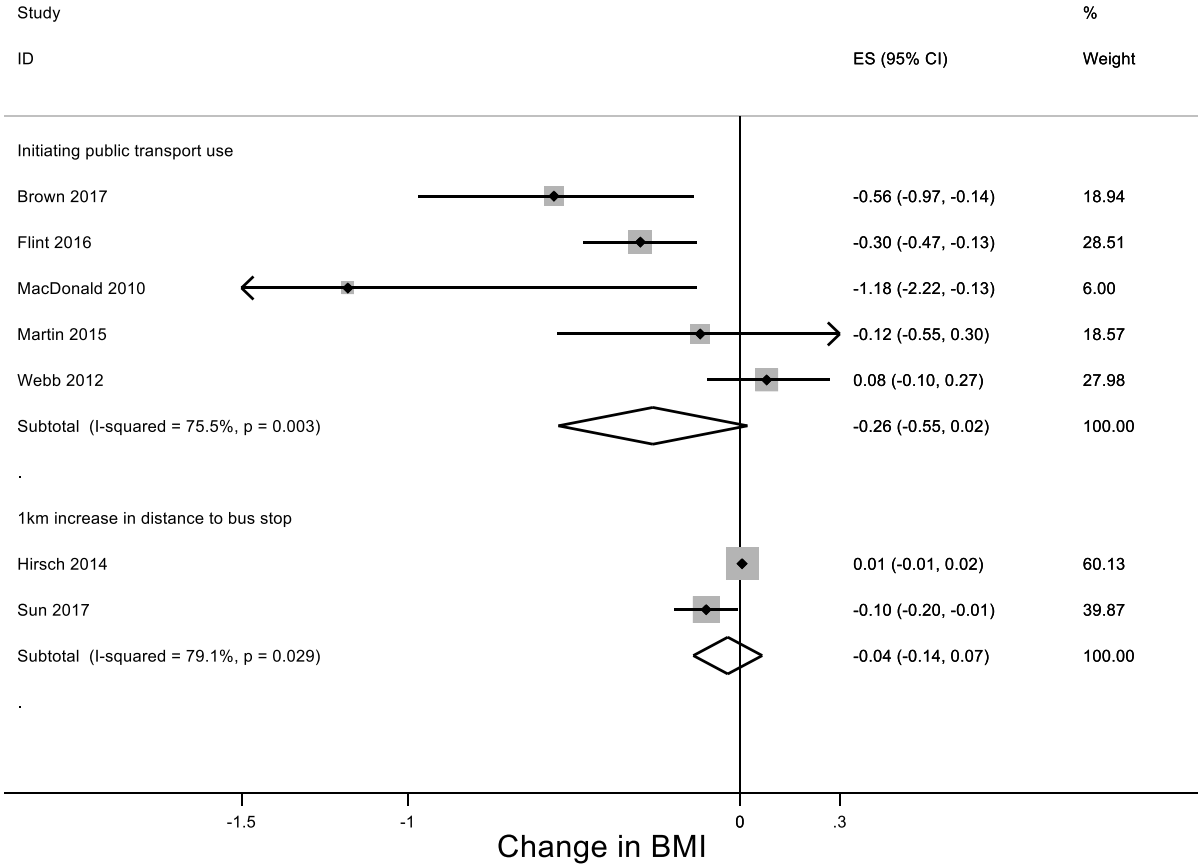
Appendix Figure A-1: Forest plot showing change in BMI (kg/m^2) associated with initiating public transport excluding MacDonald et al.



* changed from public to sedentary transport, sign reversed to allow comparison

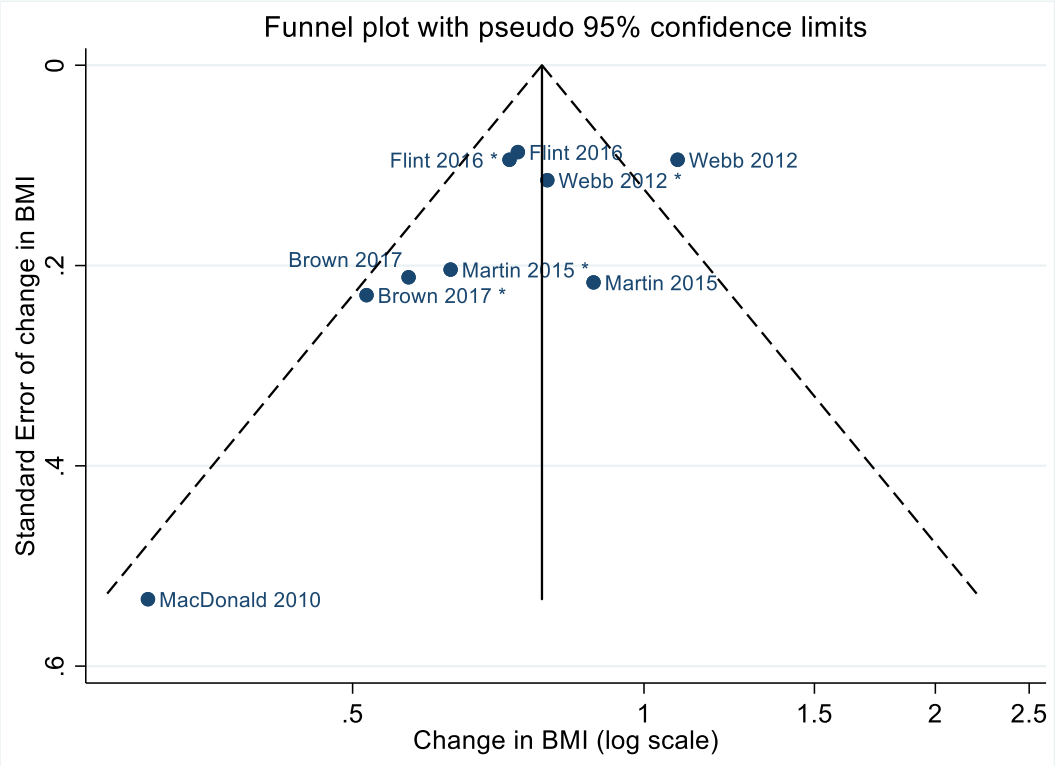
The square surrounding the point estimates represent the weighting given within each analysis

Appendix Figure A-2: Forest plot showing change in BMI (kg/m^2) associated with initiating public transport restricted to data from ititiators (exclusing ceasing public transport)



The square surrounding the point estimates represent the weighting given within each analysis

Appendix Figure A-3 :Funnel plot of studies of change in public transport use and change in BMI



* changed from public to sedentary transport

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Appendix Table A-4: A comparison of the characteristics of those public transport users who provided details of how they accessed public transport and were therefore included in the sample, and those that did not and were therefore excluded

	Data on how public transport was accessed				
	Provided		Not provided		p-value
All	3638		3820		
Public transport mode					
Bus	1723	47.4%	2884	75.5%	<0.001
Train	749	20.6%	348	9.1%	
Light-rail	350	9.6%	165	4.3%	
Multimode	816	22.4%	410	10.7%	
Gender					
Men	1704	46.8%	1599	41.9%	<0.001
Women	1934	53.2%	2221	58.1%	
Age					
17-25	758	20.8%	733	19.2%	<0.001
26-39	1051	28.9%	809	21.2%	
40-59	1027	28.2%	966	25.3%	
60+	802	22.0%	1312	34.3%	
Ethnicity					
White	2863	78.8%	3096	81.0%	0.085
South Asian	250	6.9%	220	5.8%	
Black	314	8.6%	300	7.9%	
Other	205	5.6%	204	5.3%	
Household NS-SEC - Social Class					
Managerial	2052	56.4%	1485	38.9%	<0.001
Intermediate	608	16.7%	734	19.2%	
Routine	741	20.4%	1314	34.4%	
Unclassified	237	6.5%	287	7.5%	
Household Income					
£50,000 and over	1251	34.4%	802	21.0%	<0.001
£25,000 to £49,999	1008	27.7%	1008	26.4%	
Less than £25,000	1379	37.9%	2010	52.6%	
Housing Tenure					
Owns	2170	59.7%	2078	54.6%	<0.001
Rents	1462	40.3%	1731	45.4%	
Household Car Access					
Access to a car	2139	58.8%	1984	51.9%	
No car access	1499	41.2%	1836	48.1%	
Population density*					
0-9.99	625	17.2%	690	18.1%	<0.001
10-24.99	629	17.3%	852	22.3%	
25-39.99	611	16.8%	816	21.4%	
40-74.99	1008	27.7%	976	25.5%	
75+	765	21.0%	486	12.7%	
Conurbation Type					
London	1763	48.5%	1136	29.7%	<0.001
Metropolitan & >250k	803	22.1%	1324	34.7%	
50k-250k	499	13.7%	619	16.2%	
<50k	573	15.8%	741	19.4%	

NSSEC – National Statistics Socio-economic Classification

Appendix Table A-5: Ethnicity categorisation in the different years of National Travel Survey (NTS) data collection

2006-10	N.	2011-14	N.	Total 2006-14
White		**White**		
English/Welsh/Scottish/Northern Irish/British	13,506	White British	17,742	
Irish	191	Other white background	366	
Gypsy or Irish Traveller	1			
Any Other White background	224			
	13,922		**18,108**	**32,030**
South Asian		**South Asian**		
Indian	202	Indian	157	
Pakistani	63	Pakistani	71	
Bangladeshi	38	Bangladeshi	26	
	303		**254**	**557**
Black		**Black**		
African	53	African	41	
Caribbean	119	Caribbean	122	
Any other Black/African/Caribbean background	14	Any other black background	8	
White and Black African	4	White and Black African	5	
White and Black Caribbean	13	White and Black Caribbean	24	
	203		**200**	**403**
Other		**Other**		
Chinese	22			
Arab	16	Chinese	28	
Any other Asian background	62	Any other Asian background	65	
White and Asian	8	White and Asian	13	
Any other Mixed/multiple ethnic background	9	Any other mixed background	9	
Any other ethnic group	63	Any other	59	
	180		**174**	**354**
TOTAL	14,608		18,736	**33,344**

Appendix Table A-6: Ethnicity categorisation in the different years of National Travel Survey (NTS) data collection for sensitivity analysis

2006-10	N	2011-14	N	Total 2006-14
White		**White**		
English/Welsh/Scottish/Northern Irish/British	13,506			
Irish	191			
Gypsy or Irish Traveller	1	White British	17,742	
Any Other White background	224	Other white background	366	
	13,922		**18,108**	**32,030**
Indian		**Indian**		
Indian	202	Indian	157	
	202		**157**	**359**
Pakistani/ Bangladeshi		**Pakistani/ Bangladeshi**		
Pakistani	63	Pakistani	71	
Bangladeshi	38	Bangladeshi	26	
	101		**97**	**198**
Black Caribbean		**Black Caribbean**		
Caribbean	119	Caribbean	122	
White and Black Caribbean	13	White and Black Caribbean	24	
	132		**146**	**278**
Other		**Other**		
African	53			
Any other Black/African/Caribbean background	14	African	41	
White and Black African	4	Any other black background	8	
Chinese	22	White and Black African	5	
Arab	16	Chinese	28	
Any other Asian background	62	Any other Asian background	65	
White and Asian	8	White and Asian	13	
Any other Mixed/multiple ethnic background	9	Any other mixed background	9	
Any other ethnic group	63	Any other	59	
	251		**228**	**479**
TOTAL	14,608		18,736	**33,344**

Appendix Table A-7: Characteristics of NTS participants from 2006 to 2014 who were eligible for a free older peoples bus pass (aged 60-90) by ethnic group

	White	Indian	Pakistani & Bangladeshi	Black Caribbean	Other	p-value[a]	All
	N. / %	N. / %	N. / %	N. / %	N. / %		N. / %
All participants	32 030	359	198	278	354		33 219
Mean age	71.0	69.2	69.5	71.2	69.0		71.0
Age group							
60-64	25.1%	29.5%	24.7%	20.1%	33.3%	p<0.001	25.2%
65-69	24.3%	27.6%	31.8%	28.4%	27.1%		24.4%
70-75	19.3%	20.3%	23.2%	20.5%	20.1%		19.3%
75+	31.4%	22.6%	20.2%	30.9%	19.5%		31.1%
Sex							
Men	47.1%	50.7%	54.5%	46.0%	49.2%	p=0.138	47.2%
Women	52.9%	49.3%	45.5%	54.0%	50.8%		52.8%
Geographical area							
London	11.5%	56.5%	40.4%	52.5%	59.3%	p<0.001	13.0%
>250k people (except London)	25.7%	26.7%	37.9%	34.2%	13.3%		25.7%
50k-250k people	19.8%	8.4%	15.2%	7.6%	16.9%		19.5%
<50k people	43.0%	8.4%	6.6%	5.8%	10.5%		41.7%
Area population density persons/hectare							
0-14.99	50.4%	12.8%	11.6%	9.4%	16.7%	p<0.001	49.1%
15-29.99	23.8%	15.6%	9.1%	18.7%	19.8%		23.6%
30-49.99	17.7%	34.3%	32.8%	24.1%	23.4%		18.1%
50-74.99	5.3%	22.8%	22.2%	19.8%	18.6%		5.9%
75+	2.8%	14.5%	24.2%	28.1%	21.5%		3.5%
Car access							
Have car access	77.3%	86.4%	69.7%	50.7%	67.2%	p<0.001	77.0%
No car access	22.7%	13.6%	30.3%	49.3%	32.8%		23.0%
NS Socio-Economic Classification (current or last job)							
Managerial	44.4%	51.3%	35.4%	29.1%	51.1%	p<0.001	44.3%
Intermediate	22.7%	20.1%	20.2%	19.4%	20.6%		22.6%
Routine and manual	30.5%	24.5%	35.9%	46.8%	22.9%		30.5%
Not classified	2.5%	4.2%	8.6%	4.7%	5.4%		2.6%
Housing tenure							
Owns	82.1%	91.9%	79.3%	71.2%	70.3%	p<0.001	82.0%
Rents	17.9%	8.1%	20.7%	28.8%	29.7%		18.0%
Walking frequency							
Walk < 3x /week	65.9%	66.0%	74.1%	73.7%	64.4%	p=0.009	66.0%
Walk ≥ 3x /week	34.1%	34.0%	25.9%	26.3%	35.6%		34.0%
Bus pass possession							
No bus pass	24.7%	20.6%	36.9%	14.0%	21.5%	p<0.001	24.6%
Have a bus pass	75.3%	79.4%	63.1%	86.0%	78.5%		75.4%

NTS=National Travel Survey NS-National Statistics [a]- Pearson's Chi-squared test
Ethnicity categorisation: White (White British and other White), Indian (Indian), Pakistani & Bangladeshi (Pakistani and Bangladeshi), Black Caribbean (Black Caribbean, mixed White & Black Caribbean) and other (other mixed, other Asian and any other).

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Appendix Table A-8: Travel patterns of those participants who did any active travel

	White	Indian	Pakistani & Bangladeshi	Black Caribbean	Other	p-value
N who did any active travel (%)	17 619 (55%)	192 (53%)	92 (46%)	198 (71%)	226 (64%)	p<0.001[a]
% with a bus pass	85%	91%	72%	93%	88%	p<0.001[a]
Bus travel*	2 (0-4)	3 (0-7)	2 (0-5)	4 (1-8)	4 (0-8)	p<0.001 [b]
Active travel as part of a bus journey*	1 (0-4)	2 (0-8)	2 (0-7)	4 (1-9)	4 (0-8)	p<0.001 [b]
Total active travel*	8 (4-16)	10 (4-17)	14 (6-20)	8 (4-15)	11 (4-18)	p<0.001 [b]
% of total active stages which are part of a bus journey	29%	51%	33%	59%	46%	p<0.001[a]

Ethnicity categorisation: White (White British and other White), Indian (Indian), Pakistani & Bangladeshi (Pakistani and Bangladeshi), Black Caribbean (Black Caribbean, mixed White & Black Caribbean) and other (other mixed, other Asian and any other).

*median number of stages/week (interquartile range)

[a] - Pearson's Chi-squared test, [b] - Kruskal-Wallis test

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Appendix Table A-9: Association between holding a bus pass and travel mode by ethnic group

	White	Indian	Pakistani & Bangladeshi	Black Caribbean	Other
	AOR/IRR (95% CI)	**AOR/IRR (95% CI)**	**AOR/IRR (95% CI)**	**AOR/IRR (95% CI)**	**AOR/IRR (95% CI)**
Bus Stages					
AOR of doing any travel					
No Bus Pass	0.09*** (0.08, 0.10)	0.10*** (0.04, 0.25)	0.07*** (0.03, 0.17)	0.18*** (0.08, 0.39)	0.17*** (0.08, 0.36)
With Bus Pass	1.00 (ref)	1.07 (0.78, 1.47)	0.54* (0.32, 0.92)	1.26 (0.88, 1.80)	1.16 (0.84, 1.62)
IRR of amount of travel					
No Bus Pass	0.85** (0.76, 0.96)	1.00 (0.43, 2.32)	1.11 (0.59, 2.06)	0.92 (0.35, 2.41)	1.00 (0.57, 1.76)
With Bus Pass	1.00 (ref)	1.40*** (1.19, 1.66)	1.15 (0.92, 1.43)	1.10 (0.96, 1.26)	1.29*** (1.12, 1.48)
Active stages as part of a bus trip					
AOR of doing any travel					
No Bus Pass	0.08*** (0.07, 0.09)	0.07*** (0.03, 0.20)	0.06*** (0.02, 0.16)	0.17*** (0.07, 0.39)	0.17*** (0.07, 0.39)
With Bus Pass	1.00 (ref)	1.16 (0.81, 1.66)	0.55 (0.30, 1.02)	1.29 (0.83, 2.01)	1.43 (0.94, 2.17)
IRR of amount of travel					
No Bus Pass	0.74*** (0.62, 0.87)	2.08* (1.03, 4.19)	0.96 (0.44, 2.10)	0.65 (0.26, 1.65)	0.68 (0.38, 1.23)
With Bus Pass	1.00 (ref)	1.42* (1.07, 1.88)	1.32 (0.87, 2.00)	1.14 (0.92, 1.42)	1.17 (0.93, 1.48)
Total Active Stages					
AOR of doing any travel					
No Bus Pass	0.29*** (0.27, 0.31)	0.12*** (0.07, 0.23)	0.21*** (0.12, 0.37)	0.20*** (0.10, 0.41)	0.24*** (0.14, 0.41)
With Bus Pass	1.00 (ref)	0.72 (0.52, 1.00)	0.40*** (0.26, 0.63)	1.36 (0.88, 2.09)	1.04 (0.73, 1.50)
IRR of amount of travel					
No Bus Pass	0.94** (0.90, 0.98)	1.08 (0.72, 1.62)	1.22 (0.84, 1.76)	0.42** (0.24, 0.76)	0.85 (0.59, 1.23)
With Bus Pass	1.00 (ref)	0.97 (0.80, 1.17)	1.16 (0.91, 1.47)	0.83* (0.69, 0.98)	0.95 (0.82, 1.09)
Walking ≥ 3 times/week					
AOR					
No Bus Pass	0.69*** (0.65, 0.73)	0.52* (0.29, 0.93)	0.40** (0.22, 0.74)	0.36* (0.14, 0.88)	0.43** (0.24, 0.79)
With Bus Pass	1.00 (ref)	0.92 (0.70, 1.21)	0.74 (0.48, 1.14)	0.75 (0.55, 1.04)	1.04 (0.78, 1.39)

Ethnicity categorisation: White (White British and other White), Indian (Indian), Pakistani & Bangladeshi (Pakistani and Bangladeshi), Black Caribbean (Black Caribbean, mixed White & Black Caribbean) and other (other mixed, other Asian and any other).

Covariates: Age (continuous), sex, size of area of residence, access to a car, National Statistics Socio-Economic Classification (NS-SEC), population density of household's post code sector (continuous) and home ownership.

