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Associations of active commuting with body fat and visceral adipose tissue: a cross-sectional population based study in the UK

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Abstract

The promotion of active travel (walking and cycling) is one promising approach to prevent the development of obesity and related cardio-metabolic disease. However the associations between active travel and adiposity remain uncertain. We used the Fenland study (a population based-cohort study; Cambridgeshire, UK, 2005-15) to describe the association of commuting means with DEXA measured body fat and visceral adipose tissue (VAT) amongst commuters (aged 29-65 years; n=7,680). We stratified our sample into those living near (within five miles) and far (five miles or further) from work, and categorised commuting means differently for each group reflecting their different travel options. Associations were adjusted for age, education, Mediterranean diet score, smoking, alcohol consumption, test site and either self-reported physical activity or objective physical activity. Among those living near to work, people who reported regularly cycling to work had lower body fat than those who only used the car (adjusting for self-reported physical activity: women, -1.74%, 95% CI: -2.27% to -0.76%; men, -1.30%, -2.26% to -0.33%). Among those who lived far from work, people who reported regular car-use with active

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Author contribution

NW, SG and SB are PIs of the Fenland study. OM, JP and DO developed the study question and analytic plan, with input from SG and SB. OM analysed the data and drafted the manuscript. All authors critically reviewed the manuscript. OM is the guarantor and affirms that the manuscript is an honest, accurate, and transparent account of the study being reported; that no important aspects of the study have been omitted; and that any discrepancies from the study as planned have been explained.

Competing interests

All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: the authors acknowledge support from the Medical Research Council (MC_UU_12015/1, MC_UU_12015/3, MC_UU_12015/4 and MC_UU_12015/6) and the Wellcome Trust; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work.

Data sharing

Fenland data is publically shared see: <http://epi-meta.medschl.cam.ac.uk/includes/fenland/fenland.html>

travel had lower body fat (women; -1.18%, 95% CI: -2.23% to -0.13%; men, -1.19%, -1.93% to -0.44%). Findings were similar for VAT and when adjusting for objectively measured physical activity instead of self-reported physical activity. In conclusion, active commuting may reduce adiposity and help prevent related cardio-metabolic disease. If people live too far from work to walk or cycle the whole journey, incorporating some active travel within the commute is also beneficial.

Introduction

The global epidemic of obesity and type 2 diabetes may in part be mitigated by the adoption of healthier lifestyles, including being more active.(Wareham, 2014) Public health strategies to promote physical activity have had limited success to date.(Das and Horton, 2012) Shifting travel patterns away from car-use and towards walking or cycling has been proposed as one means to enable large numbers of adults to be more active.(Centres for Disease Control and Prevention, 2010)

Whilst widespread adoption of active travel, and particularly active commuting, may have considerable potential to reduce obesity and the incidence of related cardio-metabolic disorders,(Bassett et al., 2008) there still remains considerable scientific uncertainty concerning the nature and strength of associations between different modes of travel and adiposity.

Existing studies may not have adequately adjusted for dietary behaviour or other forms of physical activity. They have variously not adjusted for diet(Berglund et al., 2016; Gordon-Larsen et al., 2009; Larouche et al., 2016; Laverty et al., 2013; Lindström, 2008; Martin et al., 2015; Mytton et al., 2016; Wojan et al., 2015), characterised only part of the diet (e.g. fruit and vegetable intake),(Flint et al., 2014; Laverty et al., 2015; McKay et al., 2015; Millett et al., 2013; Rissel et al., 2014) or used measures that may be less appropriate (e.g. energy intake).(Flint and Cummins, 2016) Dietary energy intake tends to be poorly measured and much of the intra-participant variation may be accounted for by differences in physical activity.(Willett and Stampfer, 1998) While several studies have adjusted for leisure-time physical activity(Flint et al., 2014; Flint and Cummins, 2016; Gordon-Larsen et al., 2009; Larouche et al., 2016; McKay et al., 2015; Millett et al., 2013; Mytton et al., 2016; Rissel et al., 2014) only three have explicitly adjusted for occupational physical activity. (Gordon-Larsen et al., 2009; McKay et al., 2015; Mytton et al., 2016) and no study has adjusted for objectively measured physical activity.

Existing studies have also tended to consider 'usual' mode of travel to work,(Berglund et al., 2016; Flint et al., 2014; Laverty et al., 2015, 2013; Lindström, 2008; Martin et al., 2015; Millett et al., 2013; Rissel et al., 2014) comparing car-use with walking and cycling. This may result in a biased comparison, because people who live near to work (and therefore could cycle or walk all the way) may be systematically different from those who live far from work (and therefore could not). For many commuters, it is also a somewhat uninformative exposure measure. Adopting walking or cycling as a 'usual' mode of travel is not practical for longer commutes. In the UK and the US commuting distances have been increasing.(Kneebone and Holmes, 2015; Office for National Statistics, n.d.) The average

point-to-point distance from home to work in the UK is 10 miles with over half of commutes being more than 3 miles.(Office for National Statistics, n.d.) While it is still possible to be active on a long commute by combining car or public transport use with walking or cycling, these patterns of commuting are seldom studied.(Flint and Cummins, 2016)

