Article:

Munyombwe, T orcid.org/0000-0002-1307-6691, Lovelace, R orcid.org/0000-0001-5679-6536, Green, MP et al. (9 more authors) (2020) Association of prevalence of active transport to work and incidence of myocardial infarction: A nationwide ecological study. European Journal of Preventive Cardiology, 27 (8). pp. 822-829. ISSN 2047-4873

https://doi.org/10.1177/2047487319876228

Title: Association of prevalence of active transport to work and incidence of myocardial infarction: A nationwide ecological study

Authors: Theresa Munyombwe,[1,2] Robin Lovelace,[2,3] Mark Green P,[4] Paul Norman,[7] Sarah Walpole,[5] Marlous Hall,[1,2] Adam Timmis,[10] Phil Batin,[9] Alistair Brownlee,[6] Jonathan Brownlee,[6] Ged Oliver,[8] Chris P Gale[1,2]

Affiliations:

1 Leeds Institute of Cardiovascular and Metabolic Medicine, University of Leeds, Leeds, UK

2 Leeds Institute for Data Analytics, University of Leeds, Leeds, UK

3 Institute for Transport Studies, University of Leeds, Leeds, UK

4 Department of Geography and Planning, University of Liverpool, Liverpool, UK.

5 Medecins sans Frontieres, London, UK

6 British Triathlon, UK

7 School of Geography, University of Leeds, Leeds, UK

8 Patient representative, Lancashire, United Kingdom

9 Department of Cardiology, Mid Yorkshire Hospitals NHS Trust, Wakefield, UK

10 NIHR Cardiovascular Biomedical Research Unit, Barts Heart Centre, London, UK

Corresponding author:

Professor Chris P Gale, Leeds Institute for Data Analytics, Level 11 Worsley Building, Clarendon Way, University of Leeds, Leeds, UK

Tel: +44 0113 343 8916, Email: c.p.gale@leeds.ac.uk, Twitter: @cpgale3

This work was supported by British Heart Foundation [PG/13/81/30474 to M.H and C.P.G]

Word count 4928

Abstract

Background: There is a paucity of population-based geospatial data about the association between active transport and myocardial infarction (MI). We investigated the association between active transport to work and incidence of MI.

Design: This ecological study of 325 local authorities in England included 43,077,039 employed individuals aged 25–74 years (UK Census, 2011), and 117,521 individuals with MI (Myocardial Ischaemia National Audit Project, 2011-2013).

Methods: Bayesian negative binomial regression models were used to investigate the association of active transport to work and incidence of MI adjusting for local levels of deprivation, obesity, smoking, diabetes, and physical activity.

Results: In 2011, the prevalence of active transportation to work for people in employment in England aged 25-74 years was 11.4% (4,531,182 active transporters; 8.6% walking and 2.8% cycling). Active transport in 2011 was associated with a reduced incidence of MI in 2012 amongst men cycling to work (incidence rate ratio (95% credible interval) 0.983 (0.967 to 0.999); and women walking to work (0.983 (0.967 to 0.999)) after full adjustments. However, the prevalence of active transport for men and women was not significantly associated with the combined incidence of MI between 2011 and 2013 after adjusting for physical activity, smoking and diabetes.

Conclusions: In England, the prevalence of active transportation was associated with a reduced incidence of MI for women walking and men cycling to work in corresponding local geographic areas. The overall association of active transport with MI was, however, explained by local area levels of smoking, diabetes and physical activity.

Abstract word count: 249

Keywords: Myocardial infarction, Cycling, Walking, Active transport

Introduction

Active transport, most commonly walking or cycling, is the use of physical activity to commute to work.[1, 2] Beyond the dose-response relationship between physical activity, cardiovascular fitness and mortality,[3, 4] those who engage in active transport have improved cardiovascular risk profiles, including a lower body mass index,[5, 6] less hypertension and diabetes,[6-8] and a reduced risk of cardiovascular disease and all-cause mortality.[9-11]

Active transport has been identified as a central theme for 'healthy cities' [12] and evidence suggests that the population benefits from interventions to promote cycling, such as bike hire schemes, outweigh the harms.[13-15] Moreover, the United Kingdom (UK) Government's Cycling and Walking Investment Strategy (CWIS) has recognised the potential of active transport to benefit society through cheaper travel, improved air quality and better health.[16] However, there is a paucity of population-based geospatial data about the association between active transport and myocardial infarction (MI).

The UK is unique in that there are a range of national data sources which prospectively collect information regarding active transport, population demographics and clinical outcomes such as MI. Therefore, we aimed to use data from the UK Census, the UK national heart attack register (Myocardial Ischaemia National Audit Project, MINAP) and Public Health England to investigate the association between the mode of active transport to work and the incidence of MI in men and women.

Methods

Study design and participants

We conducted an ecological study of 43,077,039 employed people aged 25–74 years in the 2011 UK Census, and 117,521 people hospitalised with MI in MINAP between 2011 and 2013, split according to the 325 Local Authorities in England.

Data sources

Exposure

The 2011 Census served as the exposure sampling frame for active transport data for the inhabitants of England. The Census collects self-reported information for all inhabitants of England and Wales, and in 2011 had a response rate of 94% for England. We extracted, by sex and decennial age band, the numbers of individuals living in England who identified their main mode of transport to work as either 'bicycle' or 'on foot'. Given that active transport data concerned only employed individuals, we restricted the cohort to those aged 25-74 years; we included ages 65-74 years because, although UK employment rates decline from the age of 65 years, the incidence of MI is elevated in this group.[17]

Primary outcome data

The primary outcome, MI in England between 2011 and 2013, was derived from MINAP, the UK national clinical register of admissions to hospital of patients with acute coronary syndrome.[18] The recorded diagnosis of MI in MINAP was made by the attending senior physician and based on the guidelines from the European Society of Cardiology, American College of Cardiology and the American Heart Association.[19]

Confounders

Data for potential confounders were obtained from the Public Health England 'FingerTips' database which can be found online.[20] This included geospatial information about the prevalence of overweight and obesity (defined as the proportion of individuals with a body mass index ≥25 kg/m^2 which was estimated from the Sport England's Active People Survey of n~150,000 per year with a minimum of 500 individuals per Local Authority), the prevalence of physical activity (defined as a minimum of 150 minutes of moderate or vigorous intensity physical activity per week which was estimated from the Sport England's Active People Survey), the prevalence of diabetes (which was estimated from the Quality Outcomes Framework data collected on individuals aged 17 years and over registered with General Practices), the prevalence of current smokers (which was estimated from the UK Office for National Statistics Integrated Household Survey (of ~200,000 participants per year),[21] and socioeconomic deprivation estimated from the 2011 English Indices of Multiple Deprivation.

Geographic units

For each of the data sources, information for England was extracted and aggregated to Local Government Unitary Authority's and Districts (Local Authority) level. English Local Authorities are administrative zones, tasked with the delivery of public health, and are the size of a large town or city (mean Local Authority population = 171,207 inhabitants). We included 325 Local Authorities (the City of London was excluded due to its small population).

Ethical approval

Given that all data were anonymised, aggregated and not linked, under the 2011 section 2.3 Governance Arrangements for Research Ethics Committees, this study did not need a favourable ethical opinion. The National Institute for Cardiovascular Outcomes Research, which includes the MINAP database, has support under section 251 of the National Health Service Act of 2006 to use patient information for medical research without informed consent.

Statistical analysis

Bayesian negative binomial regression based on the Integrated Nested Laplace Approximation (INLA) method[22, 23] was used to investigate the association between active transport and the incidence of MI stratified by sex. This method provides more precise parameter estimates, shortened computation time, and circumvents convergence issues compared to methods such as Markov Chain Monte Carlo.[24] The expected MI count was included in unadjusted and adjusted models as an offset to account for variability in the total population and its composition per Local Authority. Adjusted counts were calculated using indirect standardisation for sex and decennial age bands (25-34, 35-44, 45-54, 55-64, and 65-74 years). Models were fitted to separately investigate the association between the proportion of men and women in a Local Authority who walked or cycled to work in 2011 and the incidence of MI between 2011 and 2013. To investigate whether there was a lag effect between active transport and MI, models were fitted by MI counts for individual years (2011, 2012 and 2013). For these models, we incrementally increased the age ranges to reflect changes since the exposure in 2011 (i.e. in 2011 the population of interest in our outcome variables was ages 25-74 years, then in 2012 this was ages 26-75 years, and in 2013 it was ages 27-76 years). Analyses were adjusted for level of deprivation, prevalence of overweight and obesity, levels of physical activity, smoking, and prevalence of diabetes, estimated at each Local Authority. Results were expressed as incidence rate ratios (IRR) and associated 95% credible intervals (CI). All analyses were undertaken using the statistical software R Core 2017.[25]

Sensitivity analyses

A sensitivity analyses was conducted by adjusting the models for men and women for physically activity at the Local Authority level.