AOR-adjusted odds ratio, IRR-incident rate ratio.
*** p<0.001, ** p<0.01, * p<0.05

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Appendix Table A-10: Association between holding a bus pass and travel mode by ethnic group with additional adjustment for the year of data collection

	White	South Asian	Black	Other
	AOR/IRR (95% CI)	**AOR/IRR (95% CI)**	**AOR/IRR (95% CI)**	**AOR/IRR (95% CI)**
Bus Stages				
AOR of doing any travel				
No Bus Pass	0.09*** (0.08, 0.10)	0.08*** (0.04, 0.16)	0.31*** (0.17, 0.57)	0.17*** (0.08, 0.36)
With Bus Pass	1.00 (ref)	0.87 (0.66, 1.13)	1.33 (0.99, 1.80)	1.14 (0.82, 1.59)
IRR of amount of travel				
No Bus Pass	0.85** (0.75, 0.95)	1.07 (0.65, 1.75)	0.96 (0.55, 1.69)	1.00 (0.57, 1.76)
With Bus Pass	1.00 (ref)	1.33*** (1.16, 1.54)	1.22** (1.08, 1.37)	1.29*** (1.13, 1.48)
Active stages as part of a bus trip				
AOR of doing any travel				
No Bus Pass	0.08*** (0.07, 0.09)	0.06*** (0.03, 0.13)	0.33** (0.17, 0.64)	0.17*** (0.07, 0.39)
With Bus Pass	1.00 (ref)	0.94 (0.69, 1.28)	1.39 (0.96, 2.02)	1.39 (0.91, 2.12)
IRR of amount of travel				
No Bus Pass	0.74*** (0.62, 0.88)	1.41 (0.77, 2.61)	0.59 (0.33, 1.05)	0.69 (0.38, 1.23)
With Bus Pass	1.00 (ref)	1.38** (1.09, 1.75)	1.16 (0.97, 1.37)	1.18 (0.93, 1.49)
Total Active Stages				
AOR of doing any travel				
No Bus Pass	0.28*** (0.26, 0.30)	0.16*** (0.11, 0.25)	0.38** (0.21, 0.68)	0.23*** (0.13, 0.41)
With Bus Pass	1.00 (ref)	0.61*** (0.47, 0.80)	1.22 (0.85, 1.75)	1.06 (0.75, 1.52)
IRR of amount of travel				
No Bus Pass	0.93** (0.89, 0.97)	1.17 (0.88, 1.56)	0.46*** (0.30, 0.71)	0.86 (0.59, 1.24)
With Bus Pass	1.00 (ref)	1.03 (0.89, 1.20)	0.88 (0.76, 1.02)	0.96 (0.83, 1.10)
Walking ≥ 3 times/week				
AOR				
No Bus Pass	0.70*** (0.65, 0.75)	0.46*** (0.30, 0.70)	0.42* (0.22, 0.82)	0.44** (0.24, 0.80)
With Bus Pass	1.00 (ref)	0.85 (0.67, 1.07)	0.81 (0.62, 1.06)	1.03 (0.77, 1.37)

Ethnicity categorisation: White (White British and other White), South Asian (Indian, Pakistani and Bangladeshi), Black (Black African, mixed White & Black African, Black Caribbean, mixed White & Black Caribbean and other Black) and other (other mixed, other Asian and any other).
Covariates: Age (continuous), sex, size of area of residence, access to a car, National Statistics Socio-Economic Classification (NS-SEC), population density of household's post code sector (continuous), home ownership and year of data collection.
AOR-adjusted odds ratio, IRR-incident rate ratio.
*** p<0.001, ** p<0.01, * p<0.05

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Appendix Table A-11: Age and Sex adjusted association between holding a bus pass and travel mode by ethnic group

	White		South Asian		Black		Other	
	AOR/IRR (95% CI)		AOR/IRR (95% CI)		AOR/IRR (95% CI)		AOR/IRR (95% CI)	
Bus Stages								
AOR of doing any travel								
No Bus Pass	0.08***	(0.07, 0.09)	0.12***	(0.06, 0.22)	0.55	(0.28, 1.11)	0.25***	(0.12, 0.53)
With Bus Pass	1.00	(ref)	1.16	(0.91, 1.47)	2.79***	(2.09, 3.73)	1.89***	(1.40, 2.55)
IRR of amount of travel								
No Bus Pass	0.88*	(0.78, 1.00)	1.36	(0.73, 2.53)	1.41	(0.80, 2.49)	1.23	(0.79, 1.92)
With Bus Pass	1.00	(ref)	1.33***	(1.15, 1.53)	1.55***	(1.39, 1.74)	1.50***	(1.31, 1.72)
Active stages as part of a bus trip								
AOR of doing any travel								
No Bus Pass	0.07***	(0.06, 0.08)	0.10***	(0.05, 0.20)	0.66	(0.29, 1.54)	0.27**	(0.12, 0.60)
With Bus Pass	1.00	(ref)	1.21	(0.92, 1.58)	3.23***	(2.22, 4.70)	2.19***	(1.50, 3.19)
IRR of amount of travel								
No Bus Pass	0.79**	(0.67, 0.94)	2.04	(0.96, 4.33)	0.82	(0.44, 1.52)	0.82	(0.51, 1.31)
With Bus Pass	1.00	(ref)	1.47**	(1.15, 1.87)	1.54***	(1.28, 1.85)	1.49***	(1.19, 1.87)
Total Active Stages								
AOR of doing any travel								
No Bus Pass	0.26***	(0.24, 0.28)	0.21***	(0.14, 0.31)	0.55	(0.30, 1.02)	0.29***	(0.17, 0.50)
With Bus Pass	1.00	(ref)	0.75*	(0.59, 0.95)	2.10***	(1.46, 3.02)	1.54*	(1.09, 2.17)
IRR of amount of travel								
No Bus Pass	0.86***	(0.83, 0.90)	1.26	(0.96, 1.65)	0.62*	(0.40, 0.95)	0.95	(0.69, 1.30)
With Bus Pass	1.00	(ref)	1.14	(0.98, 1.32)	1.14	(0.99, 1.33)	1.23**	(1.07, 1.42)
Walking ≥ 3 times/week								
AOR								
No Bus Pass	0.71***	(0.67, 0.76)	0.47***	(0.31, 0.71)	0.42**	(0.22, 0.79)	0.42**	(0.23, 0.76)
With Bus Pass	1.00	(ref)	0.87	(0.70, 1.09)	0.79	(0.61, 1.02)	1.07	(0.81, 1.43)

Ethnicity categorisation: White (White British and other White), South Asian (Indian, Pakistani and Bangladeshi), Black (Black African, mixed White & Black African, Black Caribbean, mixed White & Black Caribbean and other Black) and other (other mixed, other Asian and any other).

Covariates: Age (continuous), sex.

AOR-adjusted odds ratio, IRR-incident rate ratio.

*** p<0.001, ** p<0.01, * p<0.05

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Appendix Table A-12: Walking and cycling stages only were considered active. Association between holding a bus pass and travel mode by ethnic group

	White	South Asian	Black	Other
	AOR/IRR (95% CI)	**AOR/IRR (95% CI)**	**AOR/IRR (95% CI)**	**AOR/IRR (95% CI)**
Bus Stages				
AOR of doing any travel				
No Bus Pass	0.09*** (0.08, 0.10)	0.08*** (0.04, 0.16)	0.31*** (0.17, 0.57)	0.17*** (0.08, 0.36)
With Bus Pass	1.00 (ref)	0.87 (0.66, 1.13)	1.33 (0.99, 1.80)	1.14 (0.82, 1.58)
IRR of amount of travel				
No Bus Pass	0.85** (0.76, 0.96)	1.06 (0.65, 1.75)	0.96 (0.55, 1.68)	1.00 (0.57, 1.76)
With Bus Pass	1.00 (ref)	1.33*** (1.16, 1.53)	1.22** (1.08, 1.37)	1.29*** (1.12, 1.48)
Active stages as part of a bus trip				
AOR of doing any travel				
No Bus Pass		Model would not converge.		
With Bus Pass				
IRR of amount of travel				
No Bus Pass				
With Bus Pass				
Total Active Stages				
AOR of doing any travel				
No Bus Pass	0.49*** (0.46, 0.52)	0.32*** (0.21, 0.49)	0.26*** (0.13, 0.49)	0.29*** (0.15, 0.56)
With Bus Pass	1.00 (ref)	0.54*** (0.42, 0.70)	0.68** (0.52, 0.89)	0.74 (0.55, 1.01)
IRR of amount of travel				
No Bus Pass	0.95* (0.91, 1.00)	1.30 (0.97, 1.73)	0.49* (0.27, 0.88)	0.94 (0.58, 1.53)
With Bus Pass	1.00 (ref)	1.08 (0.91, 1.28)	0.80* (0.66, 0.98)	0.93 (0.79, 1.09)
Walking ≥ 3 times/week				
AOR				
No Bus Pass	0.69*** (0.65, 0.73)	0.46*** (0.30, 0.70)	0.43* (0.22, 0.82)	0.43** (0.24, 0.79)
With Bus Pass	1.00 (ref)	0.86 (0.68, 1.08)	0.82 (0.63, 1.07)	1.04 (0.78, 1.39)

Ethnicity categorisation: White (White British and other White), South Asian (Indian, Pakistani and Bangladeshi), Black (Black African, mixed White & Black African, Black Caribbean, mixed White & Black Caribbean and other Black) and other (other mixed, other Asian and any other).
Covariates: Age (continuous), sex, size of area of residence, access to a car, National Statistics Socio-Economic Classification (NS-SEC), population density of household's post code sector (continuous) and home ownership.
AOR-adjusted odds ratio, IRR-incident rate ratio.
*** p<0.001, ** p<0.01, * p<0.05

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Appendix Table A-13: Excluding London residents. Association between holding a bus pass and travel mode by ethnic group

	White	South Asian	Black	Other
	AOR/IRR (95% CI)	**AOR/IRR (95% CI)**	**AOR/IRR (95% CI)**	**AOR/IRR (95% CI)**
Bus Stages				
AOR of doing any travel				
No Bus Pass	0.09*** (0.08, 0.11)	0.04*** (0.01, 0.10)	0.23** (0.09, 0.58)	0.14*** (0.05, 0.41)
With Bus Pass	1.00 (ref)	1.12 (0.75, 1.67)	1.39 (0.87, 2.21)	1.10 (0.64, 1.90)
IRR of amount of travel				
No Bus Pass	0.84* (0.73, 0.96)	0.77 (0.49, 1.20)	1.62 (0.77, 3.41)	1.83* (1.11, 3.04)
With Bus Pass	1.00 (ref)	1.43*** (1.19, 1.73)	1.39** (1.13, 1.70)	1.16 (0.90, 1.49)
Active stages as part of a bus trip				
AOR of doing any travel				
No Bus Pass	0.08*** (0.06, 0.09)	0.02*** (0.01, 0.08)	0.22** (0.08, 0.59)	0.14*** (0.04, 0.44)
With Bus Pass	1.00 (ref)	1.30 (0.82, 2.08)	1.36 (0.78, 2.37)	1.43 (0.72, 2.85)
IRR of amount of travel				
No Bus Pass	0.75** (0.62, 0.90)	0.62** (0.46, 0.83)	1.13 (0.53, 2.44)	1.21 (0.69, 2.11)
With Bus Pass	1.00 (ref)	1.29 (0.98, 1.72)	1.29* (1.01, 1.66)	0.91 (0.67, 1.24)
Total Active Stages				
AOR of doing any travel				
No Bus Pass	0.30*** (0.28, 0.32)	0.19*** (0.12, 0.32)	0.22*** (0.09, 0.53)	0.19*** (0.09, 0.39)
With Bus Pass	1.00 (ref)	0.80 (0.54, 1.19)	1.42 (0.83, 2.44)	1.02 (0.58, 1.80)
IRR of amount of travel				
No Bus Pass	0.95* (0.90, 0.99)	1.29 (0.93, 1.78)	0.76 (0.40, 1.44)	1.22 (0.79, 1.89)
With Bus Pass	1.00 (ref)	1.06 (0.88, 1.28)	0.92 (0.74, 1.15)	0.73* (0.58, 0.94)
Walking ≥ 3 times/week				
AOR				
No Bus Pass	0.68*** (0.64, 0.73)	0.42*** (0.25, 0.70)	0.37 (0.13, 1.06)	0.38* (0.17, 0.88)
With Bus Pass	1.00 (ref)	1.01 (0.72, 1.41)	0.81 (0.54, 1.20)	1.03 (0.66, 1.63)

Ethnicity categorisation: White (White British and other White), South Asian (Indian, Pakistani and Bangladeshi), Black (Black African, mixed White & Black African, Black Caribbean, mixed White & Black Caribbean and other Black) and other (other mixed, other Asian and any other).
Covariates: Age (continuous), sex, size of area of residence, access to a car, National Statistics Socio-Economic Classification (NS-SEC), population density of household's post code sector (continuous) and home ownership.
AOR-adjusted odds ratio, IRR-incident rate ratio.
*** p<0.001, ** p<0.01, * p<0.05

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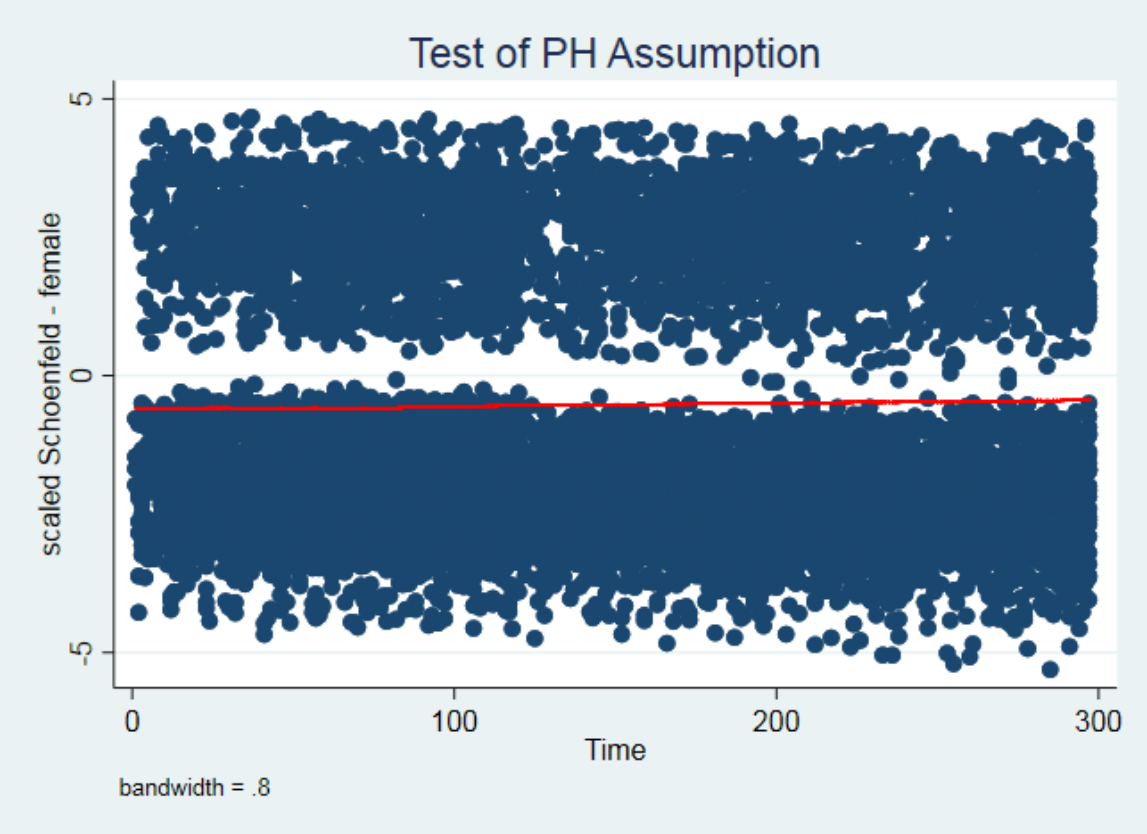
Appendix Table A-14: Commute mode options available in the census forms from 1991 to 2011

	1991	2001	2001
Sedentary	Motor cycle, scooter, moped Driving a car or van Passenger in a car or van	Motor cycle, scooter or moped Driving a car or van Passenger in a car or van Taxi	Motorcycle, scooter or moped Driving a car or van Passenger in a car or van Taxi
Public Transport	Bus, minibus or coach (public or private) Underground, tube, metro British Rail train	Bus, minibus or coach Underground, metro, light-rail, tram Train	Bus, minibus or coach Underground, metro, light rail, tram Train
Cycle	Pedal cycle	Bicycle	Bicycle
Walk	On foot	On foot	On foot
Excluded		Work mainly at or from home	Work mainly at or from home
	Other please specify	Other	Other

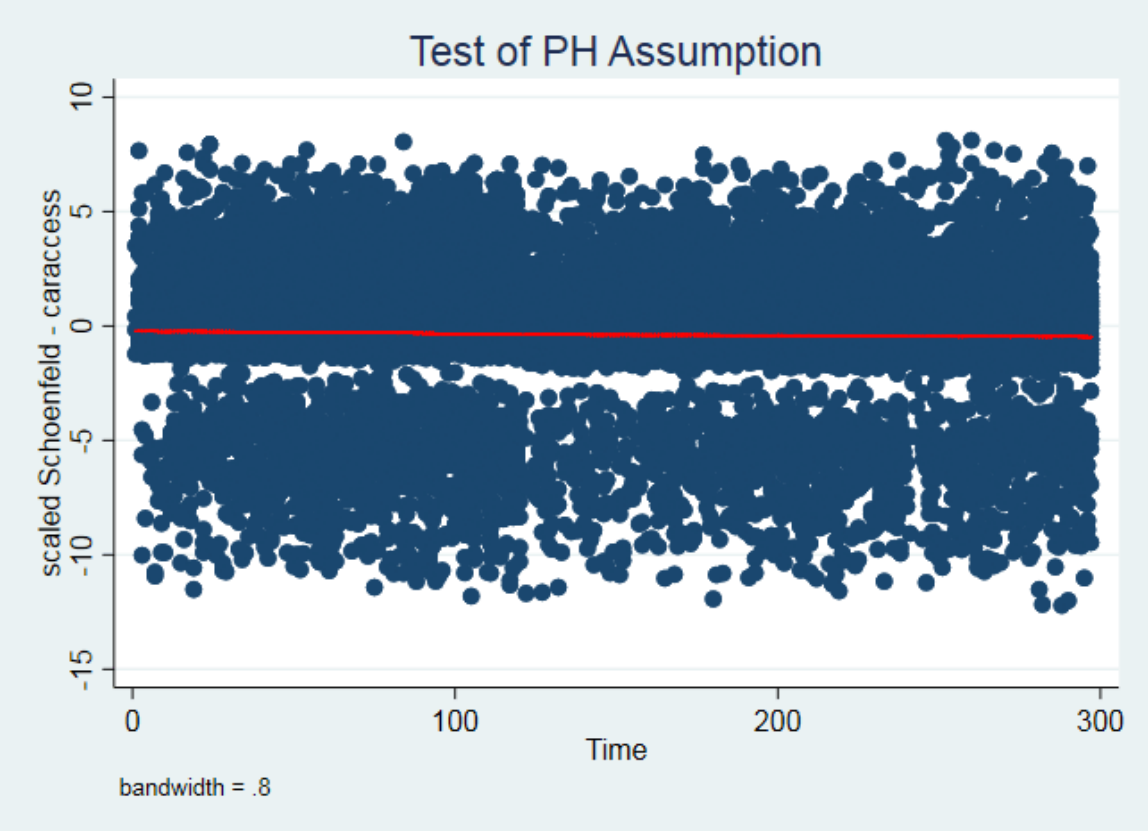
Appendix Table A-15: Median distance used to categorise long and short distance commuters in ONS-LS 2001 and 2011

Mode	Median Distance 2001 (km)	Median Distance 2011 (km)
Sedentary	6.6	6.6
Public Transport	7.3	7.9
Bus	*4.3*	*4.5*
Rail	*14.0*	*13.3*
Walk	0.7	0.8
Cycle	2.2	2.9

Appendix Figure A-4: Plot of Schoenfeld residual against time for sex in ONS-Longitudinal Study 1991-2016



Appendix Figure A-5: Plot of Schoenfeld residual against time for car access in ONS-Longitudinal Study 1991-2016



Appendix Table A-16: Characteristics of participants by commute mode with disaggregated public transport modes from ONS Longitudinal Study 1991-2016