Few studies have tested whether there is a dose-response relationship between active commuting and adiposity,(Flint and Cummins, 2016; Laverty et al., 2013; Martin et al., 2015) which might support causal inference. All studies have reported associations for body mass index (BMI),(Berglund et al., 2016; Flint et al., 2014; Flint and Cummins, 2016; Gordon-Larsen et al., 2009; Larouche et al., 2016; Laverty et al., 2015, 2013; Lindström, 2008; Martin et al., 2015; McKay et al., 2015; Millett et al., 2013; Mytton et al., 2016; Rissel et al., 2014; Wojan et al., 2015) with some using self-reported BMI.(Berglund et al., 2016; Laverty et al., 2013; Lindström, 2008; Martin et al., 2015; Mytton et al., 2016; Rissel et al., 2014; Wojan et al., 2015) Few studies have described associations with measures that are more salient for metabolic disease, e.g. percentage body fat and waist circumference. (Flint et al., 2014; Flint and Cummins, 2016; Larouche et al., 2016; Laverty et al., 2015)

The aim of this study was to contribute new evidence to support causal inference by testing the associations between active commuting (making meaningful comparisons between commuting patterns) and objective measures of adiposity (body fat and visceral adipose tissue) in a large study with detailed characterisation of physical activity (including objective measures) and dietary patterns.

Methods

Study settings and data collection

We used data from the Fenland study (ISRCTN72077169), an ongoing population-based cohort study of adults aged 29-65 years in Cambridgeshire, UK. Briefly, volunteers (n=12,434) were recruited from general practice lists between 2005 and 2015. On entry to the study all participants were invited to attend one of three clinical research facilities, where they completed a general questionnaire (socio-demographic characteristics, general health, dietary patterns, smoking and alcohol consumption), a food frequency questionnaire (FFQ) and the Recent Physical Activity Questionnaire (RPAQ).(Besson et al., 2010) At this visit, body composition was assessed by dual-energy X-ray absorptiometry (DEXA; Lunar Prodigy Advanced fan beam scanner; GE Healthcare). After their visit each participant completed up to six days of objective physical activity monitoring by combined heart rate and movement sensing (measured by Actiheart®).(Brage et al., 2005) The study was approved by the Cambridge Local Research Ethics Committee. All participants gave written informed consent.

Physical activity and food frequency questionnaire: psychometric properties

The RPAQ asked about physical activity in the past four weeks across four domains: at home, occupational, transport and leisure. It was based on the previously validated EPIC-Norfolk Physical Activity Questionnaire 2 (EPAQ2).(Wareham et al., 2002) Estimates of time in vigorous activity and total physical activity energy derived from the questionnaire

have been shown to correlate well with objective measures of physical activity.(Besson et al., 2010) Repeated estimates of overall and domain-specific physical activity from the questionnaire have been shown to have good agreement. Whilst the individual questions that we made use of have not been validated, the questions on leisure time activity and occupational activity were based on Minnesota Leisure Time Physical Activity Questionnaire and Tecumseh Occupational Physical Activity questionnaire, which have been validated elsewhere.(Ainsworth et al., 1993; Richardson et al., 1994; Wareham et al., 2002)

The 130 item FFQ was originally developed for use in the EPIC-Norfolk study.(O'Connor et al., 2015) It has been shown to have good ability to rank individuals based on intake of nutrients or food groups (e.g. correlation with weighted dietary records of 0.4-0.6 as well as showing correlation with biomarkers indicative of dietary intake).(Bingham et al., 2008, 1997)

Exposure Measure: commuting

Commuting mode was assessed in the RPAQ, with the question “how did you normally travel to work?” Participants could indicate one or more modes of travel (car/motor vehicle, works or public transport, bicycle, and walking) and a frequency for each (always, usually, occasionally or never).

Our aim was to categorise participants to enable comparisons reflecting real-world choices that commuters might face, reflecting the constraints on travel choice imposed by a long commute.(Dalton et al., 2013) We stratified our sample based on distance to work. We assumed those who lived within five miles of work could, in principle, walk or cycle all the way to work, whereas those who lived further from work would use a car or public transport.

Stratifying the sample in this way, we categorised participants who lived within five miles of work into one of five commuting patterns (car only, regular walking, regular cycling, car-use with occasional walking, car use with occasional cycling), and those who lived five miles or further from work into one of three patterns (car-use, public transport, car-use with active travel). Post-hoc, given the differences observed between cycling and walking, we re-classified those living five miles or further from work into one of four categories to test separate associations for cycling, walking and public transport use that was not associated with either (see Methods Supplement).

Outcomes: body fat and visceral adipose tissue

Percentage body fat and volume of visceral adipose tissue (VAT) were estimated from the DEXA scan using Encore software (v14.10.022).(De Lucia Rolfe et al., 2010) Percentage total body fat was estimated using a three-compartment model (fat mass, fat-free mass, and bone mineral mass). The software used an inbuilt algorithm to determine visceral adipose tissue (cm³) within the android region (the region outlined by iliac crest and with a superior height equivalent to 20% of the distance from the top of the iliac crest to the base of the skull).