Patient involvement

No patients were involved in setting the research question, the outcome measures, the design or the implementation of the study. However, we involved a patient and two Olympic triathletes in the interpretation of the research findings, critical review of the manuscript and its dissemination.

Results

Descriptive data

According to the 2011 UK Census, there were 43,077,039 employed people aged 25–74 years. In 2011, the prevalence of active transportation to work for people in employment in England aged 25-74 years was 11.4% (4,531,182 active transporters), which varied according to Local Authority (median 10.3%, range 5%-41.6%). The prevalence of active transportation to work by Local Authority alongside crude area rates of MI and the point incidence of MI are presented in Figure 1. Overall, walking was more popular (8.6%) than cycling (2.8%). Cycling was more prevalent among men than women (3.8% vs. 1.7%), and walking more prevalent among women than men (11.7% vs. 6.0%). Active transport, predominantly cycling, was more prevalent among younger individuals, with 31.3% of those who cycled to work being aged 25-34 years and 30.2% of all those aged 25-74 years walked to work.

Myocardial infarction

Between 2011 and 2013, there were 117,521 recorded cases of MI in England (75.1%, n=88,201 men and 24.9%, n=29,320 women) which equated to a Local Authority median (IQR) of 196 (138-312) men and 63 (43-108) women hospitalised with MI (Figure 1). The crude rate of MI hospitalisations for England (2011-13) was 90.7 per 100,000 capita, with the crude rate being twice as high for men than women (122.1 vs. 60.3 per 100,000). The rates of MI increased with age, being highest for ages 65-74 years (234.7 per 100,000 capita).

Association between active transport in 2011 and incidence of MI between 2011 and 2013

Active transport in 2011 was associated with a reduced incidence of MI in 2011 and 2012 for men cycling to work (incidence rate ratio (95% credible interval) 0.984 (0.969-0.999) and 0.983 (0.967 to 0.999) respectively; and a reduced incidence of MI in 2012 and 2013 for women walking to work (0.983 (0.967 to 0.999) and 0.979 (0.958-0.999)) after full adjustment (Table 1).

The prevalence of active transport in 2011 for men and women was significantly associated with a reduced combined incidence of MI between 2011 and 2013 after adjustment for level of deprivation, prevalence of overweight and obesity (supplemental Table 1). However, the association with the combined incidence of MI between 2011 and 2013 was no longer evident after further adjusting for physical activity, smoking and diabetes (Table 1).

For men, there was no significant association (unadjusted or adjusted) between walking and the incidence of MI for all three years, and for women there was no significant association after adjustment between cycling and the incidence of MI for all three years.

Association between prevalence of active transport in 2011 and incidence of MI in 2011-2013 by age band for men and women

Age-stratified analyses found an inverse association between cycling to work and the incidence of MI in men aged 55-64 years in the corresponding geographical area, whereby a 1% increase in cycling prevalence was associated with a 3.5% decrease in the incidence of MI (IRR 0.965, 95% CIs 0.937-0.997) (Table 2). For women aged 45-54, a 1% increase in cycling prevalence was associated with a 3.8% decrease in the incidence of MI in the corresponding geographical area (IRR 0.962, 95% CIs 0.933-0.993).

An increased prevalence of walking to work was associated with a reduced incidence of MI in men aged 25-34 years (IRR 0.953, 95% CIs 0.930 to 0.977), 35-44 years (0.944, 0.913 to 0.978);, 45-54 years (0.920, 0.886 to 0.957), 55-64 years (0.916, 0.881 to 0.954) and 65-74 years (0.909, 95% CIs 0.862 to 0.961). A similar pattern was evident for women aged 25-34 years (IRR 0.967, 95% CIs 0.936 to 0.998), 35-44 years (0.949, 0.922 to 0.977), 45-54 years (0.952, 0.928 to 0.978), 55-64 years (0.959, 0.933 to 0.985) and 65-74 years (0.967, 0.941 to 0.994).

Discussion

In this national ecological study of over 40 million employed inhabitants of England aged 25-74 years of whom about 5 million were active transporters, the prevalence of walking to work was higher for women than men, and the prevalence of cycling to work was higher for men than women. In areas with increased levels of women walking and men cycling to work in 2011, the incidence of MI was reduced by 1.7% for women and men in 2012. These findings were independent of area levels of deprivation, obesity, physical activity, smoking and diabetes. Age-stratified analyses found that cycling to work was independently associated with a 3.5% reduced incidence of MI for men aged 55-64 years and a 3.8% reduced incidence of MI for women aged 45-54 years. Whilst we observed associations between these subgroups of active transport in 2011 and incidence of MI in 2012, the prevalence of walking and cycling for men and women did not have a significant association with the combined incidence of MI between 2011 and 2013 after adjustment for area levels of overall physical activity, smoking and diabetes.

Our findings support previous research which has found that cycling and walking is associated with improved cardiovascular risk profiles. Previous studies report associations between cycle commuting and lower risk of cardiovascular disease, cancer and mortality,[10, 26] walking and lower risk of cardiovascular mortality[4], active transport and diabetes and lower hypertension[27], active transportation and reduced risk of being overweight and obese.[3, 7, 27]

Many of these studies, however, were limited by small samples sizes,[6, 7, 28] imperfect data collection or self-reported outcomes and these studies were conducted more than 5 years ago using data from surveys conducted from 2005-2010. Few studies have investigated the relationship between active transportation to work and MI specifically – instead focussing on cardiovascular disease,[10, 26] hypertension,[27] overweight and diabetes,[3, 27] obesity,[3] mortality,[4, 10]and cancer.[10, 26, 29]

Our findings are, however, not in agreement with a Netherlands study which reported no association between walking and cardiovascular disease, though non-walkers made up only 3% of the cohort.[30] Whilst the other largest UK study to date (of 263,450 participants and 1,110 incident cardiovascular events) did find that self-reported cycling and walking was associated with improved cancer and cardiovascular outcomes, it was limited by potential healthy user bias sampling.[10] Our study mitigated issues of self-reporting health outcomes, small sample sizes and healthy user biases by using national data for exposure, outcomes and confounder estimates of 43 million individuals and 117,521 MI cases. Therefore, we provide, for the first time, nationwide data on the association between area levels of active transport to work and the incidence of MI within age, sex and year strata as well as by cycling and walking subgroups.

More broadly, the results of this study support previous research indicating that physical inactivity has major health impacts at the national level that can be alleviated by increasing the number of people who walk and cycle to work.[31] Due to its speed (enabling greater distances of travel than walking) and efficiency, cycling is a feasible approach for commuting which can increase physical activity levels and therefore help population health outcomes.[32] A recent study showed that physical activity is associated with a reduced risk of having significant coronary artery calcium in individuals with metabolic syndrome.[33] We found that the prevalence of active transport to work in England was low, but contest, therefore, that the potential to increase its uptake is great.

We found that the overall significant inverse association of active transport to work with MI was removed by local level estimates of smoking, diabetes and physical activity. Clearly, these traditional cardiovascular risk factors remain important determinants of the incidence of MI, and with a global trend for increasing rates,[34] should not be neglected. Moreover, the significant associations identified in this study suggest that active transportation is an important additional focal point for health policy and cardiovascular outcomes.

Study limitations

We recognise the limitations of our study. Data concerning MI were derived from MINAP, and in doing so were limited to hospitalised case; not all MIs are recorded in MINAP, and deaths due to MI occurring before hospital are not captured. Active transport data are comprehensive across the UK, but self-report the duration of active commuting and not its intensity. Self-reported data may underestimate the association between active commuting and reduced incidence of MI due to a tendency for participants to over-report their duration of physical activity.[35] It is plausible that patients who were at an increased risk of MI (with a number of risk factors and/or active cardiovascular disease) did not participate in active transportation and therefore inflated the healthier user effect reported in this study. Likewise, we cannot conclude a single direction of the association because, for example, people with coronary artery disease may have been less likely to actively transport to work. We adjusted for a range of potential confounders, but residual confounding is possible. Although other factors, may explain the results, our findings are supportive of previous studies that have found an association between active transport and improved health. Given that we did not use individual-level data, the ecological fallacy (in this case, the detection of a lower incidence of MI among the population who are not active commuters) is relevant. We reduced this bias by including data, where available, at the highest possible geographical resolution. Our use of population-grouped data also meant that we could not track individuals who may have migrated between Local Authorities between 2011 and 2013. Finally, this study does not propose causation.