	Sedentary (%)	Bus (%)	Rail (%)	Walk (%)	Cycle (%)	Total
All	65.6%	10.3%	8.5%	12.4%	3.2%	391,894
Age						
16-29	62.0%	12.2%	10.3%	12.3%	3.2%	148,257
30-44	68.1%	8.3%	8.7%	11.6%	3.3%	141,857
45-59	67.8%	10.2%	5.4%	13.5%	3.0%	85,319
60+	64.3%	11.3%	5.5%	15.7%	3.2%	16,461
Sex						
Men	71.6%	6.9%	8.7%	8.7%	4.0%	208,119
Women	58.7%	14.1%	8.3%	16.6%	2.3%	183,775
Housing tenure						
Homeowner	71.4%	8.2%	7.5%	10.0%	2.9%	286,795
Non-homeowner	49.8%	16.0%	11.0%	18.9%	4.2%	105,099
Marital status						
Unmarried	60.0%	12.8%	10.7%	13.0%	3.4%	189,152
Married	70.8%	8.0%	6.4%	11.9%	3.0%	202,742
Ethnicity						
White	67.3%	9.4%	7.4%	12.4%	3.4%	351,378
Minority ethnicity	50.9%	17.7%	17.5%	12.5%	1.4%	40,516
Education						
No degree	66.3%	11.2%	5.9%	13.4%	3.2%	311,601
Has a degree	62.7%	6.9%	18.4%	8.6%	3.4%	80,293
Car access						
No car access	17.9%	30.0%	17.5%	27.9%	6.7%	53,488
Has access to a car	73.1%	7.2%	7.1%	10.0%	2.7%	338,406
Population density						
0-2,000 persons/km^2	75.3%	6.5%	4.1%	11.2%	2.9%	171,229
2,000+ persons/km^2	58.0%	13.2%	11.9%	13.4%	3.5%	220,665
NSSEC – social class						
Higher	70.6%	5.9%	13.7%	7.3%	2.6%	128,788
Intermediate	69.4%	10.0%	9.1%	9.6%	1.9%	97,664
Routine/Manual	59.4%	13.9%	4.1%	18.1%	4.5%	165,442
Carstairs quintile						
Least deprived	78.2%	4.3%	6.6%	8.0%	2.8%	76,324
2	72.4%	6.6%	7.3%	10.6%	3.1%	78,956
3	66.8%	9.0%	7.6%	13.2%	3.5%	79,892
4	61.1%	12.7%	8.1%	14.6%	3.4%	80,597
Most deprived	49.3%	19.0%	12.9%	15.6%	3.2%	76,125
Long term illness						
No illness	65.7%	10.1%	8.6%	12.3%	3.2%	374,198
Has an illness	63.2%	13.5%	6.3%	14.3%	2.7%	17,696
Entered study						
1991	68.4%	9.9%	6.3%	12.0%	3.3%	207,809
2001	65.3%	10.3%	8.9%	12.4%	3.1%	87,817
2011	59.7%	11.1%	12.7%	13.3%	3.1%	96,268

NSSEC – National Statistics socio-economic classification
Source ONS Longitudinal Study

Appendix Table A-17: Baseline characteristics of participants by commute mode and distance from ONS Longitudinal Study 1991-2016

	Sede-ntary (%)	Bus Short (%)	Bus Long (%)	Rail Short (%)	Rail Long (%)	Walk Short (%)	Walk Long (%)	Cycle Short (%)	Cycle Long (%)	Total
All	68.0%	4.4%	4.3%	4.6%	4.0%	6.0%	5.7%	1.6%	1.5%	304,125
Age										
16-29	60.9%	5.6%	6.3%	6.4%	4.7%	5.4%	7.4%	1.6%	1.6%	88,148
30-44	69.7%	3.7%	3.5%	4.9%	4.5%	5.5%	4.9%	1.6%	1.8%	115,454
45-59	72.6%	4.2%	3.4%	2.5%	2.9%	6.7%	5.0%	1.5%	1.2%	84,246
60+	70.7%	4.9%	3.7%	2.8%	2.0%	8.1%	5.3%	1.4%	1.1%	16,277
Sex										
Men	72.3%	2.6%	3.5%	4.4%	4.5%	3.8%	4.6%	2.0%	2.3%	155,097
Women	63.5%	6.3%	5.2%	4.7%	3.4%	8.2%	6.8%	1.1%	0.7%	149,028
Housing tenure										
Homeowner	73.8%	3.3%	3.4%	3.4%	4.1%	4.9%	4.4%	1.4%	1.4%	226,611
Non-homeowner	51.3%	7.9%	6.9%	7.9%	3.5%	9.2%	9.4%	2.1%	2.0%	77,514
Marital status										
Unmarried	62.1%	5.6%	5.7%	6.2%	4.3%	5.8%	7.0%	1.6%	1.8%	150,434
Married	73.8%	3.3%	3.0%	3.0%	3.7%	6.1%	4.4%	1.5%	1.3%	153,691
Ethnicity										
White	69.9%	3.9%	3.9%	3.8%	3.6%	5.9%	5.7%	1.7%	1.6%	270,192
Minority ethnicity	52.8%	8.5%	7.7%	10.4%	6.8%	6.5%	5.8%	0.8%	0.7%	33,933
Education										
No degree	68.8%	4.9%	4.7%	2.9%	2.7%	6.8%	6.1%	1.7%	1.4%	217,113
Has a degree	66.1%	3.1%	3.2%	8.8%	7.2%	3.9%	4.5%	1.3%	2.0%	87,012
Car access										
No car access	17.4%	15.5%	13.0%	14.2%	5.1%	12.5%	15.4%	3.4%	3.6%	35,501
Has access to a car	74.7%	3.0%	3.2%	3.3%	3.8%	5.1%	4.4%	1.3%	1.3%	268,624
Population density										
0-2,000 persons/km^2	77.9%	2.0%	3.1%	1.0%	3.2%	6.1%	4.1%	1.4%	1.1%	134,318
2,000+ persons/km^2	60.2%	6.3%	5.2%	7.4%	4.6%	5.9%	6.9%	1.7%	1.9%	169,807
NSSEC – social class										
Higher	71.3%	2.6%	2.9%	6.8%	6.6%	3.4%	3.7%	1.1%	1.5%	118,907
Intermediate	69.8%	4.5%	4.7%	4.6%	4.0%	5.8%	4.8%	0.9%	0.9%	63,071
Routine/Manual	63.9%	6.2%	5.4%	2.4%	1.3%	8.5%	8.0%	2.3%	1.9%	122,147
Carstairs quintile										
Least deprived	80.2%	1.3%	2.2%	1.2%	5.3%	4.5%	2.9%	1.2%	1.2%	60,851
2	74.2%	2.4%	3.2%	2.7%	4.6%	5.5%	4.3%	1.6%	1.5%	62,957
3	68.9%	3.7%	3.8%	3.9%	3.7%	6.6%	6.1%	1.8%	1.5%	62,713
4	64.1%	5.9%	5.1%	5.0%	2.9%	6.5%	7.2%	1.7%	1.7%	61,234
Most deprived	51.3%	9.4%	7.6%	10.5%	3.2%	6.8%	8.0%	1.4%	1.8%	56,370
Long term illness										
No illness	68.0%	4.3%	4.2%	4.7%	4.1%	5.9%	5.6%	1.6%	1.6%	283,559
Has an illness	67.7%	5.7%	5.2%	3.1%	2.5%	7.1%	6.0%	1.4%	1.2%	20,566
Entered study										
1991	71.3%	4.0%	3.9%	3.5%	3.5%	5.6%	5.0%	1.6%	1.5%	196,850
2001	62.0%	5.2%	5.0%	6.4%	4.8%	6.6%	6.9%	1.5%	1.6%	107,275

NSSEC – National Statistics socio-economic classification Source ONS Longitudinal Study

Appendix Table A-18: Cox regression analyses of commute mode and mortality outcomes using the ONS Longitudinal Study 1991-2016

	All-cause mortality			CVD mortality		
Commute mode	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**
Sedentary	1.00	1.00	1.00	1.00	1.00	1.00
Public Transport	0.98 (0.94, 1.03)	0.97 (0.92, 1.02)	0.96 (0.91, 1.02)	0.91 (0.82, 1.01)	0.91 (0.81, 1.02)	0.90 (0.80, 1.01)
Walk	1.17 (1.11, 1.23)	1.04 (0.98, 1.09)	0.98 (0.92, 1.03)	1.02 (0.91, 1.14)	0.99 (0.88, 1.11)	0.91 (0.81, 1.03)
Cycle	0.94 (0.85, 1.04)	0.83 (0.75, 0.92)	0.80 (0.73, 0.89)	0.93 (0.75, 1.14)	0.80 (0.65, 0.99)	0.76 (0.61, 0.94)
Age at baseline	1.09 (1.09, 1.09)	1.12 (1.11, 1.13)	1.12 (1.11, 1.13)	1.11 (1.11, 1.11)	1.20 (1.18, 1.22)	1.19 (1.17, 1.22)
Age at baseline squared	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)
Women	0.59 (0.57, 0.61)	0.60 (0.58, 0.62)	0.60 (0.58, 0.63)	0.31 (0.29, 0.34)	0.33 (0.30, 0.36)	0.33 (0.31, 0.37)
Married	1.42 (1.37, 1.47)	0.78 (0.75, 0.81)	0.81 (0.78, 0.84)	1.68 (1.55, 1.81)	0.80 (0.74, 0.87)	0.83 (0.76, 0.90)
Black minority ethnic	0.64 (0.60, 0.69)	0.73 (0.67, 0.79)	0.72 (0.67, 0.78)	0.84 (0.73, 0.98)	0.96 (0.82, 1.12)	0.94 (0.81, 1.10)
Has access to a car	0.55 (0.53, 0.58)	0.61 (0.58, 0.64)	0.69 (0.66, 0.73)	0.54 (0.49, 0.59)	0.57 (0.51, 0.64)	0.68 (0.61, 0.76)
Population density 2000+ persons/km^2	0.99 (0.96, 1.02)	1.05 (1.02, 1.09)	1.00 (0.96, 1.04)	1.05 (0.98, 1.12)	1.10 (1.02, 1.18)	0.98 (0.90, 1.06)
Has a long term illness at baseline	3.50 (3.32, 3.69)	2.00 (1.89, 2.11)	1.95 (1.84, 2.06)	4.23 (3.82, 4.69)	2.19 (1.96, 2.44)	2.12 (1.90, 2.36)
Entered study 1991	1.00	1.00	1.00	1.00	1.00	1.00
Entered study 2001	0.53 (0.50, 0.56)	0.43 (0.40, 0.45)	0.42 (0.40, 0.44)	0.44 (0.38, 0.50)	0.32 (0.28, 0.37)	0.32 (0.28, 0.36)
Entered study 2011	0.43 (0.40, 0.47)	0.19 (0.18, 0.21)	0.18 (0.17, 0.20)	0.41 (0.34, 0.51)	0.14 (0.11, 0.17)	0.13 (0.10, 0.16)
Has a degree	0.59 (0.56, 0.62)		0.82 (0.78, 0.87)	0.51 (0.45, 0.57)		0.78 (0.69, 0.89)
Non-home owner	1.24 (1.19, 1.29)		1.28 (1.22, 1.33)	1.30 (1.20, 1.41)		1.27 (1.16, 1.39)
Socio-economic classification (NSSEC)						
Higher	1.00		1.00	1.00		1.00
Intermediate	1.23 (1.17, 1.29)		1.08 (1.03, 1.14)	1.20 (1.09, 1.33)		1.07 (0.96, 1.19)
Routine/Manual	1.57 (1.51, 1.63)		1.16 (1.11, 1.21)	1.78 (1.64, 1.94)		1.24 (1.13, 1.37)
Carstairs Deprivation Index Quintile						
Least deprived	1.00		1.00	1.00		1.00
Next least deprived	1.01 (0.96, 1.06)		1.02 (0.97, 1.07)	1.22 (1.09, 1.37)		1.23 (1.10, 1.38)
Mid-point	1.03 (0.98, 1.09)		1.06 (1.01, 1.12)	1.25 (1.12, 1.40)		1.30 (1.16, 1.46)
Moderate deprivation	1.06 (1.00, 1.11)		1.10 (1.04, 1.17)	1.31 (1.17, 1.47)		1.39 (1.23, 1.57)
Most deprived	1.13 (1.07, 1.19)		1.16 (1.09, 1.23)	1.47 (1.31, 1.64)		1.48 (1.30, 1.69)
	Failures=13983	N=391894		Failures=3172	N=391894	

NSSEC – National Statistics socio-economic classification

Appendix Table A-19:Cox regression analyses of commute mode and cancer outcomes using the ONS Longitudinal Study 1991-2016

	Cancer incidence			Cancer mortality		
Commute mode	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**
Sedentary	1.00	1.00	1.00	1.00	1.00	1.00
Public Transport	0.79 (0.76, 0.82)	0.93 (0.89, 0.97)	0.93 (0.89, 0.97)	0.89 (0.83, 0.96)	0.96 (0.89, 1.04)	0.95 (0.88, 1.03)
Walk	1.00 (0.96, 1.05)	0.93 (0.89, 0.97)	0.93 (0.89, 0.97)	1.16 (1.08, 1.25)	1.02 (0.94, 1.11)	0.98 (0.91, 1.06)
Cycle	0.84 (0.77, 0.92)	0.89 (0.82, 0.97)	0.89 (0.82, 0.97)	0.88 (0.76, 1.03)	0.85 (0.73, 0.99)	0.84 (0.73, 0.98)
Age at baseline	1.07 (1.07, 1.07)	1.14 (1.13, 1.15)	1.14 (1.13, 1.15)	1.09 (1.09, 1.09)	1.20 (1.18, 1.21)	1.20 (1.18, 1.21)
Age at baseline squared	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)
Women	1.04 (1.01, 1.07)	1.12 (1.09, 1.15)	1.12 (1.09, 1.16)	0.81 (0.77, 0.85)	0.86 (0.82, 0.90)	0.86 (0.82, 0.91)
Married	1.86 (1.81, 1.92)	1.01 (0.97, 1.04)	1.01 (0.98, 1.04)	1.83 (1.73, 1.93)	0.95 (0.89, 1.00)	0.97 (0.91, 1.03)
Black minority ethnic	0.48 (0.44, 0.51)	0.57 (0.53, 0.61)	0.57 (0.53, 0.61)	0.47 (0.42, 0.54)	0.56 (0.49, 0.64)	0.56 (0.49, 0.64)
Has access to a car	1.03 (0.99, 1.08)	0.96 (0.91, 1.01)	0.98 (0.93, 1.03)	0.71 (0.66, 0.76)	0.72 (0.67, 0.79)	0.79 (0.73, 0.86)
Population density 2000+ persons/km^2	0.85 (0.83, 0.88)	0.99 (0.97, 1.02)	0.98 (0.95, 1.01)	0.94 (0.89, 0.98)	1.06 (1.01, 1.11)	1.02 (0.96, 1.07)
Has a long term illness at baseline	1.47 (1.39, 1.57)	1.04 (0.98, 1.11)	1.04 (0.98, 1.11)	2.38 (2.17, 2.60)	1.46 (1.33, 1.61)	1.43 (1.31, 1.57)
Entered study 1991	1.00	1.00	1.00	1.00	1.00	1.00
Entered study 2001	0.49 (0.47, 0.51)	0.46 (0.44, 0.48)	0.46 (0.44, 0.48)	0.47 (0.44, 0.51)	0.40 (0.37, 0.43)	0.39 (0.36, 0.42)
Entered study 2011	0.30 (0.28, 0.32)	0.22 (0.21, 0.24)	0.22 (0.20, 0.24)	0.29 (0.25, 0.33)	0.15 (0.13, 0.17)	0.15 (0.13, 0.17)
Has a degree	0.81 (0.78, 0.84)		0.97 (0.93, 1.01)	0.61 (0.57, 0.66)		0.84 (0.78, 0.91)
Non-home owner	0.77 (0.74, 0.80)		1.03 (0.99, 1.07)	1.00 (0.95, 1.07)		1.20 (1.13, 1.29)
Socio-economic classification (NSSEC)						
Higher	1.00		1.00	1.00		1.00
Intermediate	1.09 (1.05, 1.12)		1.00 (0.96, 1.04)	1.23 (1.15, 1.31)		1.06 (0.99, 1.14)
Routine/Manual	1.10 (1.07, 1.14)		0.99 (0.95, 1.02)	1.40 (1.32, 1.48)		1.05 (0.99, 1.13)
Carstairs Deprivation Index Quintile						
Least deprived	1.00		1.00	1.00		1.00
Next least deprived	0.94 (0.90, 0.97)		0.99 (0.95, 1.03)	0.94 (0.87, 1.01)		0.97 (0.90, 1.05)
Mid-point	0.84 (0.80, 0.87)		0.95 (0.91, 0.99)	0.93 (0.86, 1.00)		1.01 (0.93, 1.09)
Moderate deprivation	0.84 (0.81, 0.88)		1.03 (0.99, 1.08)	0.93 (0.86, 1.00)		1.06 (0.98, 1.15)
Most deprived	0.77 (0.73, 0.80)		1.04 (0.99, 1.10)	0.95 (0.88, 1.03)		1.14 (1.04, 1.25)
	Failures=20,930	N=390,555		Failures=6,509	N=391894	

NSSEC – National Statistics socio-economic classification

Appendix Table A-20: Cox regression analyses of commute mode with disaggregated public transport modes and mortality outcomes using the ONS Longitudinal Study 1991-2016

	All-cause mortality			CVD mortality		
Commute mode	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**
Sedentary	1.00	1.00	1.00	1.00	1.00	1.00
Bus	1.19 (1.13, 1.26)	1.07 (1.00, 1.14)	1.01 (0.94, 1.07)	1.11 (0.99, 1.25)	1.05 (0.92, 1.20)	0.97 (0.84, 1.11)
Rail	0.73 (0.68, 0.79)	0.84 (0.78, 0.91)	0.90 (0.83, 0.97)	0.66 (0.55, 0.77)	0.73 (0.62, 0.87)	0.80 (0.67, 0.95)
Walk	1.17 (1.11, 1.23)	1.05 (0.99, 1.10)	0.98 (0.93, 1.04)	1.02 (0.91, 1.14)	1.00 (0.89, 1.13)	0.92 (0.82, 1.04)
Cycle	0.94 (0.85, 1.04)	0.84 (0.76, 0.93)	0.81 (0.73, 0.89)	0.93 (0.76, 1.14)	0.81 (0.66, 1.00)	0.76 (0.62, 0.94)
Age at baseline	1.09 (1.09, 1.09)	1.12 (1.11, 1.13)	1.12 (1.11, 1.13)	1.11 (1.11, 1.11)	1.20 (1.18, 1.22)	1.19 (1.17, 1.21)
Age at baseline squared	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)
Women	0.59 (0.57, 0.61)	0.59 (0.57, 0.61)	0.60 (0.58, 0.62)	0.31 (0.29, 0.34)	0.32 (0.30, 0.35)	0.33 (0.30, 0.36)
Married	1.42 (1.37, 1.47)	0.78 (0.75, 0.81)	0.81 (0.78, 0.84)	1.68 (1.55, 1.81)	0.80 (0.73, 0.87)	0.83 (0.76, 0.90)
Black minority ethnic	0.64 (0.60, 0.69)	0.73 (0.67, 0.79)	0.73 (0.67, 0.79)	0.84 (0.73, 0.98)	0.96 (0.83, 1.12)	0.95 (0.81, 1.10)
Has access to a car	0.55 (0.53, 0.58)	0.62 (0.59, 0.66)	0.70 (0.66, 0.74)	0.54 (0.49, 0.59)	0.59 (0.53, 0.65)	0.68 (0.61, 0.77)
Population density 2000+ persons/km^2	0.99 (0.96, 1.02)	1.05 (1.02, 1.09)	1.00 (0.96, 1.04)	1.05 (0.98, 1.12)	1.10 (1.02, 1.18)	0.98 (0.91, 1.06)
Has a long term illness at baseline	3.50 (3.32, 3.69)	1.99 (1.89, 2.11)	1.95 (1.84, 2.06)	4.23 (3.82, 4.69)	2.18 (1.96, 2.43)	2.12 (1.90, 2.36)
Entered study 1991	1.00	1.00	1.00	1.00	1.00	1.00
Entered study 2001	0.53 (0.50, 0.56)	0.43 (0.40, 0.45)	0.42 (0.40, 0.44)	0.44 (0.38, 0.50)	0.33 (0.29, 0.37)	0.32 (0.28, 0.36)
Entered study 2011	0.43 (0.40, 0.47)	0.19 (0.18, 0.21)	0.18 (0.17, 0.20)	0.41 (0.34, 0.51)	0.14 (0.11, 0.17)	0.13 (0.10, 0.16)
Has a degree	0.59 (0.56, 0.62)		0.83 (0.78, 0.87)	0.51 (0.45, 0.57)		0.79 (0.69, 0.90)
Non-home owner	1.24 (1.19, 1.29)		1.27 (1.22, 1.33)	1.30 (1.20, 1.41)		1.27 (1.16, 1.39)
Socio-economic classification (NSSEC)						
Higher	1.00		1.00	1.00		1.00
Intermediate	1.23 (1.17, 1.29)		1.08 (1.03, 1.14)	1.20 (1.09, 1.33)		1.07 (0.96, 1.19)
Routine/Manual	1.57 (1.51, 1.63)		1.15 (1.10, 1.21)	1.78 (1.64, 1.94)		1.23 (1.12, 1.35)
Carstairs Deprivation Index Quintile						
Least deprived	1.00		1.00	1.00		1.00
Next least deprived	1.01 (0.96, 1.06)		1.02 (0.97, 1.07)	1.22 (1.09, 1.37)		1.23 (1.10, 1.38)
Mid-point	1.03 (0.98, 1.09)		1.06 (1.01, 1.12)	1.25 (1.12, 1.40)		1.30 (1.16, 1.46)
Moderate deprivation	1.06 (1.00, 1.11)		1.10 (1.04, 1.16)	1.31 (1.17, 1.47)		1.38 (1.22, 1.56)
Most deprived	1.13 (1.07, 1.19)		1.15 (1.08, 1.22)	1.47 (1.31, 1.64)		1.48 (1.29, 1.68)
	Failures = 13,983	N = 391,894		Failures = 3,172	N = 391,894	