Estimates of VAT derived from DEXA scans have been shown to have good agreement with gold-standard estimates from CT scan.(Micklesfield et al., 2012) Because the distribution of estimates of VAT was highly skewed, these were transformed using a square root function.

Inclusion and exclusion criteria

We only included participants who were employed and reported regular travel to work (i.e. reported using at least one mode of travel either ‘usually’ or ‘always’). Exclusion (and inclusion) criteria are summarised in Figure 1.

Co-variates

Age, sex, education, difficulty walking, smoking status and alcohol consumption were assessed on the general questionnaire. Occupational activity (categorised as sedentary, standing or manual occupation) and usual mode of travel (excluding travel to work) were assessed on the RPAQ.

Dietary consumption was assessed using a 130-item food frequency questionnaire.(Bingham et al., 2001) We used the Mediterranean diet score as an overall measure of diet quality. The relative Mediterranean diet score (rMED) (range 0-18) was estimated by assigning a score (0, 1 or 2) to each of nine dietary components based on sex specific tertiles.(Tong et al., 2016) This effectively ranks individuals within the cohort, rather than assigning a score that may be compared to other populations. The Mediterranean diet score has been associated with adiposity.(Beunza et al., 2010) Estimates of rMED and alcohol consumption were made using the FETA program.(Mulligan et al., 2014)

Leisure-time physical activity was measured in MET-hours. It was estimated by summing the product of activity duration (as reported on the RPAQ) and activity intensity (measured in metabolic equivalent of task, MET) for all reported activities.

Estimates of objective physical activity energy expenditure (PAEE) from Actiheart data were made using the branched equation framework.(Brage et al., 2005) The majority of estimates (96.6%) were individually calibrated based on partial or complete treadmill tests.

Analysis

We used linear regression to test the association of active commuting with body fat and VAT, stratified by home-work distance (as described above) and also by sex, as others have done, (Flint et al., 2014; Flint and Cummins, 2016) because of the different absolute levels and distribution of fat, differences in commuting patterns, and possible differences in activity intensity between the sexes.

We adjusted for three sets of co-variates. In Model A, we adjusted for socio-demographic characteristics (age, education level), health behaviours other than physical activity (alcohol consumption, Mediterranean diet score and smoking status), test site and difficulty walking. In Model B we adjusted for Model A co-variates and other self-reported physical activity (leisure-time physical activity, occupational activity and the usual mode of transport for getting about). Finally, as a sensitivity analysis, we adjusted for Model A co-variates and objectively measured PAEE (Model B’). Because PAEE, in theory, reflects energy

expenditure due to other activities as well as commuting, adjustment for PAEE may represent over-adjustment. For this reason we present Model B as our primary adjusted estimate of association. We undertook a complete case analysis, restricting all analyses to those who had complete data for the covariates included in Model B'.

We tested for a linear dose-response relationship by testing the association between home-work distance (as a continuous variable) and measures of adiposity, for a) those who only cycled to work; and b) those who only walked to work, adjusting for model B co-variables and sex.

Results

Descriptive characteristics of the sample are shown in Table 1. Compared to the UK population the sample was relatively educated,(Office for National Statistics, 2016) healthy (as assessed by alcohol consumption and smoking)(Craig et al., 2015) and had a high prevalence of cycling to work.(Office for National Statistics, 2014) Men had a lower average percentage body fat and greater average volume of VAT than women and were more likely to travel further to work, to have a manual job and to consume excess alcohol. Participants who lived five miles or further from work were more likely to be male, to have a degree, and to use the car than other modes of transport for non-commuting journeys. Men who lived five miles or further from work tended to have higher body fat and more VAT than those who lived closer.

The frequencies of using different modes of transport by the different commuting patterns are shown in the Results Appendix (Table A1 and Table A2). People who reported walking or cycling regularly showed limited car and public transport use. People who used the car in combination with occasional walking or cycling used the car less frequently than those who reported only using the car.

Among those who lived five miles or further from work and who undertook active travel, walking tended to be undertaken regularly and was combined with either public transport or car-use. In contrast cycling tended to be undertaken occasionally and predominantly combined with car-use.

Interaction terms for sex and adiposity were only significant for VAT amongst those living near to work ($p=0.04$, $n=3171$).

Body Fat

Associations between active commuting and body fat are shown in Table 2. Among those living within five miles of work, people who reported regularly cycling had lower body fat than those who only used the car (Model B: women, -1.74%, 95% CI: -2.27% to -0.76%; men, -1.30%, -2.26% to -0.33%). People who reported regularly walking did not have reduced body fat. Women who reported regular car-use combined with occasional walking had higher body fat than those who only used the car (Model B; 1.34%, 0.22% to 2.47%).