Future directions

Future studies using individual-level data are required to investigate the causal relationship between active transport and MI. This as, well as more detailed information regarding duration and intensity of exercise (by means of person-reported data capture tools) linked to clinical outcomes data, would provide a stronger evidence base for investment in active transport to reduce the burden of cardiovascular disease.

Conclusion

This national ecological study of nearly 5 million active transporters to work in 2011 identified an inverse association between the local geographical area prevalence of walking and cycling to work and incidence of MI for men and women. Whilst the association overall was no longer evident after accounting for area levels of smoking, diabetes and physical activity, the effects of walking were independently associated with reduced incidence of MI for women, and the effects of cycling were independently associated with reduced incidence of MI for men. Therefore, efforts to increase the uptake of active transport to work are warranted to improve population-based health.

Acknowledgments

We gratefully acknowledge the contribution of all hospitals and healthcare professionals who participate in the MINAP registry. We acknowledge the MINAP

Academic Group and the National Institute for Cardiovascular Outcomes Research (NICOR) for providing the data for research.

Funding: This work was supported by British Heart Foundation [PG/13/81/30474 to M.H and C.P.G].

Declaration of Conflicts of interest

All authors have completed the Unified Competing Interest form at www.icmje.org/coi_disclosure.pdf and declare that [M.H and C.P.G] have support from [British Heart Foundation] for the submitted work; all the other co-authors have no financial relationships with any organisations that might have an interest in the submitted work in the previous 3 years; no other relationships or activities that could appear to have influenced the submitted work.

Author Contribution: CPG, MGP, MH, TA, PB and RL contributed to the conception and design of the work. MGP, RL, SW contributed to the acquisition of data, MCP, and RL contributed to analysis and interpretation of data for the work. TM, CPG, and RL drafted the manuscript. TM, PN, CPG, SW and MH contributed to manuscript writing and interpretation of data for the work. TM, PN, CPG, AT, SW and PB critically revised the manuscript. GO was involved as a patient advisor in the interpretation of the research and the writing of the manuscript. AB and JB reviewed and provided context to the research. All authors gave final approval and agree to be accountable for all aspects of the work ensuring integrity and accuracy.

References

1. Department of Transport. What is Active Transport ? London. 2011.

2. Department of Health. Start Active , Stay Active,. London2011.

3. 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: 420-35.

4. Yates T, Zaccardi F, Dhalwani NN, et al. Association of walking pace and handgrip strength with all-cause, cardiovascular, and cancer mortality: a UK Biobank observational study. *European heart journal*. 2017; 38: 3232-40.

5. 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: g4887.

6. Furie GL and Desai MM. Active transportation and cardiovascular disease risk factors in US adults. *American journal of preventive medicine*. 2012; 43: 621-8.

7. Millett C, Agrawal S, Sullivan R, et al. Associations between active travel to work and overweight, hypertension, and diabetes in India: a cross-sectional study. *PLoS medicine*. 2013; 10: e1001459.

8. Lee I-M, Shiroma EJ, Lobelo F, et al. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. *The lancet*. 2012; 380: 219-29.

9. Matthews CE, Jurj AL, Shu X-o, et al. Influence of exercise, walking, cycling, and overall nonexercise physical activity on mortality in Chinese women. *American Journal of Epidemiology*. 2007; 165: 1343-50.

10. Celis-Morales CA, Lyall DM, Welsh P, et al. Association between active commuting and incident cardiovascular disease, cancer, and mortality: prospective cohort study. *bmj*. 2017; 357: j1456.

11. Ekelund U, Steene-Johannessen J, Brown WJ, et al. Does physical activity attenuate, or even eliminate, the detrimental association of sitting time with mortality?

A harmonised meta-analysis of data from more than 1 million men and women. *The Lancet*. 2016; 388: 1302-10.

12. Rydin Y, Bleahu A, Davies M, et al. Shaping cities for health: complexity and the planning of urban environments in the 21st century. *Lancet*. 2012; 379: 2079.

13. Yang L, Sahlqvist S, McMinn A, Griffin SJ and Ogilvie D. Interventions to promote cycling: systematic review. *Bmj*. 2010; 341: c5293.

14. Rojas-Rueda D, de Nazelle A, Tainio M and Nieuwenhuijsen MJ. The health risks and benefits of cycling in urban environments compared with car use: health impact assessment study. *BMJ*. 2011; 343: d4521-d.

15. Woodcock J, Tainio M, Cheshire J, O'Brien O and Goodman A. Health effects of the London bicycle sharing system: health impact modelling study. *BMJ*. 2014; 348: g425-g.

16. Department for Transport. Cycling and Walking Investment Strategy. London, 2016.

17. Gale CP, Cattle B, Woolston A, et al. Resolving inequalities in care? Reduced mortality in the elderly after acute coronary syndromes. The Myocardial Ischaemia National Audit Project 2003–2010. *European heart journal*. 2011; 33: 630-9.

18. Herrett E, Smeeth L, Walker L, Weston C and Group MA. The myocardial ischaemia national audit project (MINAP). *Heart*. 2010; 96: 1264-7.

19. Thygesen K, Alpert JS, Jaffe AS, et al. Third universal definition of myocardial infarction. *European heart journal*. 2012; 33: 2551-67.

20. England PH. Public Health Profiles. *https://fingertipspheorguk/ [Date accessed: March 2017]*. 2018.

21. Office for National Statistics. Integrated Household Survey (IHS). 2016.

22. Rue H, Martino S and Chopin N. Approximate Bayesian inference for latent Gaussian models by using integrated nested Laplace approximations. *Journal of the royal statistical society: Series b (statistical methodology)*. 2009; 71: 319-92.

23. Blangiardo M and Cameletti M. *Spatial and spatio-temporal Bayesian models with R-INLA*. John Wiley & Sons, 2015.

24. Neyens T, Faes C and Molenberghs G. INLA estimation for the combined model integrated nested Laplace approximation for the analysis of count data via the combined model: A simulation study. *Communications in Statistics-Simulation and Computation*. 2018: 1-18.

25. Team R Core. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. 2016. 2017.

26. Panter J, Mytton O, Sharp S, et al. Using alternatives to the car and risk of all-cause, cardiovascular and cancer mortality. *Heart*. 2018; 104: 1749-55.

27. Laverty AA, Palladino R, Lee JT and Millett C. Associations between active travel and weight, blood pressure and diabetes in six middle income countries: a cross-sectional study in older adults. *International Journal of Behavioral Nutrition and Physical Activity*. 2015; 12: 65.

28. Gordon-Larsen P, Boone-Heinonen J, Sidney S, Sternfeld B, Jacobs DR and Lewis CE. Active commuting and cardiovascular disease risk: the CARDIA study. *Archives of internal medicine*. 2009; 169: 1216-23.

29. Sahlqvist S, Goodman A, Simmons RK, et al. The association of cycling with all-cause, cardiovascular and cancer mortality: findings from the population-based EPIC-Norfolk cohort. *BMJ open*. 2013; 3: e003797.

30. Hoevenaar-Blom MP, Wendel-Vos GW, Spijkerman AM, Kromhout D and Verschuren WM. Cycling and sports, but not walking, are associated with 10-year

cardiovascular disease incidence: the MORGEN Study. *European Journal of Cardiovascular Prevention & Rehabilitation*. 2011; 18: 41-7.

31. Allender S, Foster C, Scarborough P and Rayner M. The burden of physical activity-related ill health in the UK. *Journal of Epidemiology & Community Health*. 2007; 61: 344-8.

32. Woodcock J, Edwards P, Tonne C, et al. Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. *The Lancet*. 2009; 374: 1930-43.

33. Ekblom-Bak E, Ekblom Ö, Fagman E, et al. Fitness attenuates the prevalence of increased coronary artery calcium in individuals with metabolic syndrome. *European journal of preventive cardiology*. 2018; 25: 309-16.