NSSEC – National Statistics socio-economic classification

Appendix Table A-21: Cox regression analyses of commute mode with disaggregated public transport modes and cancer outcomes using the ONS Longitudinal Study 1991-2016

	Cancer incidence			Cancer mortality		
Commute mode	**Unadjusted HR (95%CI)**		**Adjusted HR (95%CI)**	**Unadjusted HR (95%CI)**		**Adjusted HR (95%CI)**
Sedentary	1.00	1.00	1.00	1.00	1.00	1.00
Bus	0.92 (0.88, 0.97)	0.97 (0.91, 1.02)	0.96 (0.91, 1.01)	1.10 (1.01, 1.19)	1.03 (0.94, 1.13)	0.99 (0.90, 1.08)
Rail	0.64 (0.60, 0.68)	0.88 (0.83, 0.94)	0.88 (0.83, 0.94)	0.65 (0.58, 0.73)	0.86 (0.76, 0.97)	0.89 (0.79, 1.01)
Walk	1.00 (0.96, 1.05)	0.93 (0.89, 0.98)	0.93 (0.89, 0.97)	1.16 (1.08, 1.25)	1.03 (0.95, 1.11)	0.99 (0.91, 1.07)
Cycle	0.84 (0.77, 0.92)	0.89 (0.82, 0.97)	0.89 (0.82, 0.97)	0.88 (0.76, 1.03)	0.86 (0.74, 1.00)	0.85 (0.73, 0.99)
Age at baseline	1.07 (1.07, 1.07)	1.14 (1.13, 1.15)	1.14 (1.13, 1.15)	1.09 (1.09, 1.09)	1.20 (1.18, 1.21)	1.20 (1.18, 1.21)
Age at baseline squared	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)
Women	1.04 (1.01, 1.07)	1.12 (1.09, 1.15)	1.12 (1.09, 1.15)	0.81 (0.77, 0.85)	0.85 (0.81, 0.90)	0.86 (0.82, 0.90)
Married	1.86 (1.81, 1.92)	1.01 (0.97, 1.04)	1.01 (0.98, 1.04)	1.83 (1.73, 1.93)	0.95 (0.89, 1.00)	0.97 (0.91, 1.02)
Black minority ethnic	0.48 (0.44, 0.51)	0.57 (0.53, 0.62)	0.57 (0.53, 0.61)	0.47 (0.42, 0.54)	0.57 (0.50, 0.65)	0.56 (0.49, 0.64)
Has access to a car	1.03 (0.99, 1.08)	0.97 (0.92, 1.02)	0.98 (0.93, 1.03)	0.71 (0.66, 0.76)	0.73 (0.68, 0.80)	0.80 (0.73, 0.87)
Population density 2000+ persons/km^2	0.85 (0.83, 0.88)	0.99 (0.97, 1.02)	0.98 (0.96, 1.02)	0.94 (0.89, 0.98)	1.06 (1.01, 1.11)	1.02 (0.96, 1.07)
Has a long term illness at baseline	1.47 (1.39, 1.57)	1.04 (0.98, 1.11)	1.04 (0.98, 1.11)	2.38 (2.17, 2.60)	1.46 (1.33, 1.60)	1.43 (1.31, 1.57)
Entered study 1991	1.00	1.00	1.00	1.00	1.00	1.00
Entered study 2001	0.49 (0.47, 0.51)	0.46 (0.44, 0.48)	0.46 (0.44, 0.48)	0.47 (0.44, 0.51)	0.40 (0.37, 0.43)	0.39 (0.36, 0.42)
Entered study 2011	0.30 (0.28, 0.32)	0.22 (0.21, 0.24)	0.22 (0.20, 0.24)	0.29 (0.25, 0.33)	0.15 (0.13, 0.18)	0.15 (0.13, 0.17)
Has a degree	0.81 (0.78, 0.84)		0.97 (0.93, 1.01)	0.61 (0.57, 0.66)		0.84 (0.78, 0.91)
Non-home owner	0.77 (0.74, 0.80)		1.03 (0.99, 1.07)	1.00 (0.95, 1.07)		1.20 (1.13, 1.28)
Socio-economic classification (NSSEC)						
Higher	1.00		1.00	1.00		1.00
Intermediate	1.09 (1.05, 1.12)		1.00 (0.96, 1.04)	1.23 (1.15, 1.31)		1.06 (0.99, 1.14)
Routine/Manual	1.10 (1.07, 1.14)		0.98 (0.95, 1.02)	1.40 (1.32, 1.48)		1.05 (0.98, 1.12)
Carstairs Deprivation Index Quintile						
Least deprived	1.00		1.00	1.00		1.00
Next least deprived	0.94 (0.90, 0.97)		0.99 (0.95, 1.03)	0.94 (0.87, 1.01)		0.97 (0.90, 1.05)

Mid-point	0.84 (0.80, 0.87)	0.95 (0.91, 0.99)	0.93 (0.86, 1.00)	1.00 (0.93, 1.08)
Moderate deprivation	0.84 (0.81, 0.88)	1.03 (0.99, 1.08)	0.93 (0.86, 1.00)	1.06 (0.98, 1.15)
Most deprived	0.77 (0.73, 0.80)	1.04 (0.99, 1.10)	0.95 (0.88, 1.03)	1.14 (1.04, 1.24)
	Failures = 20,930 N = 390,555		Failures = 6,509 N = 391894	

NSSEC – National Statistics socio-economic classification

Appendix Table A-22: Cox regression analyses of commute mode and disaggregated mortality outcomes using the ONS Longitudinal Study 1991-2016

	IHD mortality			Stroke mortality		
Commute mode	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**
Sedentary	1.00	1.00	1.00	1.00	1.00	1.00
Public Transport	0.87 (0.78, 0.98)	0.92 (0.81, 1.05)	0.91 (0.80, 1.03)	1.06 (0.86, 1.31)	0.88 (0.69, 1.12)	0.88 (0.69, 1.12)
Walk	0.93 (0.82, 1.05)	0.97 (0.85, 1.12)	0.89 (0.78, 1.03)	1.39 (1.11, 1.73)	1.05 (0.83, 1.34)	1.00 (0.79, 1.28)
Cycle	0.89 (0.71, 1.13)	0.78 (0.62, 0.99)	0.74 (0.58, 0.94)	1.07 (0.69, 1.66)	0.89 (0.57, 1.39)	0.86 (0.55, 1.34)
Age at baseline	1.11 (1.11, 1.11)	1.23 (1.20, 1.26)	1.22 (1.20, 1.25)	1.11 (1.10, 1.11)	1.12 (1.08, 1.16)	1.12 (1.08, 1.15)
Age at baseline squared	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)
Women	0.23 (0.21, 0.26)	0.25 (0.22, 0.27)	0.25 (0.22, 0.28)	0.72 (0.62, 0.85)	0.74 (0.63, 0.87)	0.74 (0.63, 0.87)
Married	1.76 (1.61, 1.92)	0.79 (0.72, 0.87)	0.83 (0.75, 0.91)	1.40 (1.19, 1.65)	0.82 (0.68, 0.98)	0.84 (0.70, 1.00)
Black minority ethnic	0.80 (0.67, 0.95)	0.90 (0.76, 1.08)	0.88 (0.74, 1.05)	0.99 (0.74, 1.34)	1.17 (0.86, 1.60)	1.20 (0.88, 1.64)
Has access to a car	0.57 (0.52, 0.63)	0.59 (0.52, 0.66)	0.71 (0.63, 0.81)	0.44 (0.36, 0.52)	0.52 (0.42, 0.65)	0.57 (0.45, 0.72)
Population density 2000+ persons/km^2	1.05 (0.97, 1.14)	1.12 (1.03, 1.21)	0.97 (0.89, 1.06)	1.03 (0.88, 1.19)	1.04 (0.88, 1.21)	0.99 (0.84, 1.18)
Has a long term illness at baseline	4.20 (3.74, 4.72)	2.19 (1.94, 2.47)	2.12 (1.88, 2.39)	4.35 (3.48, 5.44)	2.15 (1.70, 2.73)	2.10 (1.66, 2.67)
Entered study 1991	1.00	1.00	1.00	1.00	1.00	1.00
Entered study 2001	0.42 (0.36, 0.49)	0.32 (0.27, 0.37)	0.31 (0.27, 0.36)	0.50 (0.38, 0.64)	0.35 (0.27, 0.45)	0.34 (0.26, 0.44)
Entered study 2011	0.35 (0.27, 0.45)	0.12 (0.09, 0.16)	0.11 (0.09, 0.15)	0.67 (0.45, 0.99)	0.19 (0.12, 0.29)	0.18 (0.12, 0.28)
Has a degree	0.50 (0.44, 0.57)		0.77 (0.66, 0.89)	0.54 (0.43, 0.69)		0.84 (0.64, 1.10)
Non-home owner	1.32 (1.20, 1.44)		1.30 (1.17, 1.44)	1.24 (1.04, 1.49)		1.18 (0.97, 1.43)
Socio-economic classification (NSSEC)						
Higher	1.00		1.00	1.00		1.00
Intermediate	1.11 (0.99, 1.25)		1.00 (0.89, 1.14)	1.59 (1.28, 1.97)		1.34 (1.07, 1.69)
Routine/Manual	1.77 (1.61, 1.95)		1.23 (1.11, 1.37)	1.82 (1.50, 2.20)		1.26 (1.02, 1.57)
Carstairs Deprivation Index Quintile						
Least deprived	1.00		1.00	1.00		1.00
Next least deprived	1.23 (1.08, 1.40)		1.25 (1.10, 1.42)	1.19 (0.93, 1.51)		1.17 (0.92, 1.50)
Mid-point	1.25 (1.10, 1.42)		1.32 (1.15, 1.50)	1.25 (0.98, 1.59)		1.25 (0.97, 1.60)
Moderate deprivation	1.35 (1.19, 1.54)		1.45 (1.27, 1.66)	1.17 (0.92, 1.50)		1.17 (0.90, 1.52)
Most deprived	1.53 (1.35, 1.74)		1.59 (1.37, 1.84)	1.23 (0.95, 1.58)		1.13 (0.84, 1.51)
	Failures = 2,509 N = 391894			Failures=663 N=391894		

NSSEC – National Statistics socio-economic classification, IHD – Ischaemic heart disease

Appendix Table A-23: Cox regression analyses of commute mode and disaggregated cancer outcomes using the ONS Longitudinal Study 1991-2016

	Colon cancer incidence			Colon cancer mortality		
Commute mode	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**
Sedentary	1.00	1.00	1.00	1.00	1.00	1.00
Public Transport	0.87 (0.69, 1.10)	0.99 (0.76, 1.27)	0.98 (0.76, 1.27)	0.77 (0.57, 1.04)	0.89 (0.64, 1.24)	0.88 (0.63, 1.24)
Walk	0.65 (0.49, 0.87)	0.90 (0.67, 1.21)	0.89 (0.66, 1.19)	0.71 (0.49, 1.02)	0.68 (0.46, 1.00)	0.70 (0.47, 1.03)
Cycle	1.04 (0.85, 1.26)	1.06 (0.86, 1.30)	1.06 (0.86, 1.30)	1.34 (0.82, 2.19)	1.37 (0.83, 2.25)	1.44 (0.87, 2.37)
Age at baseline	0.96 (0.67, 1.37)	1.02 (0.71, 1.47)	1.03 (0.71, 1.48)	1.10 (1.09, 1.10)	1.19 (1.13, 1.25)	1.19 (1.13, 1.26)
Age at baseline squared	1.09 (1.08, 1.09)	1.20 (1.16, 1.24)	1.20 (1.16, 1.24)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)
Women	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	0.65 (0.53, 0.80)	0.74 (0.60, 0.92)	0.75 (0.60, 0.93)
Married	0.68 (0.60, 0.77)	0.73 (0.64, 0.84)	0.74 (0.65, 0.84)	2.15 (1.70, 2.72)	1.02 (0.79, 1.31)	1.05 (0.81, 1.35)
Black minority ethnic	2.15 (1.87, 2.48)	1.03 (0.88, 1.20)	1.04 (0.89, 1.21)	0.74 (0.48, 1.15)	0.95 (0.61, 1.51)	0.95 (0.60, 1.51)
Has access to a car	0.73 (0.56, 0.95)	0.89 (0.68, 1.17)	0.88 (0.66, 1.16)	0.94 (0.68, 1.28)	0.86 (0.60, 1.23)	0.87 (0.60, 1.27)
Population density 2000+ persons/km^2	1.01 (0.83, 1.24)	0.99 (0.79, 1.24)	1.02 (0.80, 1.29)	0.80 (0.65, 0.98)	0.90 (0.73, 1.11)	0.89 (0.71, 1.11)
Has a long term illness at baseline	0.87 (0.77, 0.98)	1.00 (0.88, 1.13)	1.03 (0.89, 1.18)	1.72 (1.12, 2.65)	1.00 (0.64, 1.55)	1.00 (0.64, 1.55)
Entered study 1991	1.42 (1.07, 1.89)	0.86 (0.65, 1.15)	0.86 (0.64, 1.15)	1.00	1.00	1.00
Entered study 2001	1.00	1.00	1.00	0.52 (0.37, 0.72)	0.45 (0.32, 0.63)	0.44 (0.31, 0.62)
Entered study 2011	0.49 (0.41, 0.59)	0.44 (0.37, 0.53)	0.44 (0.36, 0.53)	0.32 (0.18, 0.56)	0.17 (0.09, 0.31)	0.16 (0.09, 0.29)
Has a degree	0.28 (0.20, 0.39)	0.16 (0.12, 0.23)	0.16 (0.11, 0.22)	0.90 (0.69, 1.18)		1.04 (0.77, 1.41)
Non-home owner	0.85 (0.73, 1.00)		1.08 (0.90, 1.29)	0.89 (0.69, 1.16)		1.25 (0.94, 1.65)
Socio-economic classification (NSSEC)	0.83 (0.71, 0.98)		1.14 (0.96, 1.35)			
Higher	1.00		1.00	1.00		1.00
Intermediate	1.08 (0.92, 1.27)		1.03 (0.86, 1.23)	1.06 (0.82, 1.38)		1.02 (0.78, 1.35)
Routine/Manual	1.14 (0.99, 1.31)		1.01 (0.85, 1.19)	0.92 (0.73, 1.17)		0.79 (0.60, 1.03)
Carstairs Deprivation Index Quintile						
Least deprived	1.00		1.00	1.00		1.00
Next least deprived	0.87 (0.73, 1.04)		0.93 (0.77, 1.11)	0.90 (0.67, 1.21)		1.00 (0.74, 1.34)
Mid-point	0.70 (0.58, 0.85)		0.80 (0.65, 0.97)	0.87 (0.64, 1.17)		1.07 (0.78, 1.45)
Moderate deprivation	0.73 (0.61, 0.89)		0.89 (0.72, 1.09)	0.81 (0.59, 1.10)		1.10 (0.79, 1.53)
Most deprived	0.74 (0.60, 0.90)		0.94 (0.75, 1.18)	0.72 (0.52, 1.01)		1.05 (0.71, 1.54)
	Failures = 1,012	N=390,555		Failures = 381	N=391894	

NSSEC – National Statistics socio-economic classification

Appendix Table A-24: Cox regression analyses of commute mode and disaggregated cancer outcomes using the ONS Longitudinal Study 1991-2016

	Breast cancer incidence			Breast cancer mortality		
Commute mode	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**
Sedentary	1.00	1.00	1.00	1.00	1.00	1.00
Public Transport	0.76 (0.69, 0.83)	0.87 (0.78, 0.96)	0.88 (0.79, 0.97)	0.77 (0.62, 0.96)	0.79 (0.62, 1.00)	0.81 (0.63, 1.03)
Walk	0.91 (0.82, 1.00)	0.82 (0.74, 0.91)	0.86 (0.77, 0.95)	1.02 (0.82, 1.26)	0.86 (0.69, 1.08)	0.91 (0.72, 1.15)
Cycle	0.99 (0.79, 1.25)	0.88 (0.69, 1.10)	0.91 (0.72, 1.14)	0.85 (0.48, 1.50)	0.71 (0.40, 1.27)	0.75 (0.42, 1.33)
Age at baseline	1.05 (1.05, 1.05)	1.20 (1.17, 1.22)	1.20 (1.17, 1.22)	1.06 (1.05, 1.07)	1.16 (1.12, 1.22)	1.16 (1.12, 1.22)
Age at baseline squared	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)
Married	1.77 (1.65, 1.90)	1.08 (1.00, 1.17)	1.08 (1.00, 1.17)	1.49 (1.27, 1.76)	0.94 (0.79, 1.12)	0.93 (0.78, 1.11)
Black minority ethnic	0.66 (0.56, 0.77)	0.78 (0.67, 0.92)	0.79 (0.67, 0.92)	0.73 (0.51, 1.03)	0.86 (0.60, 1.23)	0.88 (0.61, 1.26)
Has access to a car	1.15 (1.03, 1.28)	0.98 (0.86, 1.11)	0.95 (0.83, 1.07)	0.91 (0.73, 1.15)	0.87 (0.67, 1.14)	0.82 (0.62, 1.08)
Population density 2000+ persons/km^2	0.88 (0.82, 0.94)	1.01 (0.94, 1.08)	1.02 (0.95, 1.10)	0.94 (0.81, 1.10)	1.06 (0.90, 1.24)	1.11 (0.93, 1.32)
Has a long term illness at baseline	1.17 (0.99, 1.38)	1.03 (0.87, 1.22)	1.04 (0.88, 1.23)	2.52 (1.90, 3.34)	2.03 (1.52, 2.71)	2.07 (1.55, 2.76)
Entered study 1991	1.00	1.00	1.00	1.00	1.00	1.00
Entered study 2001	0.53 (0.48, 0.58)	0.52 (0.47, 0.57)	0.52 (0.48, 0.58)	0.60 (0.48, 0.75)	0.52 (0.42, 0.66)	0.53 (0.42, 0.67)
Entered study 2011	0.28 (0.24, 0.34)	0.26 (0.22, 0.31)	0.26 (0.22, 0.32)	0.31 (0.20, 0.46)	0.23 (0.15, 0.34)	0.23 (0.15, 0.36)
Has a degree	0.89 (0.82, 0.97)		1.00 (0.90, 1.10)	0.81 (0.66, 1.00)		0.95 (0.75, 1.20)
Non-home owner	0.67 (0.61, 0.74)		0.96 (0.87, 1.06)	0.70 (0.56, 0.86)		0.89 (0.71, 1.13)
Socio-economic classification (NSSEC)						
Higher	1.00		1.00	1.00		1.00
Intermediate	1.05 (0.96, 1.14)		1.03 (0.94, 1.13)	1.15 (0.94, 1.40)		1.09 (0.88, 1.35)
Routine/Manual	0.98 (0.91, 1.06)		0.90 (0.82, 0.99)	1.06 (0.87, 1.28)		0.92 (0.74, 1.14)
Carstairs Deprivation Index Quintile						
Least deprived	1.00		1.00	1.00		1.00
Next least deprived	0.91 (0.83, 1.01)		0.97 (0.88, 1.07)	0.89 (0.71, 1.11)		0.92 (0.73, 1.15)
Mid-point	0.83 (0.75, 0.92)		0.93 (0.84, 1.04)	0.90 (0.71, 1.12)		0.96 (0.75, 1.21)
Moderate deprivation	0.79 (0.71, 0.88)		0.95 (0.85, 1.07)	0.68 (0.53, 0.87)		0.76 (0.58, 0.99)
Most deprived	0.71 (0.63, 0.79)		0.94 (0.82, 1.06)	0.75 (0.58, 0.97)		0.88 (0.66, 1.18)
	Failures = 1,012	N=390,555		Failures = 638	N = 183,775	