Among those who lived five miles or further from work, people who reported regular car-use with active travel had lower body fat than those who only used the car (Model B: women;

-1.18%, 95% CI: -2.23% to -0.13%; men, -1.19%, -1.93% to -0.44%). Using the alternative four-category classification, only those who reported combining car or public transport with cycling had lower body fat than those who only used the car (Model B: women, -2.58%, -3.92% to -1.20%; men, -1.71%, -2.50% to -0.92%; Appendix, Table A4).

Adjustment for self-reported physical activity (Model B vs Model A) and objective PAEE (Model B' vs Model A) tended to attenuate the reported associations but did not alter their statistical significance.

Visceral Adipose Tissue

The pattern of associations for VAT (Table 3) was very similar to that observed for body fat, although the association for women living far from work who reported regular car-use was (marginally) not significant when adjusting for other self-reported physical activity.

Usual mode of travel

Usual mode of travel was also associated with adiposity, particularly for those living five miles or further from work (e.g. cycling, and walking for women, were associated with reduced body fat relative to the car as the usual mode of travel: Appendix, Table A6).

Dose-response analysis

There was an association between home-work distance and body fat among those who only cycled to work (among those living within five miles of work: -0.54 % per mile, 95% CI: -1.01 to -0.08, n=554), but the equivalent associations for VAT and for walking were not significant (cycling and VAT: -0.64 cm^{3/2} per mile, 95% CI: -1.53 to 0.25, n=530; walking and body fat: -0.32 % per mile, 95% CI: -1.51 to 0.88, n=243; walking and VAT: -1.24 cm^{3/2} per mile, 95% CI: -3.40 to 0.59, n=242).

Discussion

Principal findings

Among those living within five miles of work, people who reported regularly cycling to work had reduced body fat and visceral adipose tissue (VAT) compared to those using only the car. Among those living five miles or further from work, people who reported regular car-use combined with active travel had reduced body fat and VAT compared to those using only the car. People who reported walking or cycling as their usual mode of travel had reduced adiposity compared to people who only used the car. Among those who cycled to work, there was an inverse association between distance to work and percentage body fat.

Strengths and limitations

While this study, like many others, (Berglund et al., 2016; Flint et al., 2014; Flint and Cummins, 2016; Gordon-Larsen et al., 2009; Larouche et al., 2016; Lavery et al., 2015, 2013; Lindström, 2008; McKay et al., 2015; Millett et al., 2013; Rissel et al., 2014; Wojan et al., 2015) is cross-sectional, it has a number of strengths. These include DEXA-measured adiposity, detailed and objective characterisation of physical activity, and adjustment for dietary behaviour. The study's size enabled us to undertake sub-group analyses, stratifying

by sex and home-work distance. We have estimated associations for commuting patterns that are practically possible, given constraints imposed by distance.

Our study has not used BMI. Instead we have used percentage body fat and VAT. Percentage body fat is less affected by muscle mass, in comparison to BMI, so is a better indicator of total body fatness. VAT is strongly associated with cardio-metabolic disease, and may be a better predictor of health outcomes than other measures of adiposity.(Fox et al., 2007)

Comparison with other studies

Our findings are consistent with other reports that active travel is associated with reduced BMI relative to car-use,(Berglund et al., 2016; Flint et al., 2014; Flint and Cummins, 2016; Gordon-Larsen et al., 2009; Larouche et al., 2016; Laverty et al., 2015, 2013; Lindström, 2008; Martin et al., 2015; McKay et al., 2015; Millett et al., 2013; Mytton et al., 2016; Rissel et al., 2014; Wojan et al., 2015) and of stronger associations for cycling than for walking.(Flint and Cummins, 2016; Larouche et al., 2016; Millett et al., 2013; Mytton et al., 2016) However other studies have reported significant associations between walking commuting and adiposity,(Laverty et al., 2013; Millett et al., 2013; Rissel et al., 2014) whereas our findings were non-significant. The distance or duration of walking in those studies appears relatively high compared to ours. The lower intensity of walking compared to cycling(Costa et al., 2015) and the comparatively low prevalence of walking in our study (and consequent restriction of statistical power) may also have contributed to our non-significant findings. Nonetheless we note that compared to car-use, walking as a usual mode of travel was associated with reduced adiposity in our study. We also note that women who lived within five miles of work had increased adiposity. This may be attributable to reverse causation, e.g. overweight women choosing to walk to work in order to lose weight.

Two previous studies have described associations with body fat and report a similar size of association to ours (1.5% reduction for cycling to work and 1.4% for active travel, relative to car-use).(Flint et al., 2014; Flint and Cummins, 2016) We are not aware of any studies that have described the association between active commuting and VAT.

Previous work has demonstrated a dose-response effect (between 'intensity' of active travel and BMI,(Flint and Cummins, 2016) and duration of active travel and BMI(Martin et al., 2015)). Our findings show a relationship between distance cycled to work and body fat. Ours is the first study to adjust for a measure of overall diet quality, rather than single dietary factors or dietary energy intake.