34. Timmis A, Townsend N, Gale C, et al. European Society of Cardiology: cardiovascular disease statistics 2017. *European heart journal*. 2017; 39: 508-79.

35. Nocon M, Hiemann T, Müller-Riemenschneider F, Thalau F, Roll S and Willich SN. Association of physical activity with all-cause and cardiovascular mortality: a systematic review and meta-analysis. *European Journal of Cardiovascular Prevention & Rehabilitation*. 2008; 15: 239-46.

Figure Legends

Figure 1: Choropleths, by Local Authority in England of a) prevalence of cycling to work in 2011, b) prevalence of walking to work in 2011 and c) incidence of MI per 100,000 inhabitants in 2011-2013, and d) incidence of MI in England in 2011-13

Text tables

Table 1. Association between the prevalence of cycling and walking to work in 2011 and the incidence of hospitalised myocardial infarction in 2011, 2012 and 2013 for men and women.

Table 2: Association between prevalence of cycling and walking to work in 2011 and incidence of myocardial infarction in 2011-2013 by age band, for men and women.

Table 1. Association between the prevalence of cycling and walking to work in 2011 and the incidence of hospitalised myocardial infarction in 2011, 2012 and 2013 for men and women

	Men		**Women**	
	Walking	**Cycling**	**Walking**	**Cycling**
Unadjusted	**IRR (95%CI)**	**IRR (95%CI)**	**IRR (95%CI)**	**IRR (95%CI)**
2011	1.013 (0.995-1.030)	0.972 (0.956-0.989)	1.024 (1.008-1.041)	0.951 (0.925-0.977)
2012	1.013 (0.995-1.031)	0.972 (0.955-0.990)	1.017 (1.001-1.033)	0.944 (0.917-0.972)
2013	1.008 (0.988-1.028)	0.980 (0.961-1.001)	1.015 (0.996-1.034)	0.952 (0.921-0.984)
2011-2013	0.999 (0.986-1.012)	0.984 (0.970-0.998)	1.006 (0.995- 1.018)	0.973 (0.955-0.992)
Adjusted				
2011	0.990 (0.974-1.007)	0.984 (0.969-0.999)	0.996 (0.979-1.013)	0.988 (0.962-1.014)
2012	0.987 (0.970-1.005)	0.983 (0.967-0.999)	0.983 (0.967-0.999)	0.981 (0.955-1.007)
2013	0.986 (0.966-1.007)	0.992 (0.974-1.012)	0.979 (0.958-0.999)	0.996 (0.964-1.029)
2011-2013	0.988 (0.975-1.001)	0.996 (0.983- 1.010)	0.992 (0.981-1.004)	1.003 (0.985-1.022)

IRR: Incidence rate ratio; CI confidence interval. Adjusted for level of deprivation, prevalence of overweight and obesity, levels of physical activity, smoking and diabetes, estimated at each Local Authority. To control for age and sex differences between Local Authorities all models included an age- and sex-specific offset which was the expected count of AMI

Table 2: Association between prevalence of cycling and walking to work in 2011 and incidence of myocardial infarction in 2011-2013 by age band, for men and women.

Age band, years		Men	Women
		IRR (95% CI)	IRR (95%CI)
25-34	% Cycling	0.985 (0.955-1.016)	0.959 (0.875-1.040)
	% Walking	0.953 (0.930-0.977)	0.967 (0.936-0.998)
35-44	% Cycling	0.979 (0.953-1.007)	0.980 (0.941-1.023)
	% Walking	0.944 (0.913-0.978)	0.949 (0.922-0.977)
45-54	% Cycling	0.981 (0.954-1.010)	0.962 (0.933-0.993)
	% Walking	0.920 (0.886-0.957)	0.952 (0.928-0.978)
55-64	% Cycling	0.965 (0.937-0.997)	0.975 (0.945-1.008)
	% Walking	0.916 (0.881-0.954)	0.959 (0.933-0.985)
65-74	% Cycling	0.971 (0.936-1.010)	0.968 (0.932-1.009)
	% Walking	0.909 (0.862-0.961)	0.967 (0.943-0.994)

IRR: Incidence rate ratio; CI confidence interval. Adjusted for level of deprivation, prevalence of overweight and obesity, levels of physical activity smoking and diabetes, estimated at each Local Authority. To control for age and sex differences between Local Authorities all models included an age- and sex-specific offset which was the expected count of AMI.

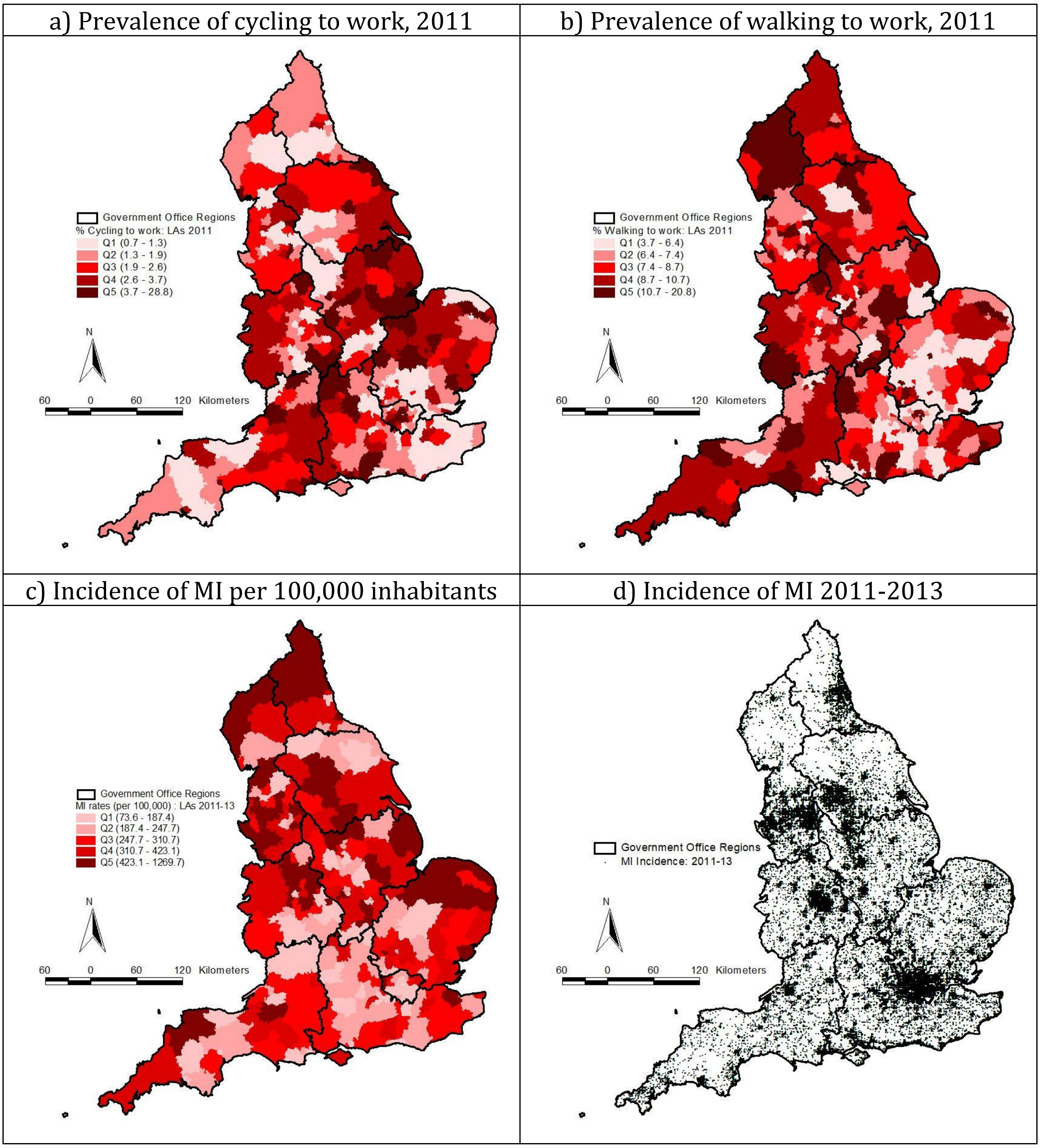

Figure 1: Choropleths, by Local Authority in England of a) prevalence of cycling to work in 2011, b) prevalence of walking to work in 2011 c) incidence of MI per 100,000 inhabitants in 2011-2013, and d) incidence of MI in England in 2011-2013.