NSSEC – National Statistics socio-economic classification

Appendix Table A-25: Cox regression analyses of commute mode and distance and mortality outcomes using the ONS Longitudinal Study 1991-2016

	All-cause mortality			CVD mortality		
Commute mode	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**
Sedentary	1.00	1.00	1.00	1.00	1.00	1.00
Bus short	1.30 (1.17, 1.44)	1.10 (0.98, 1.23)	1.04 (0.92, 1.16)	1.31 (1.03, 1.67)	1.25 (0.96, 1.63)	1.18 (0.90, 1.53)
Bus long	1.06 (0.94, 1.19)	1.02 (0.90, 1.16)	0.98 (0.87, 1.11)	1.00 (0.75, 1.32)	1.02 (0.76, 1.36)	0.97 (0.72, 1.30)
Rail short	0.74 (0.64, 0.85)	0.92 (0.79, 1.06)	0.96 (0.83, 1.11)	0.67 (0.48, 0.93)	0.84 (0.60, 1.20)	0.89 (0.63, 1.26)
Rail long	0.58 (0.50, 0.68)	0.74 (0.63, 0.87)	0.81 (0.69, 0.95)	0.44 (0.29, 0.67)	0.56 (0.37, 0.86)	0.64 (0.42, 0.97)
Walk short	1.29 (1.18, 1.41)	1.08 (0.98, 1.19)	1.02 (0.93, 1.12)	1.16 (0.93, 1.44)	1.10 (0.88, 1.37)	1.03 (0.82, 1.29)
Walk long	1.05 (0.94, 1.16)	1.02 (0.92, 1.14)	0.96 (0.86, 1.07)	0.89 (0.69, 1.15)	0.96 (0.73, 1.25)	0.90 (0.69, 1.17)
Cycle short	0.99 (0.82, 1.20)	0.88 (0.73, 1.06)	0.84 (0.70, 1.02)	0.85 (0.53, 1.35)	0.75 (0.47, 1.19)	0.71 (0.44, 1.13)
Cycle long	0.84 (0.68, 1.03)	0.82 (0.67, 1.01)	0.81 (0.66, 1.00)	0.88 (0.55, 1.40)	0.82 (0.51, 1.31)	0.81 (0.51, 1.30)
Age at baseline	1.10 (1.09, 1.10)	1.10 (1.08, 1.11)	1.09 (1.08, 1.11)	1.12 (1.11, 1.12)	1.16 (1.13, 1.20)	1.16 (1.12, 1.19)
Age at baseline squared	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)
Women	0.64 (0.61, 0.67)	0.63 (0.60, 0.66)	0.64 (0.61, 0.68)	0.34 (0.30, 0.38)	0.33 (0.29, 0.38)	0.34 (0.30, 0.39)
Married	1.35 (1.29, 1.42)	0.79 (0.75, 0.83)	0.82 (0.77, 0.86)	1.47 (1.32, 1.65)	0.74 (0.66, 0.84)	0.77 (0.68, 0.87)
Black minority ethnic	0.59 (0.53, 0.65)	0.69 (0.62, 0.76)	0.69 (0.62, 0.76)	0.78 (0.63, 0.96)	0.93 (0.75, 1.16)	0.94 (0.75, 1.17)
Has access to a car	0.55 (0.52, 0.59)	0.59 (0.55, 0.64)	0.66 (0.61, 0.71)	0.55 (0.47, 0.63)	0.57 (0.48, 0.68)	0.66 (0.55, 0.79)
Population density 2000+ persons/km^2	0.94 (0.90, 0.98)	1.05 (1.00, 1.10)	1.00 (0.95, 1.05)	0.95 (0.86, 1.06)	1.05 (0.94, 1.18)	0.96 (0.85, 1.09)
Has a long term illness at baseline	3.82 (3.61, 4.05)	1.99 (1.87, 2.11)	1.94 (1.82, 2.06)	4.38 (3.85, 4.98)	2.08 (1.82, 2.38)	2.01 (1.75, 2.30)
Entered study 2001	1.00	1.00	1.00	1.00	1.00	1.00
Entered study 2011	0.82 (0.75, 0.88)	0.46 (0.43, 0.51)	0.45 (0.41, 0.49)	0.85 (0.70, 1.03)	0.39 (0.31, 0.48)	0.37 (0.30, 0.46)
Has a degree	0.57 (0.54, 0.61)		0.83 (0.78, 0.89)	0.49 (0.42, 0.57)		0.75 (0.64, 0.89)
Non-home owner	1.11 (1.05, 1.17)		1.25 (1.18, 1.33)	1.15 (1.01, 1.30)		1.29 (1.12, 1.49)
Managerial NSSEC	1.00		1.00	1.00		1.00
Intermediate NSSEC	1.28 (1.20, 1.37)		1.05 (0.98, 1.12)	1.30 (1.11, 1.52)		1.04 (0.88, 1.23)
Routine/Manual NSSEC	1.61 (1.53, 1.70)		1.13 (1.06, 1.20)	1.76 (1.56, 2.00)		1.13 (0.98, 1.30)
Carstairs Deprivation Index Quintile						
Least deprived	1.00		1.00	1.00		1.00
Next least deprived	1.03 (0.96, 1.11)		1.04 (0.97, 1.12)	1.29 (1.09, 1.53)		1.31 (1.10, 1.55)
Mid-point	1.03 (0.96, 1.11)		1.06 (0.98, 1.14)	1.24 (1.04, 1.48)		1.30 (1.09, 1.56)
Moderate deprivation	1.07 (1.00, 1.15)		1.12 (1.03, 1.21)	1.27 (1.06, 1.51)		1.33 (1.10, 1.61)
Most deprived	1.08 (1.00, 1.17)		1.14 (1.04, 1.24)	1.32 (1.10, 1.58)		1.36 (1.10, 1.67)
		Failures = 7, 146	N = 304,125		Failures = 1,327	N = 304,125

NSSEC – National Statistics socio-economic classification

Appendix Table A-26: Cox regression analyses of commute mode and distance and cancer outcomes using the ONS Longitudinal Study 1991-2016

	Cancer incidence			Cancer mortality		
Commute mode	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**
Sedentary	1.00	1.00	1.00	1.00	1.00	1.00
Bus short	0.92 (0.84, 1.01)	0.95 (0.87, 1.05)	0.95 (0.86, 1.04)	1.15 (0.98, 1.35)	1.02 (0.86, 1.21)	0.97 (0.82, 1.15)
Bus long	0.81 (0.73, 0.89)	0.98 (0.89, 1.09)	0.98 (0.88, 1.08)	0.94 (0.79, 1.12)	0.99 (0.83, 1.20)	0.96 (0.80, 1.15)
Rail short	0.60 (0.53, 0.67)	0.93 (0.83, 1.04)	0.93 (0.83, 1.04)	0.66 (0.54, 0.82)	0.97 (0.78, 1.20)	0.99 (0.79, 1.22)
Rail long	0.64 (0.57, 0.71)	0.88 (0.79, 0.98)	0.88 (0.79, 0.98)	0.58 (0.46, 0.72)	0.81 (0.64, 1.01)	0.86 (0.68, 1.08)
Walk short	1.06 (0.99, 1.14)	0.93 (0.86, 1.00)	0.93 (0.86, 1.00)	1.34 (1.18, 1.52)	1.10 (0.96, 1.25)	1.05 (0.92, 1.20)
Walk long	0.79 (0.72, 0.86)	0.86 (0.79, 0.94)	0.86 (0.79, 0.94)	1.00 (0.86, 1.17)	1.00 (0.86, 1.17)	0.96 (0.82, 1.13)
Cycle short	0.86 (0.74, 0.99)	0.89 (0.77, 1.03)	0.90 (0.77, 1.04)	0.97 (0.74, 1.28)	0.92 (0.70, 1.21)	0.90 (0.69, 1.19)
Cycle long	0.79 (0.67, 0.92)	0.97 (0.83, 1.13)	0.97 (0.83, 1.14)	0.84 (0.62, 1.13)	0.94 (0.70, 1.27)	0.95 (0.70, 1.28)
Age at baseline	1.08 (1.07, 1.08)	1.13 (1.12, 1.14)	1.13 (1.12, 1.14)	1.10 (1.09, 1.10)	1.18 (1.16, 1.21)	1.18 (1.16, 1.21)
Age at baseline squared	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)
Women	1.07 (1.03, 1.11)	1.13 (1.09, 1.17)	1.13 (1.09, 1.17)	0.88 (0.82, 0.94)	0.90 (0.84, 0.97)	0.91 (0.85, 0.98)
Married	1.82 (1.76, 1.89)	1.01 (0.97, 1.05)	1.01 (0.97, 1.06)	1.80 (1.68, 1.94)	0.99 (0.91, 1.07)	1.01 (0.93, 1.09)
Black minority ethnic	0.47 (0.43, 0.51)	0.57 (0.52, 0.62)	0.56 (0.52, 0.61)	0.46 (0.39, 0.55)	0.56 (0.48, 0.67)	0.56 (0.47, 0.66)
Has access to a car	1.14 (1.08, 1.22)	0.99 (0.92, 1.06)	1.00 (0.93, 1.07)	0.71 (0.65, 0.79)	0.68 (0.60, 0.76)	0.73 (0.65, 0.82)
Population density 2000+ persons/km^2	0.81 (0.79, 0.84)	0.98 (0.95, 1.02)	0.98 (0.94, 1.02)	0.89 (0.84, 0.96)	1.06 (0.99, 1.13)	1.01 (0.94, 1.09)
Has a long term illness at baseline	1.66 (1.57, 1.76)	1.04 (0.98, 1.11)	1.04 (0.98, 1.11)	2.85 (2.60, 3.12)	1.56 (1.42, 1.71)	1.53 (1.39, 1.68)
Entered study 2001	1.00	1.00	1.00	1.00	1.00	1.00
Entered study 2011	0.56 (0.53, 0.59)	0.50 (0.47, 0.53)	0.50 (0.46, 0.53)	0.60 (0.53, 0.67)	0.40 (0.36, 0.46)	0.40 (0.35, 0.45)
Has a degree	0.79 (0.76, 0.83)		0.96 (0.92, 1.01)	0.61 (0.56, 0.66)		0.85 (0.77, 0.94)
Non-home owner	0.70 (0.66, 0.73)		1.02 (0.97, 1.07)	0.87 (0.80, 0.95)		1.16 (1.06, 1.27)
Managerial NSSEC	1.00		1.00	1.00		1.00
Intermediate NSSEC	1.14 (1.09, 1.20)		1.01 (0.96, 1.06)	1.28 (1.17, 1.40)		1.03 (0.93, 1.13)
Routine/Manual NSSEC	1.11 (1.06, 1.15)		0.98 (0.93, 1.02)	1.45 (1.34, 1.56)		1.05 (0.96, 1.15)
Carstairs Deprivation Index Quintile						
Least deprived	1.00		1.00	1.00		1.00
Next least deprived	0.93 (0.88, 0.98)		0.99 (0.94, 1.04)	0.93 (0.84, 1.03)		0.96 (0.87, 1.07)
Mid-point	0.82 (0.77, 0.86)		0.93 (0.88, 0.98)	0.90 (0.81, 1.00)		0.97 (0.87, 1.08)
Moderate deprivation	0.83 (0.79, 0.88)		1.03 (0.98, 1.10)	0.94 (0.85, 1.05)		1.08 (0.97, 1.21)
Most deprived	0.71 (0.67, 0.76)		1.01 (0.95, 1.08)	0.91 (0.82, 1.02)		1.13 (1.00, 1.28)
		Failures = 12,864	N = 300,709		Failures = 3,464	N = 304,125

NSSEC – National Statistics socio-economic classification

Appendix Table A-27: Cox regression analyses of commute mode mortality using the ONS Longitudinal Study 2001-2011 with sequential adjustment to explore the impact of covariates including self-reported health

	All-cause mortality				
Commute mode	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**HR (95%CI)**	**HR (95%CI)**	**Maximally Adjusted HR (95%CI)**
Sedentary	1.00	1.00	1.00	1.00	1.00
Public Transport	0.91 (0.84, 0.99)	0.91 (0.83, 1.00)	0.92 (0.84, 1.01)	0.92 (0.84, 1.01)	0.93 (0.84, 1.02)
Walk	1.23 (1.13, 1.34)	1.08 (0.98, 1.18)	1.01 (0.92, 1.11)	1.02 (0.93, 1.11)	1.02 (0.93, 1.12)
Cycle	0.95 (0.80, 1.12)	0.81 (0.69, 0.97)	0.79 (0.67, 0.94)	0.80 (0.68, 0.95)	0.81 (0.68, 0.96)
Age at baseline	1.09 (1.09, 1.09)	1.14 (1.12, 1.15)	1.14 (1.12, 1.15)	1.14 (1.12, 1.15)	1.13 (1.11, 1.15)
Age at baseline squared	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)
Women	0.60 (0.57, 0.64)	0.59 (0.55, 0.63)	0.60 (0.56, 0.64)	0.60 (0.56, 0.64)	0.60 (0.56, 0.64)
Married	1.39 (1.31, 1.47)	0.77 (0.72, 0.82)	0.79 (0.74, 0.84)	0.79 (0.74, 0.84)	0.79 (0.74, 0.85)
Black minority ethnic	0.66 (0.58, 0.75)	0.71 (0.62, 0.82)	0.73 (0.63, 0.83)	0.73 (0.63, 0.83)	0.72 (0.63, 0.83)
Has access to a car	0.54 (0.50, 0.58)	0.53 (0.49, 0.58)	0.61 (0.55, 0.67)	0.61 (0.56, 0.68)	0.62 (0.57, 0.69)
Population density 2000+ persons/km^2	0.97 (0.92, 1.03)	1.06 (1.00, 1.12)	1.01 (0.95, 1.07)	1.01 (0.95, 1.08)	1.01 (0.95, 1.08)
Entered study 1991	1.00	1.00	1.00	1.00	1.00
Entered study 2001	0.55 (0.52, 0.59)	0.48 (0.45, 0.51)	0.46 (0.44, 0.50)	0.44 (0.41, 0.47)	0.44 (0.41, 0.47)
Has a degree	0.57 (0.53, 0.62)		0.80 (0.73, 0.87)	0.80 (0.74, 0.88)	0.81 (0.74, 0.88)
Non-home owner	1.20 (1.12, 1.28)		1.27 (1.18, 1.37)	1.25 (1.16, 1.35)	1.23 (1.14, 1.33)
Socio-economic classification (NSSEC)					
Higher	1.00		1.00	1.00	1.00
Intermediate	1.27 (1.17, 1.37)		1.04 (0.96, 1.13)	1.04 (0.95, 1.13)	1.03 (0.95, 1.12)
Routine/Manual	1.58 (1.49, 1.69)		1.16 (1.08, 1.25)	1.15 (1.07, 1.24)	1.15 (1.07, 1.24)
Carstairs Deprivation Index Quintile					
Least deprived	1.00		1.00	1.00	1.00
Next least deprived	1.03 (0.95, 1.13)		1.04 (0.95, 1.13)	1.04 (0.95, 1.13)	1.03 (0.95, 1.13)
Mid-point	1.03 (0.94, 1.12)		1.04 (0.95, 1.14)	1.04 (0.95, 1.13)	1.03 (0.94, 1.12)
Moderate deprivation	1.10 (1.01, 1.20)		1.13 (1.03, 1.24)	1.11 (1.01, 1.22)	1.10 (1.00, 1.21)
Most deprived	1.12 (1.02, 1.22)		1.13 (1.02, 1.25)	1.12 (1.01, 1.24)	1.10 (0.99, 1.22)
Has a long term illness at baseline				1.84 (1.67, 2.04)	1.50 (1.35, 1.66)
Health is not good or fairly good					2.19 (1.99, 2.40)
			Failures=4,963 N=207,481		

Appendix Table A-28: Cox regression analyses of commute mode and mortality outcomes using the ONS Longitudinal Study 1991-2016, excluded the first 2 years of follow-up in each 10 year period

	All-cause mortality		CVD mortality	
Commute mode	**Unadjusted HR (95%CI)**	**Adjusted HR (95%CI)**	**Unadjusted HR (95%CI)**	**Adjusted HR (95%CI)**
Sedentary	1.00	1.00	1.00	1.00
Public Transport	1.01 (0.96, 1.06)	0.99 (0.94, 1.05)	0.94 (0.85, 1.05)	0.91 (0.81, 1.03)	0.90 (0.79, 1.02)
Walk	1.19 (1.12, 1.25)	1.05 (0.99, 1.11)	0.99 (0.93, 1.05)	1.07 (0.95, 1.20)	1.01 (0.88, 1.14)	0.92 (0.81, 1.05)
Cycle	0.94 (0.85, 1.05)	0.83 (0.75, 0.93)	0.80 (0.72, 0.90)	0.95 (0.76, 1.19)	0.80 (0.64, 1.01)	0.75 (0.60, 0.95)
Age at baseline	1.09 (1.09, 1.09)	1.12 (1.12, 1.13)	1.12 (1.11, 1.13)	1.11 (1.11, 1.11)	1.20 (1.17, 1.22)	1.19 (1.17, 1.21)
Age at baseline squared	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)
Women	0.59 (0.57, 0.62)	0.60 (0.58, 0.63)	0.61 (0.58, 0.63)	0.33 (0.30, 0.36)	0.34 (0.31, 0.38)	0.35 (0.32, 0.38)
Married	1.43 (1.37, 1.48)	0.78 (0.75, 0.82)	0.81 (0.77, 0.84)	1.60 (1.47, 1.74)	0.77 (0.70, 0.84)	0.80 (0.73, 0.88)
Black minority ethnic	0.61 (0.56, 0.67)	0.69 (0.63, 0.75)	0.68 (0.62, 0.75)	0.82 (0.69, 0.96)	0.92 (0.78, 1.09)	0.91 (0.76, 1.08)
Has access to a car	0.55 (0.52, 0.58)	0.61 (0.58, 0.64)	0.69 (0.65, 0.73)	0.51 (0.46, 0.56)	0.55 (0.48, 0.61)	0.66 (0.58, 0.74)
Population density 2000+ persons/km^2	0.99 (0.96, 1.03)	1.06 (1.02, 1.10)	1.00 (0.96, 1.04)	1.07 (0.99, 1.15)	1.11 (1.03, 1.20)	0.99 (0.91, 1.08)
Has a long term illness at baseline	3.29 (3.10, 3.49)	1.89 (1.78, 2.01)	1.84 (1.73, 1.95)	4.23 (3.77, 4.74)	2.19 (1.95, 2.47)	2.12 (1.88, 2.38)
Entered study 1991	1.00	1.00	1.00	1.00	1.00	1.00
Entered study 2001	0.52 (0.49, 0.56)	0.42 (0.40, 0.45)	0.42 (0.39, 0.44)	0.44 (0.38, 0.51)	0.32 (0.28, 0.37)	0.31 (0.27, 0.36)
Entered study 2011	0.42 (0.38, 0.46)	0.19 (0.17, 0.21)	0.18 (0.16, 0.20)	0.40 (0.31, 0.51)	0.13 (0.10, 0.17)	0.12 (0.10, 0.16)
Has a degree	0.57 (0.54, 0.60)		0.81 (0.76, 0.86)	0.48 (0.42, 0.55)		0.75 (0.65, 0.87)
Non-home owner	1.25 (1.19, 1.30)		1.27 (1.21, 1.33)	1.39 (1.27, 1.52)		1.32 (1.20, 1.46)
Socio-economic classification (NSSEC)						
Higher	1.00		1.00	1.00		1.00
Intermediate	1.24 (1.18, 1.31)		1.10 (1.04, 1.16)	1.24 (1.10, 1.39)		1.09 (0.97, 1.23)
Routine/Manual	1.60 (1.53, 1.67)		1.18 (1.12, 1.24)	1.88 (1.71, 2.06)		1.27 (1.15, 1.42)
Carstairs Deprivation Index Quintile						
Least deprived	1.00		1.00	1.00		1.00
Next least deprived	1.01 (0.96, 1.07)		1.02 (0.96, 1.08)	1.23 (1.08, 1.39)		1.23 (1.08, 1.39)
Mid-point	1.05 (0.99, 1.11)		1.07 (1.01, 1.14)	1.29 (1.14, 1.46)		1.32 (1.16, 1.50)
Moderate deprivation	1.06 (1.00, 1.12)		1.10 (1.04, 1.17)	1.33 (1.17, 1.51)		1.37 (1.20, 1.56)
Most deprived	1.15 (1.08, 1.22)		1.17 (1.09, 1.25)	1.53 (1.35, 1.74)		1.49 (1.29, 1.72)
	Failures=11,893	N=390,772		Failures=2,618	N = 390,772	