Interpretation and Implications

This study suggests that active travel may have a role in preventing accumulation of, or reducing, both total and visceral adipose tissue. Being cross-sectional, it does not demonstrate a causal relationship, but alongside other work it provides further evidence that active travel may have an important role in reducing obesity and related cardio-metabolic disease. The associations with visceral adipose tissue provide a more specific potential causal mechanism linking active travel to cardio-metabolic disease, given the suggested causal role of visceral adipose tissue in the development of metabolic disease.(Luna-Luna et al., 2015) These findings are important for doctors advising patients on strategies for

preventing or delaying onset of cardio-metabolic disease, as well as policy makers and employers who may influence how people travel and commute.

This is the first study to show that for the majority of commuters, who live too far from work to walk or cycle the whole journey, incorporating some active travel as part of commuting is associated with reduced adiposity. This is particularly important because those with long commutes and car journeys may be predisposed to develop obesity (Berglund et al., 2016; Flórez Pregonero et al., 2012) and average commuting distances are increasing. (Office for National Statistics, 2013) Active travel may be incorporated into long-distance commutes by a variety of means, e.g. use of public transport, use of park-and-ride facilities or alternating between driving and active travel. (Panter et al., 2013) In our sample, and in keeping with patterns of UK commuting, car-use dominates. (Department for Transport, 2015; Goodman, 2013) On the one hand this may suggest significant opportunity to increase population levels of activity on the other it underscores the tremendous challenge in shifting travel patterns. Facilitating a shift to more active travel patterns is likely to require a significant cultural shift as well as investment in appropriate infrastructure (e.g. public transport, cycle infrastructure).

While we did not find any significant associations between commuting by public transport and adiposity, the estimated effect sizes were in the expected direction. Many public transport users reported no walking (40% reported some walking, and 27% some cycling and estimates of effect size were close to zero when isolating individuals who did not report combining public transport with active travel. Assuming these people undertook minimal levels of walking at public transport access points (rather than just omitted to report walking or cycling to access points), this might suggest that associations between public transport and adiposity are due to incorporation of walking or cycling at either end of the journey rather than other means (e.g. reduced sitting time). Variations in the extent to which active travel is incorporated alongside public transport may account for the inconsistent associations between public transport use and adiposity reported in other studies (Flint et al., 2014; Flint and Cummins, 2016; Lindström, 2008; Millett et al., 2013). Facilitating and encouraging active travel to public transport access points may be a valuable opportunity to promote physical activity.

Adjustment for overall PAEE might be expected to (nearly) fully attenuate the association between active commuting and adiposity if the association were mediated through energy expenditure. However, we only observed partial attenuation. This lack of full attenuation may reflect measurement error, failure to account for past PAEE or the existence of other pathways between commuting and adiposity (e.g. snacking in cars).

Future Research

Future work should clarify the associations of adiposity with the dose, frequency, intensity and patterns of active travel. This is likely to necessitate using objective measures of active travel or detailed diary records of commuting behaviour. Longitudinal analyses, particularly making use of changes in commute mode or time, (Martin et al., 2015; Mytton et al., 2016) may yield more informative estimates of effect size from which stronger inference about the contribution of active travel to population health could be made.

Conclusions

In our study active travel was associated with reduced visceral adipose tissue. Given past studies and the postulated role of visceral adipose tissue in the development of cardio-metabolic disease, it provides further evidence that promoting active travel may contribute to improving cardio-metabolic health. Of particular importance, we have shown that incorporating active travel into long-distance commutes is associated with reduced adiposity. Enabling long-distance commuters to do this may require facilities that enable walking or cycling in combination with car-use and public transport.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Highlights

- Cycling to work was associated with reduced adiposity relative to exclusive car-use
- Many people live too far from work to cycle or walk the whole journey to work
- Walking or cycling part of the commute was associated with reduced adiposity
- Walking or cycling for non-work travel was associated with reduced adiposity