Manuscript with track chnages

Title: Association of prevalence of active transport to work and incidence of myocardial infarction: A nationwide ecological study

Authors: Theresa Munyombwe,[1,2] Robin Lovelace,[2,3] Mark Green P,[4] Paul Norman,[7] Sarah Walpole,[5] Marlous Hall,[1,2] Adam Timmis,[10] Phil Batin,[9] Alistair Brownlee,[6] Jonathan Brownlee,[6] Ged Oliver,[8] Chris P Gale[1,2]

Affiliations:

1 Leeds Institute of Cardiovascular and Metabolic Medicine, University of Leeds, Leeds, UK

2 Leeds Institute for Data Analytics, University of Leeds, Leeds, UK

3 Institute for Transport Studies, University of Leeds, Leeds, UK

4 Department of Geography and Planning, University of Liverpool, Liverpool, UK.

5 Medecins sans Frontieres, London, UK

6 British Triathlon, UK

7 School of Geography, University of Leeds, Leeds, UK

8 Patient representative, Lancashire, United Kingdom

9 Department of Cardiology, Mid Yorkshire Hospitals NHS Trust, Wakefield, UK

10 NIHR Cardiovascular Biomedical Research Unit, Barts Heart Centre, London, UK

Corresponding author:

Professor Chris P Gale, Leeds Institute for Data Analytics, Level 11 Worsley Building, Clarendon Way, University of Leeds, Leeds, UK

Tel: +44 0113 343 8916, Email: c.p.gale@leeds.ac.uk, Twitter: @cpgale3

This work was supported by British Heart Foundation [PG/13/81/30474 to M.H and C.P.G]

Word count 4928

Abstract

Background: There is a paucity of population-based geospatial data about the association between active transport and myocardial infarction (MI). We investigated the association between active transport to work and incidence of MI.

Design: This ecological study of 325 local authorities in England included 43,077,039 employed individuals aged 25–74 years (UK Census, 2011), and 117,521 individuals with MI (Myocardial Ischaemia National Audit Project, 2011-2013).

Methods: Bayesian negative binomial regression models were used to investigate the association of active transport to work and incidence of MI adjusting for local levels of deprivation, obesity, smoking, diabetes, and physical activity.

Results: In 2011, the prevalence of active transportation to work for people in employment in England aged 25-74 years was 11.4% (4,531,182 active transporters; 8.6% walking and 2.8% cycling). Active transport in 2011 was associated with a reduced incidence of MI in 2012 amongst men cycling to work (incidence rate ratio (95% credible interval) 0.983 (0.967 to 0.999); and women walking to work (0.983 (0.967 to 0.999)) after full adjustments. However, the prevalence of active transport for men and women was not significantly associated with the combined incidence of MI between 2011 and 2013 after adjusting for physical activity, smoking and diabetes.

Conclusions: In England, the prevalence of active transportation was associated with a reduced incidence of MI for women walking and men cycling to work in corresponding local geographic areas. The overall association of active transport with MI was, however, explained by local area levels of smoking, diabetes and physical activity.

Abstract word count: 249

Keywords: Myocardial infarction, Cycling, Walking, Active transport

Introduction

Active transport, most commonly walking or cycling, is the use of physical activity to commute to work.[1, 2] Beyond the dose-response relationship between physical activity, cardiovascular fitness and mortality,[3, 4] those who engage in active transport have improved cardiovascular risk profiles, including a lower body mass index,[5, 6] less hypertension and diabetes,[6-8] and a reduced risk of cardiovascular disease and all-cause mortality.[9-11]

Active transport has been identified as a central theme for 'healthy cities' [12] and evidence suggests that the population benefits from interventions to promote cycling, such as bike hire schemes, outweigh the harms.[13-15] Moreover, the United Kingdom (UK) Government's Cycling and Walking Investment Strategy (CWIS) has recognised the potential of active transport to benefit society through cheaper travel, improved air quality and better health.[16] However, there is a paucity of population-based geospatial data about the association between active transport and myocardial infarction (MI).

The UK is unique in that there are a range of national data sources which prospectively collect information regarding active transport, population demographics and clinical outcomes such as MI. Therefore, we aimed to use data from the UK Census, the UK national heart attack register (Myocardial Ischaemia National Audit Project, MINAP) and Public Health England to investigate the association between the mode of active transport to work and the incidence of MI in men and women.

Methods

Study design and participants

We conducted an ecological study of 43,077,039 employed people aged 25–74 years in the 2011 UK Census, and 117,521 people hospitalised with MI in MINAP between 2011 and 2013, split according to the 325 Local Authorities in England.

Data sources

Exposure

The 2011 Census served as the exposure sampling frame for active transport data for the inhabitants of England. The Census collects self-reported information for all inhabitants of England and Wales, and in 2011 had a response rate of 94% for England. We extracted, by sex and decennial age band, the numbers of individuals living in England who identified their main mode of transport to work as either 'bicycle' or 'on foot'. Given that active transport data concerned only employed individuals, we restricted the cohort to those aged 25-74 years; we included ages 65-74 years because, although UK employment rates decline from the age of 65 years, the incidence of MI is elevated in this group.[17]

Primary outcome data

The primary outcome, MI in England between 2011 and 2013, was derived from MINAP, the UK national clinical register of admissions to hospital of patients with acute coronary syndrome.[18] The recorded diagnosis of MI in MINAP was made by the attending senior physician and based on the guidelines from the European Society of Cardiology, American College of Cardiology and the American Heart Association.[19]

Confounders

Data for potential confounders were obtained from the Public Health England 'FingerTips' database which can be found online.[20] This included geospatial information about the prevalence of overweight and obesity (defined as the proportion of individuals with a body mass index ≥25 kg/m^2 which was estimated from the Sport England's Active People Survey of n~150,000 per year with a minimum of 500 individuals per Local Authority), the prevalence of physical activity (defined as a minimum of 150 minutes of moderate or vigorous intensity physical activity per week which was estimated from the Sport England's Active People Survey), the prevalence of diabetes (which was estimated from the Quality Outcomes Framework data collected on individuals aged 17 years and over registered with General Practices), the prevalence of current smokers (which was estimated from the UK Office for National Statistics Integrated Household Survey (of ~200,000 participants per year),[21] and socioeconomic deprivation estimated from the 2011 English Indices of Multiple Deprivation.

Geographic units

For each of the data sources, information for England was extracted and aggregated to Local Government Unitary Authority's and Districts (Local Authority) level. English Local Authorities are administrative zones, tasked with the delivery of public health, and are the size of a large town or city (mean Local Authority population = 171,207 inhabitants). We included 325 Local Authorities (the City of London was excluded due to its small population).

Ethical approval

Given that all data were anonymised, aggregated and not linked, under the 2011 section 2.3 Governance Arrangements for Research Ethics Committees, this study did not need a favourable ethical opinion. The National Institute for Cardiovascular Outcomes Research, which includes the MINAP database, has support under section 251 of the National Health Service Act of 2006 to use patient information for medical research without informed consent.

Statistical analysis

Bayesian negative binomial regression based on the Integrated Nested Laplace Approximation (INLA) method[22, 23] was used to investigate the association between active transport and the incidence of MI stratified by sex. This method provides more precise parameter estimates, shortened computation time, and circumvents convergence issues compared to methods such as Markov Chain Monte Carlo.[24] The expected MI count was included in unadjusted and adjusted models as an offset to account for variability in the total population and its composition per Local Authority. Adjusted counts were calculated using indirect standardisation for sex and decennial age bands (25-34, 35-44, 45-54, 55-64, and 65-74 years). Models were fitted to separately investigate the association between the proportion of men and women in a Local Authority who walked or cycled to work in 2011 and the incidence of MI between 2011 and 2013. To investigate whether there was a lag effect between active transport and MI, models were fitted by MI counts for individual years (2011, 2012 and 2013). For these models, we incrementally increased the age ranges to reflect changes since the exposure in 2011 (i.e. in 2011 the population of interest in our outcome variables was ages 25-74 years, then in 2012 this was ages 26-75 years, and in 2013 it was ages 27-76 years). Analyses were adjusted for level of deprivation, prevalence of overweight and obesity, levels of physical activity, smoking, and prevalence of diabetes, estimated at each Local Authority. Results were expressed as incidence rate ratios (IRR) and associated 95% credible intervals (CI). All analyses were undertaken using the statistical software R Core 2017.[25]

Sensitivity analyses

A sensitivity analyses was conducted by adjusting the models for men and women for physically activity at the Local Authority level.