NSSEC – National Statistics socio-economic classification

Appendix Table A-29: NSSEC Stratified – Managerial - Cox regression analyses of commute mode and mortality outcomes from the ONS Longitudinal Study 1991-2016

	All-cause mortality			CVD mortality		
Commute mode	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**
Sedentary	1.00	1.00	1.00	1.00	1.00	1.00
Bus	1.14 (0.99, 1.31)	1.00 (0.86, 1.17)	0.95 (0.82, 1.11)	1.20 (0.89, 1.61)	1.13 (0.81, 1.58)	1.08 (0.77, 1.50)
Rail	0.66 (0.58, 0.74)	0.75 (0.66, 0.85)	0.76 (0.67, 0.86)	0.49 (0.36, 0.66)	0.52 (0.38, 0.72)	0.54 (0.40, 0.74)
Walk	1.10 (0.97, 1.24)	1.03 (0.90, 1.18)	0.98 (0.86, 1.12)	0.92 (0.68, 1.23)	0.90 (0.66, 1.24)	0.86 (0.63, 1.18)
Cycle	0.64 (0.49, 0.83)	0.70 (0.54, 0.91)	0.71 (0.55, 0.92)	0.73 (0.43, 1.24)	0.78 (0.46, 1.34)	0.80 (0.47, 1.37)
Age at baseline	1.09 (1.09, 1.10)	1.13 (1.12, 1.15)	1.13 (1.12, 1.15)	1.11 (1.11, 1.12)	1.19 (1.15, 1.23)	1.19 (1.15, 1.23)
Age at baseline squared	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)
Women	0.59 (0.55, 0.63)	0.64 (0.60, 0.69)	0.65 (0.60, 0.70)	0.24 (0.19, 0.29)	0.27 (0.22, 0.32)	0.27 (0.22, 0.33)
Married	1.44 (1.35, 1.55)	0.80 (0.74, 0.86)	0.82 (0.76, 0.89)	1.80 (1.53, 2.11)	0.82 (0.69, 0.98)	0.85 (0.71, 1.01)
Black minority ethnic	0.71 (0.61, 0.82)	0.81 (0.70, 0.94)	0.80 (0.68, 0.92)	0.76 (0.55, 1.04)	0.89 (0.64, 1.22)	0.86 (0.62, 1.20)
Has access to a car	0.60 (0.54, 0.67)	0.53 (0.47, 0.60)	0.59 (0.52, 0.67)	0.58 (0.46, 0.73)	0.46 (0.35, 0.61)	0.52 (0.39, 0.69)
Population density 2000+ persons/km^2	0.91 (0.85, 0.97)	1.06 (1.00, 1.14)	0.99 (0.92, 1.06)	0.97 (0.84, 1.11)	1.17 (1.02, 1.36)	1.04 (0.89, 1.22)
Has a long term illness at baseline	3.94 (3.54, 4.38)	2.35 (2.11, 2.63)	2.29 (2.05, 2.56)	5.06 (4.10, 6.25)	2.74 (2.19, 3.42)	2.66 (2.13, 3.32)
Entered study 1991	1.00	1.00	1.00	1.00	1.00	1.00
Entered study 2001	0.51 (0.46, 0.56)	0.41 (0.38, 0.46)	0.41 (0.37, 0.45)	0.37 (0.29, 0.48)	0.29 (0.22, 0.37)	0.29 (0.22, 0.37)
Entered study 2011	0.41 (0.35, 0.48)	0.19 (0.16, 0.22)	0.18 (0.15, 0.21)	0.42 (0.29, 0.63)	0.15 (0.10, 0.22)	0.14 (0.09, 0.22)
Has a degree	0.67 (0.63, 0.72)		0.81 (0.75, 0.86)	0.60 (0.51, 0.70)		0.77 (0.66, 0.90)
Non-home owner	0.97 (0.88, 1.06)		1.25 (1.13, 1.38)	0.91 (0.74, 1.12)		1.18 (0.94, 1.48)
Carstairs Deprivation Index Quintile						
Least deprived	1.00		1.00	1.00		1.00
Next least deprived	1.03 (0.94, 1.13)		1.09 (1.00, 1.19)	1.19 (0.98, 1.45)		1.27 (1.04, 1.55)
Mid-point	0.98 (0.89, 1.07)		1.12 (1.01, 1.23)	1.15 (0.93, 1.41)		1.35 (1.09, 1.67)
Moderate deprivation	0.94 (0.85, 1.04)		1.15 (1.04, 1.29)	0.98 (0.78, 1.23)		1.26 (0.99, 1.61)
Most deprived	1.10 (0.99, 1.22)		1.39 (1.23, 1.57)	1.30 (1.03, 1.63)		1.72 (1.32, 2.24)
	Failures = 3,833	N = 166,469		Failures = 794	N = 166,469	

NSSEC – National Statistics socio-economic classification

Appendix Table A-30: NSSEC Stratified – Managerial - Cox regression analyses of commute mode and cancer outcomes from the ONS Longitudinal Study 1991-2015/16

	Cancer incidence			Cancer mortality		
Commute mode	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**
Sedentary	1.00	1.00	1.00	1.00	1.00	1.00
Bus	0.81 (0.72, 0.91)	0.95 (0.84, 1.08)	0.94 (0.83, 1.07)	0.89 (0.71, 1.11)	0.85 (0.67, 1.08)	0.81 (0.64, 1.03)
Rail	0.64 (0.59, 0.70)	0.91 (0.83, 1.00)	0.92 (0.84, 1.00)	0.63 (0.53, 0.75)	0.82 (0.69, 0.98)	0.84 (0.70, 1.00)
Walk	0.82 (0.74, 0.91)	0.89 (0.80, 0.99)	0.89 (0.80, 0.99)	1.05 (0.88, 1.26)	1.03 (0.86, 1.25)	0.99 (0.82, 1.20)
Cycle	0.72 (0.60, 0.85)	0.93 (0.78, 1.10)	0.93 (0.78, 1.11)	0.69 (0.48, 0.98)	0.84 (0.59, 1.19)	0.86 (0.60, 1.22)
Age at baseline	1.07 (1.07, 1.07)	1.13 (1.12, 1.15)	1.13 (1.12, 1.15)	1.09 (1.09, 1.09)	1.19 (1.16, 1.21)	1.19 (1.16, 1.21)
Age at baseline squared	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)
Women	1.03 (0.99, 1.08)	1.21 (1.15, 1.27)	1.21 (1.15, 1.27)	0.83 (0.76, 0.91)	0.97 (0.89, 1.07)	0.98 (0.89, 1.08)
Married	1.80 (1.71, 1.89)	1.02 (0.96, 1.08)	1.02 (0.96, 1.08)	1.82 (1.64, 2.01)	0.98 (0.88, 1.10)	1.00 (0.90, 1.12)
Black minority ethnic	0.50 (0.44, 0.56)	0.62 (0.55, 0.70)	0.62 (0.55, 0.70)	0.69 (0.56, 0.84)	0.83 (0.67, 1.02)	0.81 (0.65, 1.00)
Has access to a car	1.30 (1.17, 1.44)	0.95 (0.84, 1.06)	0.95 (0.85, 1.07)	0.82 (0.70, 0.97)	0.63 (0.52, 0.77)	0.69 (0.56, 0.84)
Population density 2000+ persons/km^2	0.77 (0.73, 0.81)	0.97 (0.92, 1.01)	0.95 (0.90, 1.00)	0.85 (0.78, 0.93)	1.05 (0.95, 1.15)	0.96 (0.86, 1.06)
Has a long term illness at baseline	1.48 (1.32, 1.67)	1.13 (1.00, 1.27)	1.12 (1.00, 1.27)	2.78 (2.34, 3.31)	1.83 (1.53, 2.19)	1.79 (1.50, 2.14)
Entered study 1991	1.00	1.00	1.00	1.00	1.00	1.00
Entered study 2001	0.45 (0.42, 0.48)	0.43 (0.40, 0.46)	0.43 (0.40, 0.46)	0.49 (0.43, 0.56)	0.41 (0.36, 0.47)	0.41 (0.36, 0.47)
Entered study 2011	0.25 (0.22, 0.28)	0.19 (0.16, 0.21)	0.19 (0.16, 0.21)	0.26 (0.20, 0.34)	0.14 (0.10, 0.18)	0.14 (0.10, 0.18)
Has a degree	0.83 (0.79, 0.88)		0.95 (0.90, 1.00)	0.68 (0.61, 0.75)		0.81 (0.73, 0.89)
Non-home owner	0.57 (0.53, 0.62)		0.95 (0.87, 1.03)	0.73 (0.63, 0.84)		1.07 (0.92, 1.25)
Carstairs Deprivation Index Quintile						
Least deprived	1.00		1.00	1.00		1.00
Next least deprived	0.96 (0.90, 1.02)		1.05 (0.99, 1.12)	0.98 (0.86, 1.11)		1.06 (0.93, 1.20)
Mid-point	0.83 (0.78, 0.89)		1.00 (0.93, 1.07)	0.93 (0.81, 1.06)		1.10 (0.96, 1.27)
Moderate deprivation	0.78 (0.73, 0.84)		1.06 (0.98, 1.15)	0.88 (0.76, 1.02)		1.17 (1.00, 1.36)
Most deprived	0.71 (0.65, 0.77)		1.13 (1.03, 1.24)	1.02 (0.88, 1.19)		1.50 (1.27, 1.78)
	Failures = 7,118	N = 165,297		Failures = 1,897	N = 166469	

NSSEC – National Statistics socio-economic classification

Appendix Table A-31: NSSEC Stratified – Intermediate - Cox regression analyses of commute mode and mortality outcomes from the ONS Longitudinal Study 1991-2016

	All-cause mortality			CVD mortality		
Commute mode	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**
Sedentary	1.00	1.00	1.00	1.00	1.00	1.00
Bus	0.97 (0.86, 1.10)	1.09 (0.95, 1.25)	1.06 (0.92, 1.22)	0.85 (0.64, 1.12)	1.20 (0.87, 1.65)	1.16 (0.84, 1.60)
Rail	0.72 (0.62, 0.84)	0.89 (0.76, 1.04)	0.90 (0.77, 1.06)	0.65 (0.46, 0.91)	0.86 (0.60, 1.22)	0.88 (0.62, 1.25)
Walk	1.18 (1.05, 1.32)	1.15 (1.03, 1.30)	1.13 (1.00, 1.27)	1.04 (0.80, 1.34)	1.15 (0.88, 1.51)	1.12 (0.86, 1.46)
Cycle	0.81 (0.61, 1.07)	0.83 (0.62, 1.11)	0.84 (0.63, 1.12)	0.77 (0.41, 1.44)	0.85 (0.45, 1.60)	0.87 (0.46, 1.63)
Age at baseline	1.09 (1.08, 1.09)	1.10 (1.09, 1.12)	1.11 (1.09, 1.12)	1.11 (1.10, 1.12)	1.18 (1.14, 1.22)	1.18 (1.14, 1.23)
Age at baseline squared	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)
Women	0.52 (0.49, 0.56)	0.59 (0.55, 0.64)	0.61 (0.56, 0.65)	0.26 (0.22, 0.31)	0.31 (0.25, 0.37)	0.31 (0.26, 0.38)
Married	1.43 (1.33, 1.54)	0.79 (0.73, 0.86)	0.82 (0.76, 0.89)	1.69 (1.43, 1.99)	0.78 (0.66, 0.93)	0.81 (0.68, 0.97)
Black minority ethnic	0.66 (0.57, 0.77)	0.79 (0.68, 0.93)	0.77 (0.66, 0.91)	0.96 (0.71, 1.29)	1.17 (0.86, 1.59)	1.11 (0.81, 1.52)
Has access to a car	0.61 (0.55, 0.67)	0.65 (0.58, 0.74)	0.73 (0.65, 0.83)	0.65 (0.52, 0.81)	0.67 (0.51, 0.87)	0.73 (0.55, 0.97)
Population density 2000+ persons/km^2	0.95 (0.89, 1.02)	1.05 (0.98, 1.13)	0.99 (0.92, 1.08)	0.93 (0.80, 1.07)	1.00 (0.86, 1.17)	0.89 (0.75, 1.05)
Has a long term illness at baseline	3.96 (3.57, 4.40)	2.22 (1.99, 2.47)	2.16 (1.93, 2.41)	5.05 (4.10, 6.23)	2.46 (1.98, 3.07)	2.41 (1.93, 3.01)
Entered study 1991	1.00	1.00	1.00	1.00	1.00	1.00
Entered study 2001	0.51 (0.45, 0.57)	0.38 (0.34, 0.42)	0.37 (0.33, 0.41)	0.44 (0.33, 0.57)	0.28 (0.21, 0.37)	0.27 (0.21, 0.36)
Entered study 2011	0.51 (0.43, 0.59)	0.19 (0.16, 0.22)	0.17 (0.15, 0.21)	0.57 (0.38, 0.85)	0.14 (0.09, 0.22)	0.14 (0.09, 0.21)
Has a degree	0.68 (0.60, 0.77)		0.88 (0.77, 1.00)	0.71 (0.53, 0.95)		0.92 (0.69, 1.24)
Non-home owner	1.17 (1.08, 1.28)		1.39 (1.27, 1.53)	1.03 (0.84, 1.26)		1.17 (0.94, 1.45)
Carstairs Deprivation Index Quintile						
Least deprived	1.00		1.00	1.00		1.00
Next least deprived	0.92 (0.83, 1.02)		0.96 (0.86, 1.06)	1.31 (1.04, 1.65)		1.37 (1.09, 1.72)
Mid-point	0.96 (0.86, 1.06)		1.06 (0.95, 1.18)	1.11 (0.87, 1.42)		1.29 (1.00, 1.65)
Moderate deprivation	0.98 (0.88, 1.09)		1.12 (1.00, 1.25)	1.39 (1.10, 1.77)		1.68 (1.31, 2.16)
Most deprived	0.99 (0.88, 1.11)		1.15 (1.01, 1.31)	1.28 (0.99, 1.65)		1.57 (1.18, 2.10)
	Failures = 3,277	N = 124,800		Failures = 690	N = 124,800	

NSSEC – National Statistics socio-economic classification

Appendix Table A-32: NSSEC Stratified – Intermediate - Cox regression analyses of commute mode and cancer outcomes from the ONS Longitudinal Study 1991-2015/16

	Cancer incidence			Cancer mortality		
Commute mode	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**
Sedentary	1.00	1.00	1.00	1.00	1.00	1.00
Bus	0.80 (0.72, 0.90)	0.93 (0.83, 1.04)	0.92 (0.82, 1.04)	0.94 (0.79, 1.13)	1.05 (0.86, 1.28)	1.03 (0.84, 1.26)
Rail	0.61 (0.54, 0.69)	0.85 (0.75, 0.97)	0.85 (0.75, 0.97)	0.59 (0.47, 0.75)	0.81 (0.64, 1.03)	0.82 (0.64, 1.04)
Walk	1.07 (0.97, 1.17)	1.04 (0.94, 1.14)	1.03 (0.94, 1.13)	1.21 (1.03, 1.42)	1.17 (0.99, 1.37)	1.14 (0.97, 1.35)
Cycle	0.71 (0.56, 0.91)	0.80 (0.63, 1.01)	0.80 (0.63, 1.01)	0.78 (0.52, 1.18)	0.85 (0.56, 1.29)	0.86 (0.57, 1.30)
Age at baseline	1.07 (1.07, 1.07)	1.14 (1.12, 1.15)	1.14 (1.12, 1.15)	1.09 (1.08, 1.09)	1.19 (1.16, 1.21)	1.19 (1.16, 1.22)
Age at baseline squared	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)
Women	1.00 (0.95, 1.06)	1.16 (1.09, 1.22)	1.16 (1.10, 1.23)	0.72 (0.66, 0.80)	0.84 (0.76, 0.93)	0.86 (0.77, 0.95)
Married	1.81 (1.71, 1.93)	1.00 (0.94, 1.06)	1.01 (0.95, 1.08)	1.80 (1.62, 2.01)	0.95 (0.84, 1.06)	0.98 (0.87, 1.10)
Black minority ethnic	0.45 (0.39, 0.52)	0.56 (0.48, 0.64)	0.55 (0.48, 0.64)	0.46 (0.35, 0.59)	0.58 (0.44, 0.75)	0.57 (0.44, 0.75)
Has access to a car	1.11 (1.00, 1.24)	0.99 (0.88, 1.11)	1.03 (0.92, 1.16)	0.77 (0.65, 0.90)	0.75 (0.62, 0.91)	0.84 (0.69, 1.01)
Population density 2000+ persons/km^2	0.82 (0.78, 0.87)	0.99 (0.93, 1.05)	0.99 (0.93, 1.05)	0.91 (0.83, 1.00)	1.08 (0.97, 1.19)	1.05 (0.94, 1.17)
Has a long term illness at baseline	1.50 (1.33, 1.70)	1.04 (0.92, 1.18)	1.03 (0.91, 1.17)	2.78 (2.34, 3.29)	1.68 (1.41, 2.01)	1.64 (1.38, 1.96)
Entered study 1991	1.00	1.00	1.00	1.00	1.00	1.00
Entered study 2001	0.52 (0.48, 0.57)	0.47 (0.44, 0.51)	0.47 (0.43, 0.51)	0.48 (0.41, 0.57)	0.37 (0.32, 0.44)	0.36 (0.31, 0.43)
Entered study 2011	0.37 (0.33, 0.43)	0.25 (0.22, 0.29)	0.24 (0.21, 0.28)	0.33 (0.26, 0.43)	0.14 (0.11, 0.19)	0.14 (0.10, 0.18)
Has a degree	0.76 (0.69, 0.84)		0.99 (0.90, 1.09)	0.63 (0.52, 0.76)		0.86 (0.71, 1.04)
Non-home owner	0.78 (0.72, 0.84)		1.16 (1.07, 1.26)	1.00 (0.88, 1.14)		1.41 (1.22, 1.62)
Carstairs Deprivation Index Quintile						
Least deprived	1.00		1.00	1.00		1.00
Next least deprived	0.90 (0.83, 0.97)		0.96 (0.88, 1.03)	0.83 (0.72, 0.95)		0.87 (0.76, 1.01)
Mid-point	0.83 (0.76, 0.90)		0.96 (0.89, 1.05)	0.90 (0.78, 1.03)		1.02 (0.88, 1.18)
Moderate deprivation	0.80 (0.74, 0.87)		1.03 (0.94, 1.13)	0.84 (0.72, 0.97)		1.02 (0.87, 1.20)
Most deprived	0.67 (0.61, 0.73)		0.97 (0.87, 1.08)	0.78 (0.66, 0.92)		1.02 (0.85, 1.23)
	Failures = 5,150	N = 123,836		Failures = 1,609	N = 124, 800	

NSSEC – National Statistics socio-economic classification

Appendix Table A-33: NSSEC Stratified – Routine and Manual - Cox regression analyses of commute mode and mortality outcomes from the ONS Longitudinal Study 1991-2016