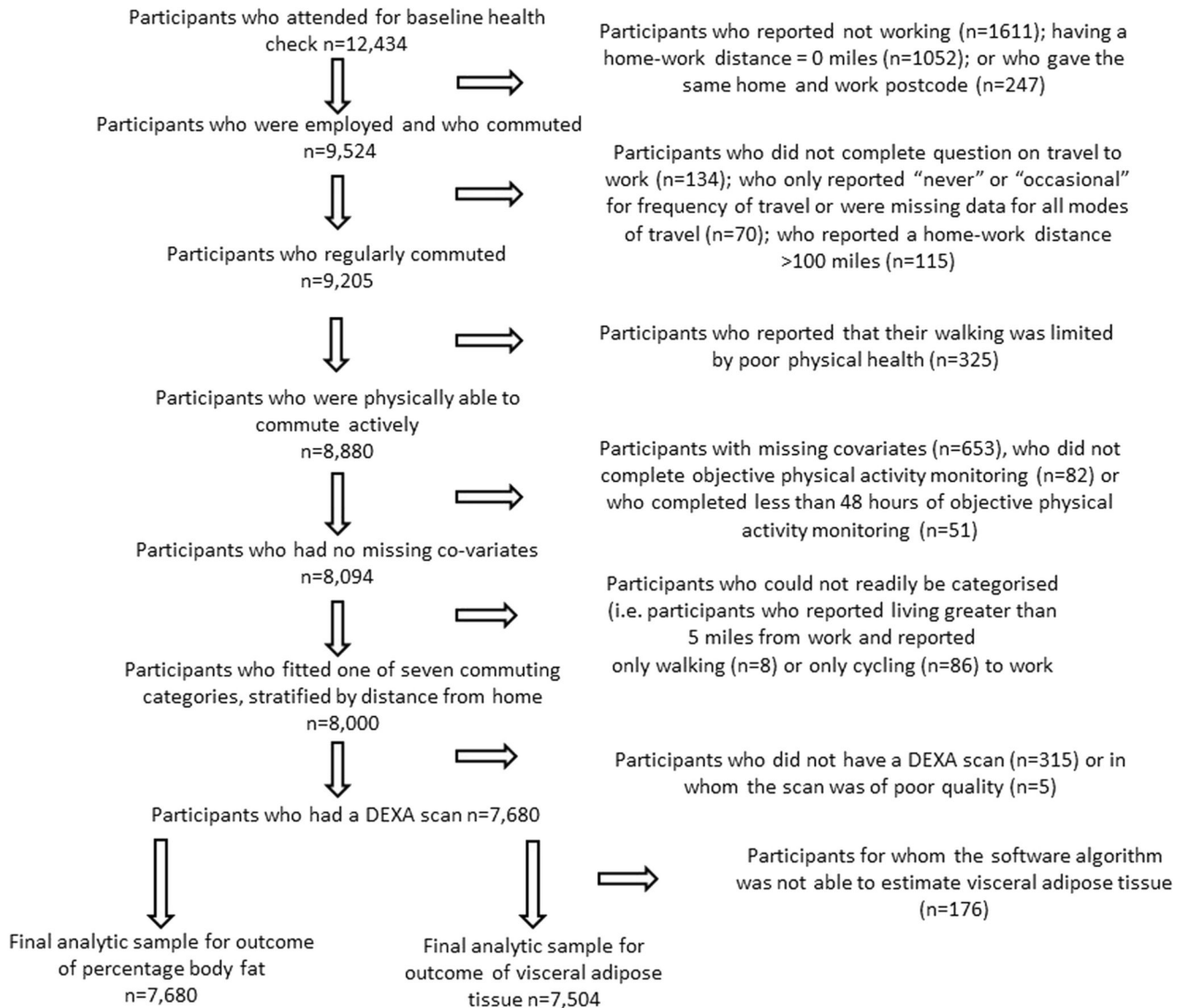


Table 1
Descriptive characteristics of participants included in the analysis of percentage body fat
(n=7,680)

	People living within 5 miles of work		People living 5 miles or further from work		Total
	Women (n=1,999)	Men (n=1,268)	Women (n=1,950)	Men (n=2,463)	
Car only	845 (42.3)	489 (38.6)	1639 (84.1)	1958 (79.5)	4931 (64.2)
Regular walking	339 (17.0)	122 (9.6)	n/a	n/a	461 (6.0)
Regular cycling	480 (24.0)	460 (36.3)	n/a	n/a	940 (12.2)
Car with occasional walking	141 (7.1)	48 (3.8)	n/a	n/a	189 (2.5)
Car with occasional cycling	194 (9.7)	149 (11.8)	n/a	n/a	343 (4.5)
Public Transport	n/a	n/a	154 (7.9)	265 (10.8)	419 (5.5)
Car with active travel	n/a	n/a	157 (8.1)	240 (9.7)	397 (5.2)
Age (years)	48.8 (43.4-54.1)	48.2 (42.2-54.5)	48.2 (42.5-53.8)	47.9 (42.2-53.8)	48.3 (42.6 to 54.0)
Education					
Degree or equivalent	624 (31.2)	556 (43.9)	790 (40.5)	1052 (42.7)	3022 (39.4)
A-Level or equivalent	910 (45.5)	463 (36.5)	858 (44.0)	1067 (43.3)	3298 (42.9)
GCSE or equivalent	465 (23.3)	249 (19.6)	302 (15.5)	344 (14.0)	1360 (17.7)
Smoking status					
Never	1116 (55.8)	671 (52.9)	1106(56.7)	1323 (53.7)	4293 (55.0)
Ex-smoker	654 (32.7)	437 (34.5)	653 (33.5)	836 (33.9)	2616 (33.5)
Current smoker	229 (11.5)	160 (12.6)	191 (9.8)	304 (12.3)	897 (11.5)
Alcohol consumption					
None	422 (21.1)	141 (11.1)	339 (17.4)	221 (9.0)	1123 (14.6)
Within guidelines (<16g per week)	1420 (71.0)	840 (66.2)	1459 (74.8)	1711 (69.5)	5430 (70.7)
Moderate (16-34.99g per week)	132 (6.6)	182 (14.4)	129 (6.6)	346 (14.1)	789 (10.3)
Heavy (>35g per week)	25 (1.3)	105 (8.2)	23 (1.2)	185 (7.5)	338 (4.4)
Mediterranean diet score	9 (7-11)	9 (7-11)	9 (7-11)	9 (7-11)	9 (7-11)
Usual method of getting about					
Car/motor vehicle	1194 (59.7)	723 (57.0)	1497 (76.8)	1890 (76.7)	5304 (69.1)
Public transport	475 (23.8)	237 (18.7)	356 (18.3)	411 (16.7)	97 (1.2)
Walking	21 (1.1)	10 (0.8)	33 (1.7)	33 (1.3)	1479 (19.3)
Cycling	309 (15.5)	298 (23.5)	64 (3.3)	129 (5.2)	800 (10.4)
Occupation					
Sedentary	986 (49.3)	629 (49.6)	1206 (61.9)	1391 (56.5)	4212 (54.8)
Standing	832 (41.6)	219 (17.3)	616 (31.6)	337 (13.7)	2004 (26.1)
Manual	181 (9.1)	420 (33.1)	128 (6.5)	735 (29.8)	1464 (19.1)