Patient involvement

No patients were involved in setting the research question, the outcome measures, the design or the implementation of the study. However, we involved a patient and two Olympic triathletes in the interpretation of the research findings, critical review of the manuscript and its dissemination.

Results

Descriptive data

According to the 2011 UK Census, there were 43,077,039 employed people aged 25–74 years. In 2011, the prevalence of active transportation to work for people in employment in England aged 25-74 years was 11.4% (4,531,182 active transporters), which varied according to Local Authority (median 10.3%, range 5%-41.6%). The prevalence of active transportation to work by Local Authority alongside crude area rates of MI and the point incidence of MI are presented in Figure 1. Overall, walking was more popular (8.6%) than cycling (2.8%). Cycling was more prevalent among men than women (3.8% vs. 1.7%), and walking more prevalent among women than men (11.7% vs. 6.0%). Active transport, predominantly cycling, was more prevalent among younger individuals, with 31.3% of those who cycled to work being aged 25-34 years and 30.2% of all those aged 25-74 years walked to work.

Myocardial infarction

Between 2011 and 2013, there were 117,521 recorded cases of MI in England (75.1%, n=88,201 men and 24.9%, n=29,320 women) which equated to a Local Authority median (IQR) of 196 (138-312) men and 63 (43-108) women hospitalised with MI (Figure 1). The crude rate of MI hospitalisations for England (2011-13) was 90.7 per 100,000 capita, with the crude rate being twice as high for men than women (122.1 vs. 60.3 per 100,000). The rates of MI increased with age, being highest for ages 65-74 years (234.7 per 100,000 capita).

Association between active transport in 2011 and incidence of MI between 2011 and 2013

Active transport in 2011 was associated with a reduced incidence of MI in 2011 and 2012 for men cycling to work (incidence rate ratio (95% credible interval) 0.984 (0.969-0.999) and 0.983 (0.967 to 0.999) respectively; and a reduced incidence of MI in 2012 and 2013 for women walking to work (0.983 (0.967 to 0.999) and 0.979 (0.958-0.999)) after full adjustment (Table 1).

The prevalence of active transport in 2011 for men and women was significantly associated with a reduced combined incidence of MI between 2011 and 2013 after adjustment for level of deprivation, prevalence of overweight and obesity (supplemental Table 1). However, the association with the combined incidence of MI between 2011 and 2013 was no longer evident after further adjusting for physical activity, smoking and diabetes (Table 1).

For men, there was no significant association (unadjusted or adjusted) between walking and the incidence of MI for all three years, and for women there was no significant association after adjustment between cycling and the incidence of MI for all three years.

Association between prevalence of active transport in 2011 and incidence of MI in 2011-2013 by age band for men and women

Age-stratified analyses found an inverse association between cycling to work and the incidence of MI in men aged 55-64 years in the corresponding geographical area, whereby a 1% increase in cycling prevalence was associated with a 3.5% decrease in the incidence of MI (IRR 0.965, 95% CIs 0.937-0.997) (Table 2). For women aged 45-54, a 1% increase in cycling prevalence was associated with a 3.8% decrease in the incidence of MI in the corresponding geographical area (IRR 0.962, 95% CIs 0.933-0.993).

An increased prevalence of walking to work was associated with a reduced incidence of MI in men aged 25-34 years (IRR 0.953, 95% CIs 0.930 to 0.977), 35-44 years (0.944, 0.913 to 0.978);, 45-54 years (0.920, 0.886 to 0.957), 55-64 years (0.916, 0.881 to 0.954) and 65-74 years (0.909, 95% CIs 0.862 to 0.961). A similar pattern was evident for women aged 25-34 years (IRR 0.967, 95% CIs 0.936 to 0.998), 35-44 years (0.949, 0.922 to 0.977), 45-54 years (0.952, 0.928 to 0.978), 55-64 years (0.959, 0.933 to 0.985) and 65-74 years (0.967, 0.941 to 0.994).

Discussion

In this national ecological study of over 40 million employed inhabitants of England aged 25-74 years of whom about 5 million were active transporters, the prevalence of walking to work was higher for women than men, and the prevalence of cycling to work was higher for men than women. In areas with increased levels of women walking and men cycling to work in 2011, the incidence of MI was reduced by 1.7% for women and men in 2012. These findings were independent of area levels of deprivation, obesity, physical activity, smoking and diabetes. Age-stratified analyses found that cycling to work was independently associated with a 3.5% reduced incidence of MI for men aged 55-64 years and a 3.8% reduced incidence of MI for women aged 45-54 years. Whilst we observed associations between these subgroups of active transport in 2011 and incidence of MI in 2012, the prevalence of walking and cycling for men and women did not have a significant association with the combined incidence of MI between 2011 and 2013 after adjustment for area levels of overall physical activity, smoking and diabetes.

Our findings support previous research which has found that cycling and walking is associated with improved cardiovascular risk profiles. Previous studies report associations between cycle commuting and lower risk of cardiovascular disease, cancer and mortality,[10, 26] walking and lower risk of cardiovascular mortality[4], active transport and diabetes and lower hypertension[27], active transportation and reduced risk of being overweight and obese.[3, 7, 27]

Many of these studies, however, were limited by small samples sizes,[6, 7, 28] imperfect data collection or self-reported outcomes and these studies were conducted more than 5 years ago using data from surveys conducted from 2005-2010. Few studies have investigated the relationship between active transportation to work and MI specifically – instead focussing on cardiovascular disease,[10, 26] hypertension,[27] overweight and diabetes,[3, 27] obesity,[3] mortality,[4, 10]and cancer.[10, 26, 29]

Our findings are, however, not in agreement with a Netherlands study which reported no association between walking and cardiovascular disease, though non-walkers made up only 3% of the cohort.[30] Whilst the other largest UK study to date (of 263,450 participants and 1,110 incident cardiovascular events) did find that self-reported cycling and walking was associated with improved cancer and cardiovascular outcomes, it was limited by potential healthy user bias sampling.[10] Our study mitigated issues of self-reporting health outcomes, small sample sizes and healthy user biases by using national data for exposure, outcomes and confounder estimates of 43 million individuals and 117,521 MI cases. Therefore, we provide, for the first time, nationwide data on the association between area levels of active transport to work and the incidence of MI within age, sex and year strata as well as by cycling and walking subgroups.

More broadly, the results of this study support previous research indicating that physical inactivity has major health impacts at the national level that can be alleviated by increasing the number of people who walk and cycle to work.[31] Due to its speed (enabling greater distances of travel than walking) and efficiency, cycling is a feasible approach for commuting which can increase physical activity levels and therefore help population health outcomes.[32] A recent study showed that physical activity is associated with a reduced risk of having significant coronary artery calcium in individuals with metabolic syndrome.[33] We found that the prevalence of active transport to work in England was low, but contest, therefore, that the potential to increase its uptake is great.

We found that the overall significant inverse association of active transport to work with MI was removed by local level estimates of smoking, diabetes and physical activity. Clearly, these traditional cardiovascular risk factors remain important determinants of the incidence of MI, and with a global trend for increasing rates,[34] should not be neglected. Moreover, the significant associations identified in this study suggest that active transportation is an important additional focal point for health policy and cardiovascular outcomes.

Study limitations

We recognise the limitations of our study. Data concerning MI were derived from MINAP, and in doing so were limited to hospitalised case; not all MIs are recorded in MINAP, and deaths due to MI occurring before hospital are not captured. Active transport data are comprehensive across the UK, but self-report the duration of active commuting and not its intensity. Self-reported data may underestimate the association between active commuting and reduced incidence of MI due to a tendency for participants to over-report their duration of physical activity.[35] It is plausible that patients who were at an increased risk of MI (with a number of risk factors and/or active cardiovascular disease) did not participate in active transportation and therefore inflated the healthier user effect reported in this study. Likewise, we cannot conclude a single direction of the association because, for example, people with coronary artery disease may have been less likely to actively transport to work. We adjusted for a range of potential confounders, but residual confounding is possible. Although other factors, may explain the results, our findings are supportive of previous studies that have found an association between active transport and improved health. Given that we did not use individual-level data, the ecological fallacy (in this case, the detection of a lower incidence of MI among the population who are not active commuters) is relevant. We reduced this bias by including data, where available, at the highest possible geographical resolution. Our use of population-grouped data also meant that we could not track individuals who may have migrated between Local Authorities between 2011 and 2013. Finally, this study does not propose causation.