	All-cause mortality		CVD mortality	
Commute mode	**Unadjusted HR (95%CI)**	**Adjusted HR (95%CI)**	**Unadjusted HR (95%CI)**	**Adjusted HR (95%CI)**
Sedentary	1.00	1.00	1.00	1.00
Bus	1.16 (1.08, 1.24)	1.05 (0.97, 1.14)	1.03 (0.95, 1.11)	1.01 (0.87, 1.17)	0.94 (0.79, 1.11)	0.90 (0.76, 1.06)
Rail	1.13 (0.99, 1.28)	1.10 (0.96, 1.25)	1.10 (0.96, 1.25)	1.18 (0.92, 1.52)	1.04 (0.80, 1.34)	1.03 (0.79, 1.33)
Walk	1.04 (0.98, 1.11)	0.98 (0.91, 1.05)	0.96 (0.90, 1.04)	0.86 (0.75, 0.99)	0.89 (0.77, 1.04)	0.87 (0.74, 1.01)
Cycle	0.96 (0.86, 1.08)	0.83 (0.73, 0.93)	0.83 (0.73, 0.93)	0.86 (0.68, 1.10)	0.74 (0.58, 0.94)	0.73 (0.57, 0.94)
Age at baseline	1.09 (1.09, 1.09)	1.12 (1.11, 1.13)	1.12 (1.11, 1.13)	1.11 (1.10, 1.11)	1.20 (1.17, 1.24)	1.20 (1.17, 1.24)
Age at baseline squared	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)
Women	0.62 (0.59, 0.66)	0.56 (0.53, 0.59)	0.57 (0.54, 0.60)	0.38 (0.34, 0.43)	0.36 (0.32, 0.40)	0.37 (0.33, 0.41)
Married	1.46 (1.39, 1.53)	0.78 (0.74, 0.83)	0.80 (0.76, 0.85)	1.69 (1.52, 1.87)	0.80 (0.71, 0.89)	0.83 (0.74, 0.93)
Black minority ethnic	0.59 (0.52, 0.66)	0.64 (0.57, 0.72)	0.65 (0.58, 0.73)	0.81 (0.66, 0.99)	0.90 (0.73, 1.11)	0.90 (0.73, 1.12)
Has access to a car	0.59 (0.56, 0.62)	0.68 (0.63, 0.72)	0.72 (0.67, 0.77)	0.59 (0.53, 0.66)	0.65 (0.57, 0.74)	0.71 (0.62, 0.82)
Population density 2000+ persons/km^2	1.03 (0.98, 1.08)	1.02 (0.97, 1.07)	1.01 (0.96, 1.07)	1.11 (1.01, 1.22)	1.07 (0.97, 1.18)	0.99 (0.89, 1.11)
Has a long term illness at baseline	2.93 (2.72, 3.16)	1.73 (1.60, 1.87)	1.71 (1.58, 1.85)	3.38 (2.93, 3.91)	1.84 (1.59, 2.14)	1.83 (1.57, 2.12)
Entered study 1991	1.00	1.00	1.00	1.00	1.00	1.00
Entered study 2001	0.53 (0.50, 0.58)	0.46 (0.43, 0.50)	0.45 (0.42, 0.49)	0.46 (0.38, 0.54)	0.37 (0.31, 0.44)	0.36 (0.30, 0.43)
Entered study 2011	0.39 (0.34, 0.44)	0.20 (0.18, 0.23)	0.19 (0.17, 0.22)	0.32 (0.23, 0.43)	0.13 (0.09, 0.18)	0.12 (0.09, 0.17)
Has a degree	0.69 (0.60, 0.80)		0.90 (0.78, 1.04)	0.55 (0.38, 0.78)		0.74 (0.52, 1.06)
Non-home owner	1.23 (1.17, 1.30)		1.24 (1.18, 1.32)	1.32 (1.19, 1.46)		1.32 (1.18, 1.47)
Carstairs Deprivation Index Quintile						
Least deprived	1.00		1.00	1.00		1.00
Next least deprived	0.97 (0.89, 1.05)		0.97 (0.90, 1.06)	1.09 (0.92, 1.30)		1.11 (0.93, 1.32)
Mid-point	0.97 (0.90, 1.06)		0.99 (0.91, 1.08)	1.19 (1.00, 1.40)		1.23 (1.04, 1.46)
Moderate deprivation	0.98 (0.90, 1.05)		1.02 (0.94, 1.11)	1.18 (1.00, 1.39)		1.26 (1.06, 1.50)
Most deprived	1.00 (0.92, 1.08)		1.02 (0.94, 1.12)	1.28 (1.08, 1.51)		1.32 (1.09, 1.58)
	Failures = 6,873	N = 184,415		Failures = 1,688	N = 184,415	

NSSEC – National Statistics socio-economic classification

Appendix Table A-34: NSSEC Stratified – Routine and Manual - Cox regression analyses of commute mode and cancer outcomes from the ONS Longitudinal Study 1991-2015/16

	Cancer incidence			Cancer mortality		
Commute mode	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**
Sedentary	1.00	1.00	1.00	1.00	1.00	1.00
Bus	1.00 (0.94, 1.07)	1.00 (0.93, 1.07)	0.99 (0.92, 1.07)	1.14 (1.02, 1.27)	1.07 (0.95, 1.21)	1.05 (0.93, 1.19)
Rail	0.70 (0.61, 0.81)	0.87 (0.75, 1.00)	0.87 (0.75, 1.00)	0.94 (0.76, 1.16)	1.07 (0.86, 1.33)	1.07 (0.86, 1.33)
Walk	1.03 (0.97, 1.09)	0.93 (0.88, 0.99)	0.93 (0.88, 0.99)	1.09 (0.99, 1.20)	0.98 (0.88, 1.09)	0.97 (0.87, 1.08)
Cycle	0.93 (0.83, 1.03)	0.90 (0.81, 1.00)	0.90 (0.81, 1.00)	0.93 (0.77, 1.11)	0.84 (0.70, 1.01)	0.84 (0.70, 1.01)
Age at baseline	1.07 (1.07, 1.07)	1.14 (1.13, 1.16)	1.14 (1.13, 1.16)	1.09 (1.09, 1.10)	1.21 (1.19, 1.24)	1.22 (1.19, 1.24)
Age at baseline squared	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)
Women	1.07 (1.03, 1.12)	1.02 (0.97, 1.07)	1.02 (0.98, 1.07)	0.85 (0.79, 0.91)	0.78 (0.72, 0.84)	0.78 (0.72, 0.85)
Married	1.96 (1.87, 2.06)	1.00 (0.95, 1.05)	1.00 (0.95, 1.06)	1.91 (1.77, 2.07)	0.94 (0.86, 1.02)	0.95 (0.88, 1.04)
Black minority ethnic	0.47 (0.42, 0.53)	0.54 (0.48, 0.61)	0.53 (0.48, 0.60)	0.35 (0.28, 0.44)	0.40 (0.32, 0.50)	0.40 (0.32, 0.50)
Has access to a car	0.96 (0.91, 1.02)	0.97 (0.91, 1.04)	0.98 (0.91, 1.04)	0.72 (0.66, 0.79)	0.78 (0.70, 0.87)	0.82 (0.73, 0.91)
Population density 2000+ persons/km^2	0.94 (0.90, 0.98)	1.02 (0.98, 1.06)	1.02 (0.97, 1.06)	0.99 (0.92, 1.06)	1.04 (0.97, 1.12)	1.03 (0.96, 1.12)
Has a long term illness at baseline	1.43 (1.31, 1.56)	1.00 (0.91, 1.09)	1.00 (0.91, 1.09)	1.91 (1.66, 2.18)	1.19 (1.03, 1.36)	1.18 (1.03, 1.36)
Entered study 1991	1.00	1.00	1.00	1.00	1.00	1.00
Entered study 2001	0.50 (0.47, 0.53)	0.49 (0.46, 0.52)	0.49 (0.46, 0.52)	0.45 (0.40, 0.51)	0.41 (0.36, 0.46)	0.40 (0.35, 0.45)
Entered study 2011	0.30 (0.26, 0.33)	0.24 (0.22, 0.27)	0.24 (0.21, 0.27)	0.27 (0.22, 0.33)	0.17 (0.13, 0.21)	0.16 (0.13, 0.20)
Has a degree	0.79 (0.70, 0.88)		1.02 (0.91, 1.14)	0.70 (0.57, 0.86)		0.98 (0.79, 1.21)
Non-home owner	0.83 (0.79, 0.88)		1.01 (0.95, 1.06)	1.03 (0.95, 1.12)		1.17 (1.07, 1.27)
Carstairs Deprivation Index Quintile						
Least deprived	1.00		1.00	1.00		1.00
Next least deprived	0.92 (0.86, 0.99)		0.95 (0.88, 1.02)	0.91 (0.81, 1.03)		0.93 (0.83, 1.05)
Mid-point	0.82 (0.76, 0.88)		0.88 (0.82, 0.94)	0.85 (0.75, 0.95)		0.89 (0.79, 1.01)
Moderate deprivation	0.86 (0.81, 0.92)		0.98 (0.92, 1.06)	0.87 (0.78, 0.98)		0.97 (0.86, 1.10)
Most deprived	0.80 (0.75, 0.86)		0.99 (0.92, 1.07)	0.86 (0.76, 0.96)		1.00 (0.87, 1.14)
	Failures = 8,662	N = 183,446		Failures = 3,003	N = 184,415	

NSSEC – National Statistics socio-economic classification

Appendix Table A-35: Population density stratified – <2000 ppkm^2 - Cox regression analyses of commute mode and cancer outcomes from the ONS Longitudinal Study 1991-2016

	All-cause mortality			CVD mortality		
Commute mode	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**
Sedentary	1.00	1.00	1.00	1.00	1.00	1.00
Bus	1.06 (0.95, 1.18)	1.02 (0.91, 1.14)	0.95 (0.85, 1.07)	0.91 (0.72, 1.15)	0.97 (0.75, 1.25)	0.88 (0.68, 1.13)
Rail	0.72 (0.62, 0.83)	0.81 (0.70, 0.94)	0.89 (0.77, 1.04)	0.56 (0.39, 0.79)	0.61 (0.43, 0.88)	0.71 (0.49, 1.01)
Walk	1.20 (1.11, 1.29)	1.06 (0.98, 1.15)	0.97 (0.90, 1.06)	1.11 (0.94, 1.30)	1.08 (0.91, 1.29)	0.96 (0.81, 1.15)
Cycle	1.04 (0.90, 1.20)	0.92 (0.80, 1.07)	0.86 (0.74, 1.00)	0.96 (0.70, 1.31)	0.84 (0.61, 1.15)	0.76 (0.55, 1.05)
Age at baseline	1.09 (1.09, 1.09)	1.11 (1.10, 1.12)	1.11 (1.10, 1.12)	1.11 (1.10, 1.11)	1.19 (1.15, 1.22)	1.18 (1.15, 1.21)
Age at baseline squared	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)
Women	0.57 (0.54, 0.60)	0.59 (0.56, 0.62)	0.59 (0.56, 0.63)	0.29 (0.26, 0.33)	0.31 (0.27, 0.35)	0.31 (0.27, 0.35)
Married	1.39 (1.32, 1.46)	0.75 (0.71, 0.80)	0.79 (0.74, 0.83)	1.67 (1.48, 1.88)	0.79 (0.69, 0.89)	0.84 (0.74, 0.95)
Black minority ethnic	0.59 (0.48, 0.72)	0.75 (0.61, 0.92)	0.78 (0.63, 0.96)	0.78 (0.52, 1.16)	1.00 (0.67, 1.48)	1.04 (0.70, 1.55)
Has access to a car	0.52 (0.48, 0.56)	0.63 (0.58, 0.69)	0.72 (0.66, 0.79)	0.51 (0.43, 0.59)	0.57 (0.47, 0.69)	0.68 (0.56, 0.82)
Has a long term illness at baseline	3.25 (3.00, 3.52)	1.94 (1.79, 2.11)	1.90 (1.74, 2.06)	4.06 (3.47, 4.75)	2.22 (1.89, 2.62)	2.16 (1.83, 2.54)
Entered study 1991	1.00	1.00	1.00	1.00	1.00	1.00
Entered study 2001	0.55 (0.51, 0.60)	0.44 (0.40, 0.47)	0.43 (0.39, 0.46)	0.46 (0.38, 0.55)	0.33 (0.27, 0.40)	0.32 (0.26, 0.39)
Entered study 2011	0.50 (0.44, 0.57)	0.20 (0.18, 0.23)	0.20 (0.17, 0.23)	0.51 (0.37, 0.72)	0.16 (0.11, 0.22)	0.15 (0.11, 0.22)
Has a degree	0.63 (0.59, 0.68)		0.82 (0.76, 0.89)	0.55 (0.47, 0.65)		0.78 (0.65, 0.94)
Non-home owner	1.31 (1.23, 1.39)		1.33 (1.25, 1.42)	1.40 (1.24, 1.59)		1.37 (1.20, 1.57)
Socio-economic classification (NSSEC)						
Higher	1.00		1.00	1.00		1.00
Intermediate	1.21 (1.13, 1.29)		1.09 (1.01, 1.17)	1.24 (1.08, 1.44)		1.15 (0.98, 1.34)
Routine/Manual	1.48 (1.40, 1.57)		1.19 (1.11, 1.27)	1.67 (1.48, 1.89)		1.29 (1.12, 1.48)
Carstairs Deprivation Index Quintile						
Least deprived	1.00		1.00	1.00		1.00
Next least deprived	1.03 (0.97, 1.09)		1.03 (0.97, 1.09)	1.25 (1.10, 1.43)		1.25 (1.09, 1.42)
Mid-point	1.05 (0.98, 1.12)		1.06 (0.99, 1.14)	1.22 (1.05, 1.41)		1.23 (1.06, 1.43)
Moderate deprivation	1.06 (0.98, 1.15)		1.10 (1.01, 1.19)	1.26 (1.07, 1.49)		1.32 (1.12, 1.57)
Most deprived	1.04 (0.93, 1.17)		1.08 (0.96, 1.22)	1.24 (0.98, 1.58)		1.30 (1.02, 1.66)
	Failures = 6,599	N = 199,303		Failures = 1,461	N = 199303	

NSSEC – National Statistics socio-economic classification, ppkm^2 – persons per square kilometre

Appendix Table A-36: Population density stratified –<2000 ppkm^2 - Cox regression analyses of commute mode and cancer outcomes from the ONS Longitudinal Study 1991-2015/16

	Cancer incidence			Cancer mortality		
Commute mode	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**
Sedentary	1.00	1.00	1.00	1.00	1.00	1.00
Bus	0.94 (0.86, 1.03)	0.98 (0.89, 1.08)	0.98 (0.89, 1.08)	0.99 (0.85, 1.16)	0.98 (0.83, 1.16)	0.94 (0.79, 1.11)
Rail	0.75 (0.67, 0.84)	0.92 (0.82, 1.03)	0.92 (0.82, 1.03)	0.67 (0.54, 0.84)	0.82 (0.66, 1.02)	0.87 (0.70, 1.09)
Walk	1.04 (0.98, 1.11)	0.93 (0.87, 0.99)	0.93 (0.87, 1.00)	1.19 (1.07, 1.33)	1.04 (0.93, 1.17)	0.98 (0.87, 1.10)
Cycle	0.84 (0.74, 0.96)	0.84 (0.74, 0.96)	0.85 (0.75, 0.97)	0.99 (0.80, 1.23)	0.94 (0.75, 1.16)	0.90 (0.72, 1.12)
Age at baseline	1.07 (1.07, 1.07)	1.14 (1.13, 1.15)	1.14 (1.13, 1.15)	1.09 (1.09, 1.09)	1.20 (1.17, 1.22)	1.20 (1.17, 1.22)
Age at baseline squared	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)
Women	1.04 (1.00, 1.08)	1.13 (1.09, 1.18)	1.13 (1.09, 1.18)	0.78 (0.72, 0.83)	0.84 (0.78, 0.90)	0.84 (0.78, 0.91)
Married	1.90 (1.82, 1.99)	1.03 (0.98, 1.07)	1.03 (0.98, 1.08)	1.85 (1.71, 2.01)	0.93 (0.86, 1.02)	0.96 (0.88, 1.05)
Black minority ethnic	0.52 (0.44, 0.61)	0.64 (0.54, 0.75)	0.63 (0.54, 0.75)	0.54 (0.40, 0.74)	0.71 (0.52, 0.96)	0.74 (0.54, 1.00)
Has access to a car	0.98 (0.90, 1.06)	0.99 (0.91, 1.08)	1.00 (0.91, 1.09)	0.69 (0.61, 0.78)	0.77 (0.67, 0.89)	0.85 (0.74, 0.98)
Has a long term illness at baseline	1.35 (1.23, 1.48)	0.98 (0.89, 1.08)	0.98 (0.89, 1.08)	2.17 (1.90, 2.49)	1.39 (1.21, 1.61)	1.37 (1.19, 1.58)
Entered study 1991	1.00	1.00	1.00	1.00	1.00	1.00
Entered study 2001	0.50 (0.48, 0.53)	0.45 (0.42, 0.48)	0.45 (0.42, 0.48)	0.49 (0.44, 0.55)	0.39 (0.34, 0.43)	0.38 (0.34, 0.43)
Entered study 2011	0.35 (0.31, 0.39)	0.23 (0.21, 0.26)	0.23 (0.21, 0.26)	0.34 (0.28, 0.42)	0.16 (0.13, 0.20)	0.15 (0.12, 0.19)
Has a degree	0.91 (0.87, 0.96)		0.99 (0.94, 1.05)	0.66 (0.59, 0.73)		0.81 (0.72, 0.90)
Non-home owner	0.78 (0.74, 0.83)		1.02 (0.96, 1.08)	1.04 (0.95, 1.14)		1.23 (1.11, 1.35)
Socio-economic classification (NSSEC)						
Higher	1.00		1.00	1.00		1.00
Intermediate	1.06 (1.01, 1.11)		1.00 (0.95, 1.06)	1.19 (1.08, 1.31)		1.05 (0.95, 1.16)
Routine/Manual	1.01 (0.97, 1.06)		0.98 (0.93, 1.03)	1.31 (1.20, 1.42)		1.07 (0.98, 1.18)
Carstairs Deprivation Index Quintile						
Least deprived	1.00		1.00	1.00		1.00
Next least deprived	0.94 (0.90, 0.98)		0.98 (0.94, 1.03)	0.95 (0.87, 1.04)		0.97 (0.89, 1.06)
Mid-point	0.84 (0.79, 0.89)		0.93 (0.88, 0.98)	0.95 (0.86, 1.05)		1.01 (0.91, 1.12)
Moderate deprivation	0.86 (0.81, 0.92)		1.03 (0.97, 1.10)	0.94 (0.84, 1.05)		1.07 (0.95, 1.20)
Most deprived	0.83 (0.76, 0.91)		1.07 (0.97, 1.18)	0.95 (0.80, 1.12)		1.12 (0.95, 1.33)
	Failures = 20,930	N = 390,555		Failures = 3,158	N = 199,303	

NSSEC – National Statistics socio-economic classification, ppkm^2 – persons per square kilometre

Appendix Table A-37: Population density stratified – 2000+ ppkm^2 - Cox regression analyses of commute mode and cancer outcomes from the ONS Longitudinal Study 1991-2016