	People living within 5 miles of work		People living 5 miles or further from work		Total
	Women (n=1,999)	Men (n=1,268)	Women (n=1,950)	Men (n=2,463)	
Leisure time physical activity (MET-hours)	2.63 (1.25-4.78)	3.99 (2.02-6.90)	2.75 (1.32-4.95)	4.11 (2.28-7.27)	3.3 (1.7-6.0)
Physical Activity Energy Expenditure (kJ/day/kg)	48.1 (36.1-61.8)	58.9 (44.0-75.7)	45.6 (35.1-58.4)	56.4 (42.1-73.2)	51.4 (38.5-66.9)
Difficultly walking					
None	1385 (69.3)	933 (73.6)	1334 (68.4)	1757 (71.3)	5409 (70.4)
Very little	395 (19.8)	214 (16.9)	389 (20.0)	451 (18.3)	1449 (18.9)
Somewhat	147 (7.4)	89 (7.0)	147 (7.1)	134 (5.4)	508 (6.6)
Question not asked	72 (3.6)	32 (2.5)	72 (4.6)	121 (4.9)	314 (4.1)
Home to work distance (miles)	2.0 (1.0-3.0)	2.0 (2.0-3.0)	14.0 (9.0-20.0)	17.0 (11.0-30.0)	8.0 (3.0-17.0)
Test Site					
Cambridge	818 (40.9)	660 (52.1)	591 (30.3)	735 (29.8)	2804 (36.5)
Ely	613 (30.7)	246 (19.4)	976 (50.1)	1182(48.0)	3017 (39.3)
Wisbech	568 (28.4)	362 (28.6)	383 (19.6)	546 (22.2)	1859 (24.2)
Percentage Body Fat (%)	37.5 (32.4-42.3)	28.8 (24.8-32.6)	37.4 (32.5-42.2)	29.3 (25.6-32.7)	32.7 (28.1-38.5)
Visceral Adipose Tissue (cm³)[±]	514 (226-948)	1229 (700-1880)	492 (220-949)	1348 (798-1985)	848 (376-1520)
BMI (kg/m²)	25.2 (22.7-29.1)	26.4 (24.1-28.9)	25.3 (22.8-28.9)	26.9 (24.7-29.6)	26.1 (23.6-29.2)

Median and inter-quartile range shown for continuous variables; counts (n) and frequency (%) for categorical variables;

[±] for visceral adipose tissue, n=7,504; n/a = not applicable; BMI = body mass index and was measured objectively at one of three research facilities; study population from Cambridgeshire, UK (2005-15).

Table 2
Associations between active commuting and percentage body fat stratified by home-work distance and by sex (n=7,680)