Future directions

Future studies using individual-level data are required to investigate the causal relationship between active transport and MI. This as, well as more detailed information regarding duration and intensity of exercise (by means of person-reported data capture tools) linked to clinical outcomes data, would provide a stronger evidence base for investment in active transport to reduce the burden of cardiovascular disease.

Conclusion

This national ecological study of nearly 5 million active transporters to work in 2011 identified an inverse association between the local geographical area prevalence of walking and cycling to work and incidence of MI for men and women. Whilst the association overall was no longer evident after accounting for area levels of smoking, diabetes and physical activity, the effects of walking were independently associated with reduced incidence of MI for women, and the effects of cycling were independently associated with reduced incidence of MI for men. Therefore, efforts to increase the uptake of active transport to work are warranted to improve population-based health.

Acknowledgments

We gratefully acknowledge the contribution of all hospitals and healthcare professionals who participate in the MINAP registry. We acknowledge the MINAP

Academic Group and the National Institute for Cardiovascular Outcomes Research (NICOR) for providing the data for research.

Funding: This work was supported by British Heart Foundation [PG/13/81/30474 to M.H and C.P.G].

Declaration of Conflicts of interest

All authors have completed the Unified Competing Interest form at www.icmje.org/coi_disclosure.pdf and declare that [M.H and C.P.G] have support from [British Heart Foundation] for the submitted work; all the other co-authors have no financial relationships with any organisations that might have an interest in the submitted work in the previous 3 years; no other relationships or activities that could appear to have influenced the submitted work.

Author Contribution: CPG, MGP, MH, TA, PB and RL contributed to the conception and design of the work. MGP, RL, SW contributed to the acquisition of data, MCP, and RL contributed to analysis and interpretation of data for the work. TM, CPG, and RL drafted the manuscript. TM, PN, CPG, SW and MH contributed to manuscript writing and interpretation of data for the work. TM, PN, CPG, AT, SW and PB critically revised the manuscript. GO was involved as a patient advisor in the interpretation of the research and the writing of the manuscript. AB and JB reviewed and provided context to the research. All authors gave final approval and agree to be accountable for all aspects of the work ensuring integrity and accuracy.

References

1. Department of Transport. What is Active Transport ? London. 2011.

2. Department of Health. Start Active , Stay Active,. London2011.

3. 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: 420-35.

4. Yates T, Zaccardi F, Dhalwani NN, et al. Association of walking pace and handgrip strength with all-cause, cardiovascular, and cancer mortality: a UK Biobank observational study. *European heart journal*. 2017; 38: 3232-40.

5. 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: g4887.

6. Furie GL and Desai MM. Active transportation and cardiovascular disease risk factors in US adults. *American journal of preventive medicine*. 2012; 43: 621-8.

7. Millett C, Agrawal S, Sullivan R, et al. Associations between active travel to work and overweight, hypertension, and diabetes in India: a cross-sectional study. *PLoS medicine*. 2013; 10: e1001459.

8. Lee I-M, Shiroma EJ, Lobelo F, et al. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. *The lancet*. 2012; 380: 219-29.

9. Matthews CE, Jurj AL, Shu X-o, et al. Influence of exercise, walking, cycling, and overall nonexercise physical activity on mortality in Chinese women. *American Journal of Epidemiology*. 2007; 165: 1343-50.

10. Celis-Morales CA, Lyall DM, Welsh P, et al. Association between active commuting and incident cardiovascular disease, cancer, and mortality: prospective cohort study. *bmj*. 2017; 357: j1456.

11. Ekelund U, Steene-Johannessen J, Brown WJ, et al. Does physical activity attenuate, or even eliminate, the detrimental association of sitting time with mortality?

A harmonised meta-analysis of data from more than 1 million men and women. *The Lancet*. 2016; 388: 1302-10.

12. Rydin Y, Bleahu A, Davies M, et al. Shaping cities for health: complexity and the planning of urban environments in the 21st century. *Lancet*. 2012; 379: 2079.

13. Yang L, Sahlqvist S, McMinn A, Griffin SJ and Ogilvie D. Interventions to promote cycling: systematic review. *Bmj*. 2010; 341: c5293.

14. Rojas-Rueda D, de Nazelle A, Tainio M and Nieuwenhuijsen MJ. The health risks and benefits of cycling in urban environments compared with car use: health impact assessment study. *BMJ*. 2011; 343: d4521-d.

15. Woodcock J, Tainio M, Cheshire J, O'Brien O and Goodman A. Health effects of the London bicycle sharing system: health impact modelling study. *BMJ*. 2014; 348: g425-g.

16. Department for Transport. Cycling and Walking Investment Strategy. London, 2016.

17. Gale CP, Cattle B, Woolston A, et al. Resolving inequalities in care? Reduced mortality in the elderly after acute coronary syndromes. The Myocardial Ischaemia National Audit Project 2003–2010. *European heart journal*. 2011; 33: 630-9.

18. Herrett E, Smeeth L, Walker L, Weston C and Group MA. The myocardial ischaemia national audit project (MINAP). *Heart*. 2010; 96: 1264-7.

19. Thygesen K, Alpert JS, Jaffe AS, et al. Third universal definition of myocardial infarction. *European heart journal*. 2012; 33: 2551-67.

20. England PH. Public Health Profiles. *https://fingertipspheorguk/ [Date accessed: March 2017]*. 2018.

21. Office for National Statistics. Integrated Household Survey (IHS). 2016.

22. Rue H, Martino S and Chopin N. Approximate Bayesian inference for latent Gaussian models by using integrated nested Laplace approximations. *Journal of the royal statistical society: Series b (statistical methodology)*. 2009; 71: 319-92.

23. Blangiardo M and Cameletti M. *Spatial and spatio-temporal Bayesian models with R-INLA*. John Wiley & Sons, 2015.

24. Neyens T, Faes C and Molenberghs G. INLA estimation for the combined model integrated nested Laplace approximation for the analysis of count data via the combined model: A simulation study. *Communications in Statistics-Simulation and Computation*. 2018: 1-18.

25. Team R Core. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. 2016. 2017.

26. Panter J, Mytton O, Sharp S, et al. Using alternatives to the car and risk of all-cause, cardiovascular and cancer mortality. *Heart*. 2018; 104: 1749-55.

27. Laverty AA, Palladino R, Lee JT and Millett C. Associations between active travel and weight, blood pressure and diabetes in six middle income countries: a cross-sectional study in older adults. *International Journal of Behavioral Nutrition and Physical Activity*. 2015; 12: 65.

28. Gordon-Larsen P, Boone-Heinonen J, Sidney S, Sternfeld B, Jacobs DR and Lewis CE. Active commuting and cardiovascular disease risk: the CARDIA study. *Archives of internal medicine*. 2009; 169: 1216-23.

29. Sahlqvist S, Goodman A, Simmons RK, et al. The association of cycling with all-cause, cardiovascular and cancer mortality: findings from the population-based EPIC-Norfolk cohort. *BMJ open*. 2013; 3: e003797.

30. Hoevenaar-Blom MP, Wendel-Vos GW, Spijkerman AM, Kromhout D and Verschuren WM. Cycling and sports, but not walking, are associated with 10-year

cardiovascular disease incidence: the MORGEN Study. *European Journal of Cardiovascular Prevention & Rehabilitation*. 2011; 18: 41-7.

31. Allender S, Foster C, Scarborough P and Rayner M. The burden of physical activity-related ill health in the UK. *Journal of Epidemiology & Community Health*. 2007; 61: 344-8.

32. Woodcock J, Edwards P, Tonne C, et al. Public health benefits of strategies to reduce greenhouse-gas emissions: urban land transport. *The Lancet*. 2009; 374: 1930-43.

33. Ekblom-Bak E, Ekblom Ö, Fagman E, et al. Fitness attenuates the prevalence of increased coronary artery calcium in individuals with metabolic syndrome. *European journal of preventive cardiology*. 2018; 25: 309-16.

34. Timmis A, Townsend N, Gale C, et al. European Society of Cardiology: cardiovascular disease statistics 2017. *European heart journal*. 2017; 39: 508-79.