	All-cause mortality			CVD mortality		
Commute mode	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**
Sedentary	1.00	1.00	1.00	1.00	1.00	1.00
Bus	1.26 (1.17, 1.34)	1.09 (1.01, 1.17)	1.03 (0.95, 1.11)	1.17 (1.02, 1.35)	1.08 (0.92, 1.27)	1.00 (0.85, 1.18)
Rail	0.74 (0.68, 0.81)	0.86 (0.79, 0.95)	0.90 (0.82, 0.99)	0.68 (0.56, 0.82)	0.78 (0.64, 0.95)	0.83 (0.68, 1.01)
Walk	1.15 (1.07, 1.23)	1.04 (0.96, 1.12)	0.99 (0.92, 1.07)	0.95 (0.82, 1.10)	0.95 (0.80, 1.11)	0.88 (0.75, 1.04)
Cycle	0.87 (0.76, 1.00)	0.78 (0.68, 0.89)	0.77 (0.67, 0.88)	0.90 (0.69, 1.19)	0.79 (0.60, 1.05)	0.76 (0.58, 1.01)
Age at baseline	1.09 (1.09, 1.10)	1.13 (1.12, 1.14)	1.13 (1.12, 1.14)	1.11 (1.11, 1.12)	1.21 (1.18, 1.24)	1.20 (1.17, 1.23)
Age at baseline squared	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)
Women	0.60 (0.57, 0.63)	0.59 (0.56, 0.62)	0.60 (0.57, 0.64)	0.33 (0.30, 0.37)	0.34 (0.30, 0.38)	0.35 (0.31, 0.39)
Married	1.45 (1.38, 1.52)	0.81 (0.77, 0.85)	0.83 (0.78, 0.87)	1.70 (1.53, 1.88)	0.81 (0.72, 0.90)	0.83 (0.74, 0.92)
Black minority ethnic	0.65 (0.60, 0.71)	0.72 (0.66, 0.79)	0.71 (0.65, 0.78)	0.84 (0.71, 0.98)	0.95 (0.81, 1.13)	0.92 (0.78, 1.09)
Has access to a car	0.56 (0.53, 0.59)	0.62 (0.58, 0.66)	0.68 (0.64, 0.73)	0.55 (0.49, 0.61)	0.59 (0.52, 0.68)	0.68 (0.59, 0.78)
Has a long term illness at baseline	3.72 (3.47, 3.98)	2.03 (1.89, 2.19)	1.98 (1.84, 2.14)	4.37 (3.81, 5.02)	2.15 (1.86, 2.48)	2.09 (1.81, 2.41)
Entered study 1991	1.00	1.00	1.00	1.00	1.00	1.00
Entered study 2001	0.50 (0.47, 0.54)	0.42 (0.39, 0.45)	0.41 (0.38, 0.44)	0.42 (0.35, 0.50)	0.32 (0.27, 0.39)	0.32 (0.27, 0.38)
Entered study 2011	0.40 (0.36, 0.45)	0.19 (0.17, 0.21)	0.18 (0.16, 0.20)	0.35 (0.27, 0.46)	0.12 (0.09, 0.17)	0.12 (0.09, 0.16)
Has a degree	0.55 (0.51, 0.59)		0.84 (0.77, 0.91)	0.48 (0.40, 0.56)		0.79 (0.66, 0.95)
Non-home owner	1.21 (1.15, 1.27)		1.23 (1.16, 1.30)	1.23 (1.11, 1.37)		1.19 (1.06, 1.34)
Socio-economic classification (NSSEC)						
Higher	1.00		1.00	1.00		1.00
Intermediate	1.25 (1.17, 1.34)		1.07 (1.00, 1.15)	1.17 (1.01, 1.35)		0.99 (0.85, 1.16)
Routine/Manual	1.66 (1.57, 1.75)		1.12 (1.05, 1.19)	1.88 (1.67, 2.11)		1.17 (1.03, 1.34)
Carstairs Deprivation Index Quintile						
Least deprived	1.00		1.00	1.00		1.00
Next least deprived	1.02 (0.93, 1.13)		1.00 (0.90, 1.10)	1.26 (1.01, 1.57)		1.23 (0.98, 1.53)
Mid-point	1.09 (0.99, 1.19)		1.06 (0.97, 1.16)	1.44 (1.17, 1.77)		1.41 (1.14, 1.74)
Moderate deprivation	1.13 (1.03, 1.24)		1.10 (1.01, 1.21)	1.52 (1.24, 1.87)		1.49 (1.21, 1.83)
Most deprived	1.24 (1.13, 1.35)		1.17 (1.07, 1.28)	1.74 (1.42, 2.12)		1.62 (1.31, 1.99)
	Failures = 7,384	N = 244,166		Failures = 1,711	N = 244,166	

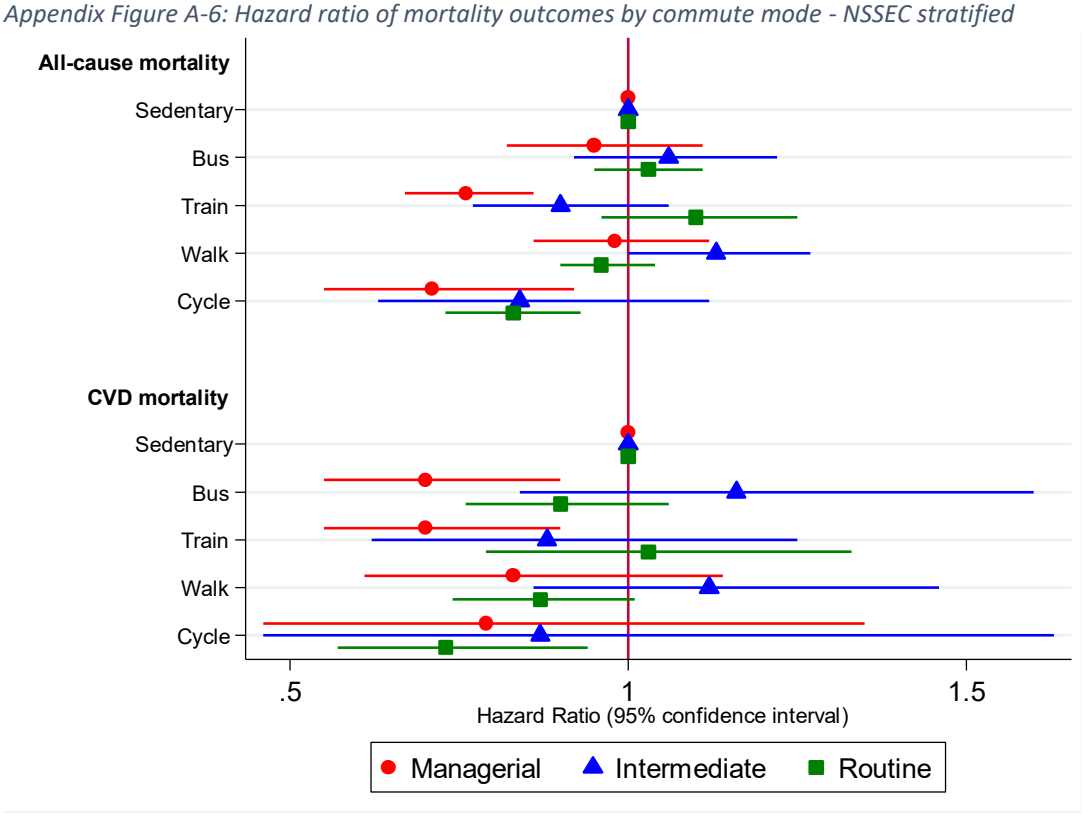
NSSEC – National Statistics socio-economic classification, ppkm^2 – persons per square kilometre

Appendix Table A-38: Population density stratified –2000+ ppkm^2 - Cox regression analyses of commute mode and cancer outcomes from the ONS Longitudinal Study 1991-20015/16

	Cancer incidence			Cancer mortality		
Commute mode	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**	**Unadjusted HR (95%CI)**	**HR (95%CI)**	**Adjusted HR (95%CI)**
Sedentary	1.00	1.00	1.00	1.00	1.00	1.00
Bus	0.95 (0.89, 1.01)	0.96 (0.90, 1.03)	0.95 (0.89, 1.02)	1.16 (1.05, 1.29)	1.05 (0.93, 1.18)	1.01 (0.90, 1.13)
Rail	0.63 (0.58, 0.68)	0.86 (0.80, 0.94)	0.87 (0.80, 0.94)	0.66 (0.58, 0.76)	0.88 (0.76, 1.01)	0.90 (0.78, 1.04)
Walk	1.00 (0.94, 1.06)	0.94 (0.88, 1.00)	0.93 (0.87, 0.99)	1.16 (1.05, 1.28)	1.02 (0.92, 1.14)	0.99 (0.89, 1.11)
Cycle	0.87 (0.78, 0.97)	0.93 (0.83, 1.04)	0.93 (0.83, 1.04)	0.82 (0.67, 1.01)	0.80 (0.65, 0.98)	0.80 (0.65, 0.99)
Age at baseline	1.07 (1.07, 1.07)	1.14 (1.13, 1.15)	1.14 (1.13, 1.15)	1.09 (1.09, 1.10)	1.20 (1.18, 1.22)	1.20 (1.18, 1.22)
Age at baseline squared	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)	1.00 (1.00, 1.00)
Women	1.04 (1.00, 1.08)	1.10 (1.06, 1.15)	1.11 (1.06, 1.15)	0.84 (0.79, 0.90)	0.86 (0.80, 0.93)	0.87 (0.81, 0.94)
Married	1.79 (1.72, 1.87)	0.99 (0.94, 1.03)	0.99 (0.95, 1.04)	1.81 (1.68, 1.94)	0.96 (0.88, 1.04)	0.97 (0.90, 1.06)
Black minority ethnic	0.49 (0.46, 0.53)	0.56 (0.52, 0.61)	0.56 (0.52, 0.61)	0.47 (0.41, 0.54)	0.54 (0.47, 0.62)	0.53 (0.46, 0.61)
Has access to a car	1.00 (0.95, 1.06)	0.96 (0.90, 1.02)	0.98 (0.92, 1.04)	0.70 (0.64, 0.76)	0.71 (0.65, 0.79)	0.77 (0.69, 0.86)
Has a long term illness at baseline	1.60 (1.47, 1.74)	1.10 (1.01, 1.20)	1.09 (1.00, 1.19)	2.57 (2.28, 2.89)	1.52 (1.34, 1.72)	1.49 (1.32, 1.69)
Entered study 1991	1.00	1.00	1.00	1.00	1.00	1.00
Entered study 2001	0.48 (0.46, 0.51)	0.47 (0.45, 0.50)	0.47 (0.45, 0.50)	0.46 (0.42, 0.51)	0.41 (0.37, 0.45)	0.40 (0.36, 0.45)
Entered study 2011	0.28 (0.26, 0.31)	0.22 (0.20, 0.24)	0.21 (0.19, 0.24)	0.26 (0.22, 0.31)	0.15 (0.12, 0.18)	0.14 (0.12, 0.17)
Has a degree	0.71 (0.68, 0.75)		0.95 (0.89, 1.00)	0.57 (0.52, 0.64)		0.88 (0.78, 0.98)
Non-home owner	0.78 (0.74, 0.82)		1.04 (0.98, 1.09)	0.99 (0.92, 1.08)		1.18 (1.08, 1.29)
Socio-economic classification (NSSEC)						
Higher	1.00		1.00	1.00		1.00
Intermediate	1.12 (1.07, 1.18)		0.99 (0.94, 1.05)	1.27 (1.16, 1.40)		1.07 (0.97, 1.18)
Routine/Manual	1.22 (1.17, 1.28)		0.99 (0.94, 1.04)	1.50 (1.38, 1.63)		1.03 (0.94, 1.13)
Carstairs Deprivation Index Quintile						
Least deprived	1.00		1.00	1.00		1.00
Next least deprived	0.99 (0.92, 1.07)		1.03 (0.95, 1.11)	0.96 (0.83, 1.10)		0.96 (0.84, 1.11)
Mid-point	0.92 (0.85, 0.99)		0.98 (0.92, 1.06)	0.96 (0.85, 1.10)		1.00 (0.87, 1.14)
Moderate deprivation	0.93 (0.86, 1.00)		1.05 (0.98, 1.13)	0.99 (0.87, 1.12)		1.06 (0.93, 1.20)
Most deprived	0.85 (0.79, 0.91)		1.06 (0.98, 1.14)	1.02 (0.90, 1.16)		1.14 (1.00, 1.30)
	Failures = 10,355	N = 243,029		Failures = 3,351	N = 244,166	

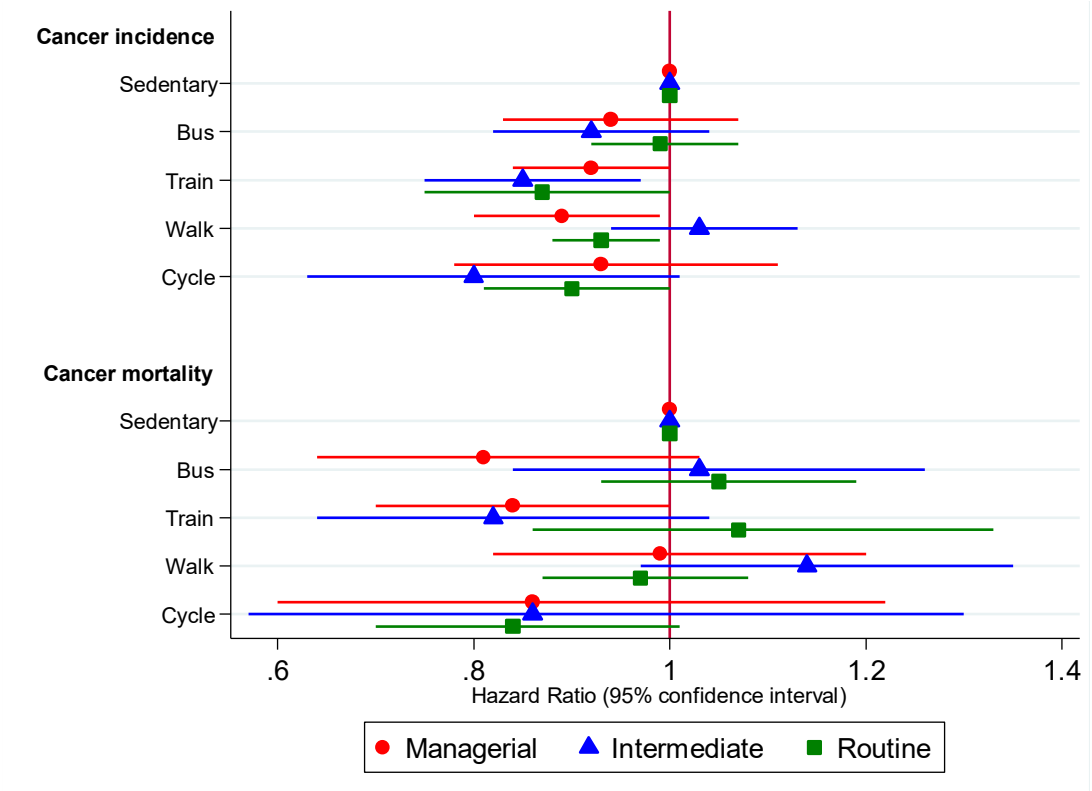
NSSEC – National Statistics socio-economic classification, ppkm^2 – persons per square kilometre

Appendix Figure A-6: Hazard ratio of mortality outcomes by commute mode - NSSEC stratified



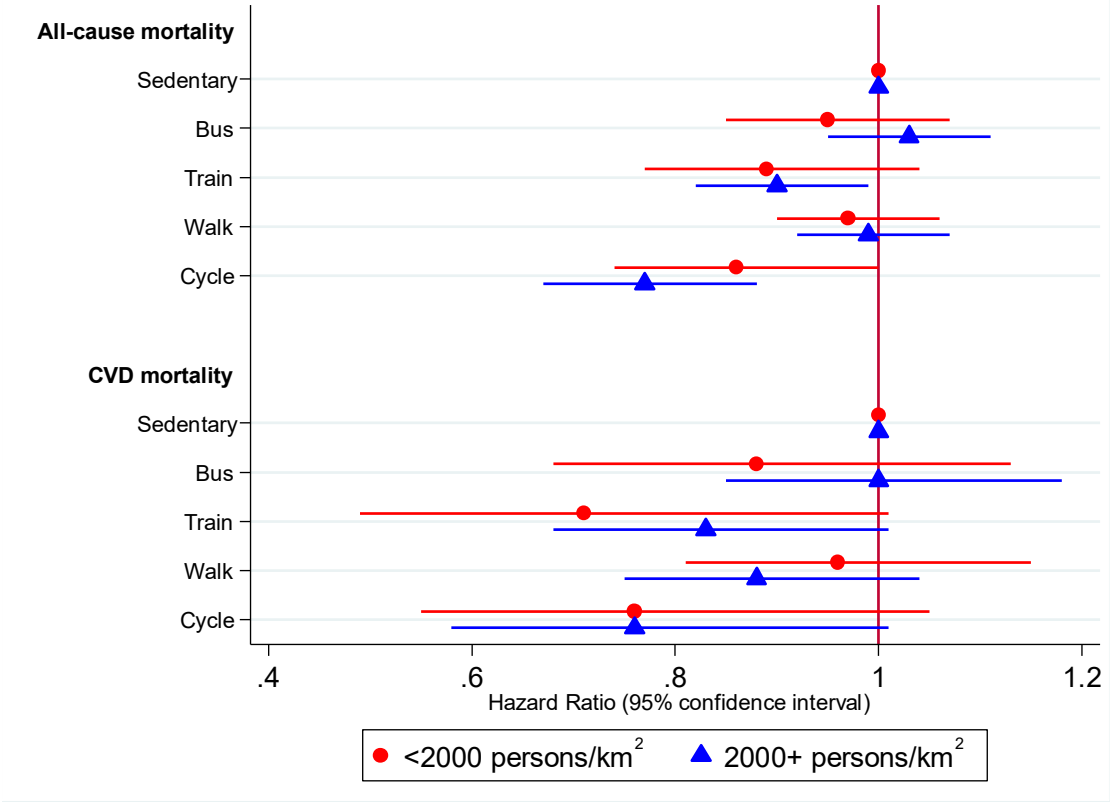
Source: ONS – Longitudinal Study *NSSEC – National Statistics Socio-economic Classification*

Appendix Figure A-7: Hazard ratio of cancer outcomes by commute mode - NSSEC stratified



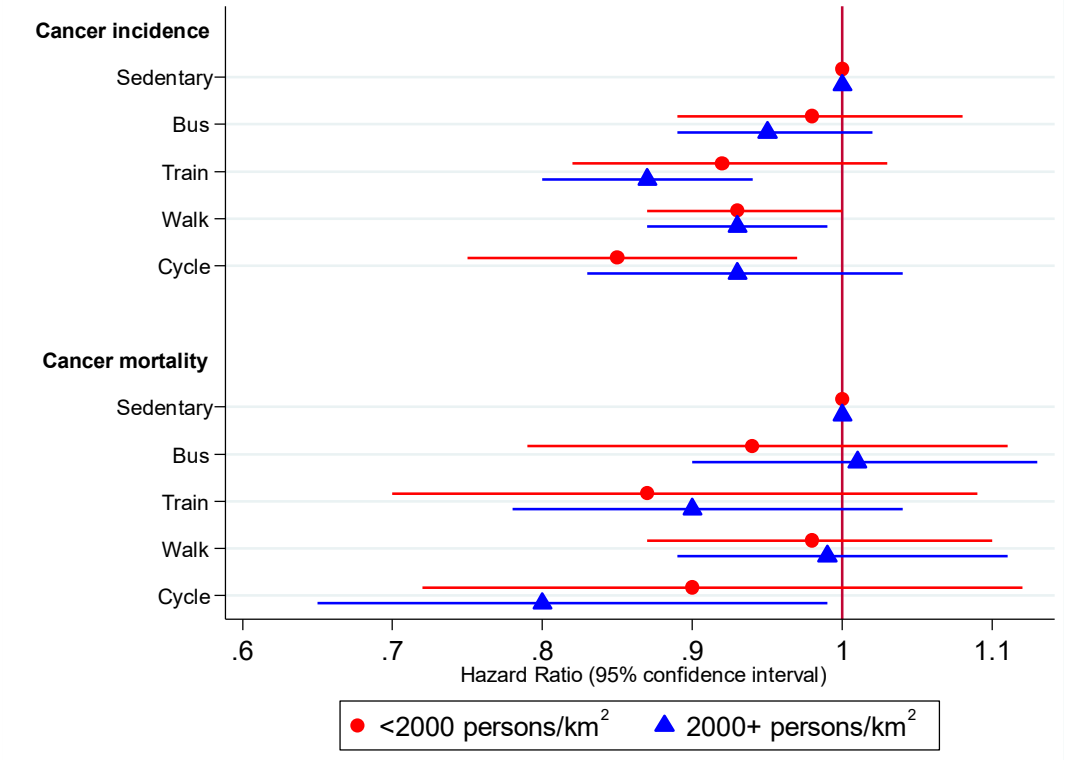
Source: ONS – Longitudinal Study *NSSEC – National Statistics Socio-economic Classification*

Appendix Figure A-8: Hazard ratio of mortality outcomes by commute mode - population density stratified



Source: ONS – Longitudinal Study

Appendix Figure A-9: Hazard ratio of cancer outcomes by commute mode - population density stratified



Source: ONS – Longitudinal Study

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Title: Ethnic group differences in impacts of free bus passes in England: A national study

Author: Richard Patterson,Elizabeth Webb,Jennifer S. Mindell,Christopher Millett,Anthony A. Laverty

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