	Unadjusted	Model A	Model B	Model B'
Participants living within five miles of work (n=3267)				
Women (n=1999)				
Car only (reference)				
Regular walking	-0.59 (-1.44, 0.25)	-0.14 (-0.95, 0.66)	-0.05 (-0.94, 0.85)	-0.21 (-0.96, 0.54)
Regular cycling	-3.01 (-3.76, -2.26)	-2.08 (-2.85, -1.30)	-1.74 (-2.72, -0.76)	-1.37 (-2.10, -0.64)
Car with occasional walking	1.73 (0.53, 2.93)	1.37 (0.24, 2.50)	1.34 (0.22, 2.47)	0.93 (-0.12, 1.99)
Car with occasional cycling	-0.89 (-1.94, 0.16)	-0.20 (-1.20, 0.80)	-0.15 (-1.15, 0.84)	0.26 (-0.67, 1.19)
Men (n=1268)				
Car only (reference)				
Regular walking	0.37 (-0.77, 1.51)	0.82 (-0.34, 1.97)	0.91 (-0.32, 2.15)	0.26 (-0.85, 1.37)
Regular cycling	-2.31 (-3.05, -1.58)	-1.59 (-2.42, -0.77)	-1.30 (-2.26, -0.33)	-1.42 (-2.20, -0.63)
Car with occasional walking	-0.26 (-1.96, 1.45)	-0.09 (-1.75, 1.57)	-0.35 (-2.01, 1.31)	-0.31 (-1.90, 1.27)
Car with occasional cycling	-1.39 (-2.44, -0.33)	0.99 (-2.04, 0.05)	-0.88 (-1.92, 0.16)	-0.81 (-1.81, 0.19)
Participants living five miles or further from work (n=4413)				
Women (n=1950)				
Car only (reference)				
Public transport	-1.32 (-2.45, -0.19)	-0.59 (-1.66, 0.49)	-0.38 (-1.52, 0.76)	-0.47 (-1.47, 0.54)
Car with active travel	-2.11 (-3.23, -0.98)	-1.55 (-2.62, -0.49)	-1.18 (-2.23, -0.13)	-1.30 (-2.30, -0.31)
Men (n=2463)				
Car only (reference)				
Public transport	-0.64 (-1.37, 0.10)	-0.13 (-0.86, 0.61)	-0.17 (-0.95, 0.60)	-0.02 (-0.72, 0.68)
Car with active travel	-1.63 (-2.40, -0.87)	-1.38 (-2.13, -0.62)	-1.19 (-1.93, -0.44)	-1.20 (-1.92, -0.48)

Model A adjusted for age, education, difficulty walking, alcohol consumption, Mediterranean diet score, smoking status and site; Model B adjusted for all co-variables in Model A and leisure time physical activity, usual method for getting about and work type; Model C adjusted for all co-variables in Model A and physical activity energy expenditure.; adjusted co-efficient shown that represent difference in percentage body fat (%) for given commuting pattern relative to reference; ; study population from Cambridgeshire, UK (2005-15).

Table 3
Associations between active commuting and visceral adipose tissue stratified by home-work distance and by sex (n=7,504)

	Unadjusted	Model A	Model B	Model B'
Participants living within five miles of work (n=3171)				
Women (n=1904)				
Car only (reference)				
Regular walking	-0.79 (-2.14, 0.57)	-0.08 (-1.38, 1.21)	0.30 (-1.17, 1.76)	-0.21 (-1.45, 1.03)
Regular cycling	-3.44 (-4.66, -2.23)	-1.81 (-3.08, -0.55)	-1.92 (-3.51, -0.33)	-0.93 (-2.14, 0.29)
Car with occasional walking	3.19 (1.28, 5.10)	2.85 (1.04, 4.67)	2.89 (1.07, 4.71)	2.28 (0.54, 4.02)
Car with occasional cycling	-1.11 (-2.78, 0.56)	-0.13 (-1.73, 1.47)	-0.07 (-1.67, 1.53)	0.50 (-1.04, 2.04)
Men (n=1267)				
Car only (reference)				
Regular walking	-2.03 (-4.40, 0.35)	-0.16 (-2.48, 2.15)	-0.63 (-1.85, 3.11)	-1.10 (-3.36, 1.15)
Regular cycling	-5.69 (-7.21, -4.17)	-2.79 (-4.44, -1.15)	-1.95 (-3.88, -0.02)	-2.49 (-4.09, -0.90)
Car with occasional walking	-2.54 (-6.08, 1.00)	-1.48 (-4.80, 1.84)	-1.82 (-5.14, 1.49)	-1.85 (-5.07, 1.37)
Car with occasional cycling	-2.95 (-5.14, -0.77)	-1.19 (-3.28, 0.90)	-1.04 (-3.12, 1.04)	-0.88 (-2.91, 1.14)
Participants living five miles or further from work (n=4333)				
Women (n=1875)				
Car only (reference)				
Public transport	-2.90 (-4.74, -1.06)	-1.91 (-3.66, -0.16)	-1.60 (-3.48, 0.27)	-1.71 (-3.39, -0.03)
Car with active travel	-3.04 (-4.88, -1.21)	-2.04 (-3.78, -0.29)	-1.70 (-3.44, 0.05)	-1.73 (-3.40, -0.06)
Men (n=2458)				
Car only (reference)				
Public transport	-1.65 (-3.16, -0.15)	0.42 (-1.04, 1.88)	0.61 (-0.93, 2.16)	0.61 (-0.80, 2.03)
Car with active travel	-3.15 (-4.71, -1.58)	-2.14 (-3.63, -0.64)	-1.79 (-3.27, -0.32)	-1.86 (-3.31, -0.41)

Model A adjusted for age, education, difficulty walking, alcohol consumption, Mediterranean diet score, smoking status and site; Model B adjusted for all co-variables in Model A and leisure time physical activity, usual method for getting about and work type; Model C adjusted for all co-variables in Model A and physical activity energy expenditure; adjusted co-efficient shown that represent difference in visceral adipose tissue ($\text{cm}^{3/2}$) for given commuting pattern relative to reference; ; study population from Cambridgeshire, UK (2005-15).