35. Nocon M, Hiemann T, Müller-Riemenschneider F, Thalau F, Roll S and Willich SN. Association of physical activity with all-cause and cardiovascular mortality: a systematic review and meta-analysis. *European Journal of Cardiovascular Prevention & Rehabilitation*. 2008; 15: 239-46.

Figure Legends

Figure 1: Choropleths, by Local Authority in England of a) prevalence of cycling to work in 2011, b) prevalence of walking to work in 2011 and c) incidence of MI per 100,000 inhabitants in 2011-2013, and d) incidence of MI in England in 2011-13

Text tables

Table 1. Association between the prevalence of cycling and walking to work in 2011 and the incidence of hospitalised myocardial infarction in 2011, 2012 and 2013 for men and women.

Table 2: Association between prevalence of cycling and walking to work in 2011 and incidence of myocardial infarction in 2011-2013 by age band, for men and women.

Table 1. Association between the prevalence of cycling and walking to work in 2011 and the incidence of hospitalised myocardial infarction in 2011, 2012 and 2013 for men and women

	Men		**Women**	
	Walking	**Cycling**	**Walking**	**Cycling**
Unadjusted	**IRR (95%CI)**	**IRR (95%CI)**	**IRR (95%CI)**	**IRR (95%CI)**
2011	1.013 (0.995-1.030)	0.972 (0.956-0.989)	1.024 (1.008-1.041)	0.951 (0.925-0.977)
2012	1.013 (0.995-1.031)	0.972 (0.955-0.990)	1.017 (1.001-1.033)	0.944 (0.917-0.972)
2013	1.008 (0.988-1.028)	0.980 (0.961-1.001)	1.015 (0.996-1.034)	0.952 (0.921-0.984)
2011-2013	0.999 (0.986-1.012)	0.984 (0.970-0.998)	1.006 (0.995- 1.018)	0.973 (0.955-0.992)
Adjusted				
2011	0.990 (0.974-1.007)	0.984 (0.969-0.999)	0.996 (0.979-1.013)	0.988 (0.962-1.014)
2012	0.987 (0.970-1.005)	0.983 (0.967-0.999)	0.983 (0.967-0.999)	0.981 (0.955-1.007)
2013	0.986 (0.966-1.007)	0.992 (0.974-1.012)	0.979 (0.958-0.999)	0.996 (0.964-1.029)
2011-2013	0.988 (0.975-1.001)	0.996 (0.983- 1.010)	0.992 (0.981-1.004)	1.003 (0.985-1.022)

IRR: Incidence rate ratio; CI confidence interval. Adjusted for level of deprivation, prevalence of overweight and obesity, levels of physical activity, smoking and diabetes, estimated at each Local Authority. To control for age and sex differences between Local Authorities all models included an age- and sex-specific offset which was the expected count of AMI

Table 2: Association between prevalence of cycling and walking to work in 2011 and incidence of myocardial infarction in 2011-2013 by age band, for men and women.

Age band, years		Men	Women
		IRR (95% CI)	IRR (95%CI)
25-34	% Cycling	0.985 (0.955-1.016)	0.959 (0.875-1.040)
	% Walking	0.953 (0.930-0.977)	0.967 (0.936-0.998)
35-44	% Cycling	0.979 (0.953-1.007)	0.980 (0.941-1.023)
	% Walking	0.944 (0.913-0.978)	0.949 (0.922-0.977)
45-54	% Cycling	0.981 (0.954-1.010)	0.962 (0.933-0.993)
	% Walking	0.920 (0.886-0.957)	0.952 (0.928-0.978)
55-64	% Cycling	0.965 (0.937-0.997)	0.975 (0.945-1.008)
	% Walking	0.916 (0.881-0.954)	0.959 (0.933-0.985)
65-74	% Cycling	0.971 (0.936-1.010)	0.968 (0.932-1.009)
	% Walking	0.909 (0.862-0.961)	0.967 (0.943-0.994)

IRR: Incidence rate ratio; CI confidence interval. Adjusted for level of deprivation, prevalence of overweight and obesity, levels of physical activity smoking and diabetes, estimated at each Local Authority. To control for age and sex differences between Local Authorities all models included an age- and sex-specific offset which was the expected count of AMI.

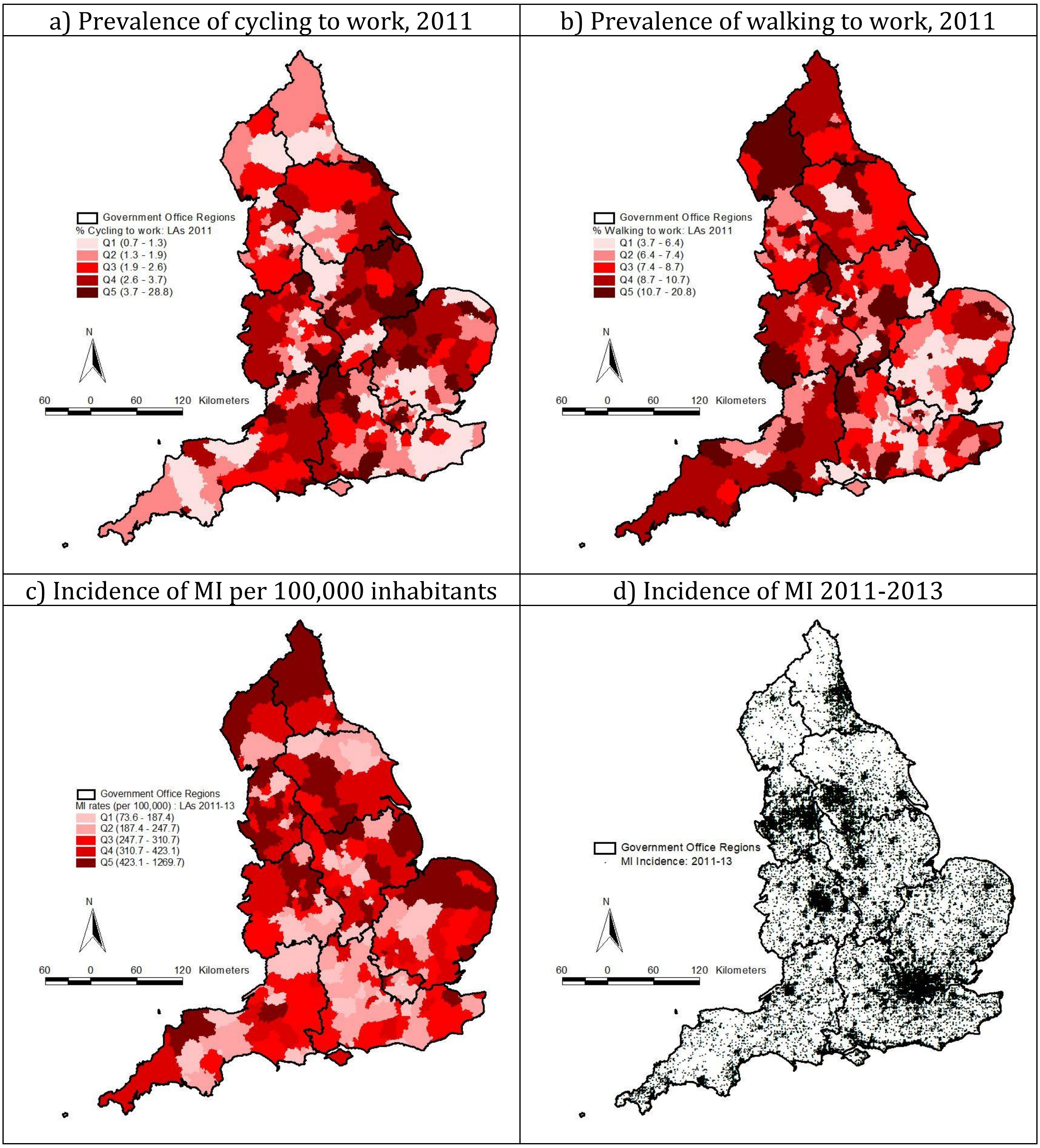

Figure 1: Choropleths, by Local Authority in England of a) prevalence of cycling to work in 2011, b) prevalence of walking to work in 2011 c) incidence of MI per 100,000 inhabitants in 2011-2013, and d) incidence of MI in England in 2011-2013.