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Prospective trends in body mass index by main transport mode, 2007–2013

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A R T I C L E I N F O

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A B S T R A C T

Background: Cohort studies have examined whether change in transport mode is associated with change in bodyweight among commuters. We complement this research by examining trends in body mass index (BMI) for men and women who used the same transport mode between 2007 and 2013, and where transport was used for any activity of daily life.
Methods: Data are from the HABITAT study, a longitudinal investigation of health among 11,035 persons aged 40–65 residing in 200 neighbourhoods in Brisbane, Australia. Transport mode was measured as private motor vehicle (PMV), public transport, walking, and cycling. Analyses were conducted using random effects models before and after adjustment for time-varying and time-invariant confounders. Interactions between transport mode and time were modelled to assess whether the rate of change in BMI differed by mode.
Results: Averaged over the four time-points, the BMI of men who consistently walked or cycled was -3.20 kg/m^2 (95%CI -4.28, -2.12) and -2.15 kg/m^2 (95%CI -3.22, -1.08) lower respectively than PMV users: the corresponding difference for women who walked or cycled was -2.42 kg/m^2 (95%CI -3.66, -1.18) and -2.44 kg/m^2 (95%CI -5.98, 1.11). For men, there were no BMI differences between PMV and public transport users; among women, those who mainly used public transport had higher BMI (1.06 kg/m^2 95%CI 0.51, 1.62) than PMV users. For men, no significant interactions were found between transport mode and time; for women, those who mainly walked for transport experienced a significant decline in BMI compared with PMV users.
Conclusion: Those who consistently walked or cycled sustained a lower BMI over time relative to those who consistently used a PMV. Transport and land use policies and behavioural interventions that successfully shift mode-share from PMV to active travel might help stem the global increase in obesity related chronic disease.

1. Introduction

During the last two decades Australia experienced rapidly rising rates of overweight and obesity amongst its adult population

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(Australian National Preventive Health Agency, 2014). In 2013, the prevalence of obesity among Australians aged 20 years and older was 29%, placing it 25th out of 188 countries surveyed for the Global Burden of Disease Study; and since 1980, the obesity prevalence in Australia increased by 81%, compared with 66% in the UK and 65% in the US (Ng et al., 2014). International health authorities have attempted to stem the rising tide of overweight and obesity and address the related increases in chronic disease by calling for a shift in transport mode-share from private motor vehicle (PMV) use to active transport (public transport, walking and cycling) as a way of incorporating physical activity into everyday life (World Health Organisation, 2013; British Medical Association, 2012; National Heart Foundation of Australia, 2014). The use of active transport translates into higher levels of physical activity (Besser and Dannenberg, 2005; Sallis et al., 2004) and the physiological benefits and increased energy expenditure that accrue from this probably partly accounts for the lower rates of mortality (Andersen et al., 2000), type 2 diabetes (Hu et al., 2003), and cardiovascular disease (Hamer and Chida, 2008) among regular users of active travel.

Research examining relationships between transport and bodyweight is mostly cross-sectional. This work shows that, compared with PMV users, users of public transport, and those who walk or cycle, have significantly lower body mass index (BMI) (Wanner et al., 2012; Flint et al., 2014; Flint and Cummins, 2016), a lower odds of overweight and obesity (Lindstrom, 2008; Wen and Rissel, 2008; Laverty et al., 2013; Millett et al., 2013), and a lower percentage body fat (Flint et al., 2014; Flint and Cummins, 2016). There are few longitudinal studies of transport mode and bodyweight; however, the limited findings to date lend credence to a causal interpretation of the relationship. Prospective ecologic research shows that population-level reductions in active travel (Bassett et al., 2008; Pucher et al., 2010) and increases in travel by PMV (Jacobson et al., 2011; Behzad et al., 2013) are correlated with later increases in average BMI and prevalence of obesity. Natural experiment studies of public transport interventions show that older adults who commenced using free travel on local busses in England had a lower odds of becoming obese (Webb et al., 2012), and residents of Charlotte (North Carolina) who used light rail after its introduction experienced a reduction in BMI (MacDonald et al., 2010). Cohort studies show that changing from PMV to active travel over two time-points within a 5 year period was associated with significant reductions in BMI (Martin et al., 2015; Flint et al., 2016) and the consistent use of an active mode over one year was associated with a sustained lower average BMI (Mytton et al., 2016).

The aim of this paper is to examine prospective trends in BMI for men and women who consistently used the same mode of transport at four time-points between 2007 and 2013. Whilst we know that BMI gradually increases over time as we age, we don't know if the rate of increase differs depending on transport mode. By tracking trends in transport mode and BMI over a seven year period we examine a question that is central to the advocacy efforts of health authorities who are calling for policies that promote active travel: Does the consistent use of active travel help mitigate the increases in overweight and obesity that have been observed in Australia and elsewhere during the last few decades?

In addition, a notable feature of previous cross-sectional and longitudinal research is its almost exclusive focus on commuting (i.e. travel to work), consequently it has focused on a relatively narrow and circumscribed cross-section of the population, namely, working-aged people in paid employment. This has necessarily excluded sizeable population sub-groups outside the labour market such as the unemployed, the retired, or those doing home duties. Put differently, earlier research may have focused primarily on healthier higher status respondents (i.e. the 'healthy worker' effect). As a complement to this work, we examine the relationship between transport mode and BMI in a population-representative sample of mid-to older-aged men and women who reported on their main mode of travel irrespective of purpose (e.g. commuting, shopping, socialising, errands); and using a sample that included employed and non-employed groups.

2. Materials and methods

2.1. Data

This investigation used data from the HABITAT (**H**ow **A**reas in **B**risbane **I**nfluence Heal**T**h and **A**c**T**ivity) study. HABITAT is a multilevel longitudinal study of mid-aged adults living in the Brisbane Local Government Area, Australia (Turrell et al., 2010). The primary aim of HABITAT is to examine patterns of change in health and well-being over the period 2007–2016 and to assess the relative contributions of environmental, social, psychological and socio-demographic factors to these changes. In this paper, we used data from Waves 1–4 of the study which were collected in May-July 2007, 2009, 2011 and 2013.

2.2. Ethics approval

The HABITAT study received ethical clearance from the Queensland University of Technology Human Research Ethics Committee (Ref. Nos. 3967H & 1300000161).

2.3. Sample design

Details about HABITAT's sampling design have been published elsewhere (Burton et al., 2009). Briefly, a multi-stage probability sampling design was used to select a stratified random sample (n = 200) of Census Collector's Districts (CCD), and from within each CCD, a random sample of people aged 40–65 years (on average 85 people per CCD).

2.4. Data collection and response rates

A structured self-administered questionnaire was developed (available at https://iha.acu.edu.au/research/research-projects/habitat-project/) and copies were sent to 17,000 potentially eligible participants in May 2007 using a mail survey method developed by Dillman (2000). After excluding 873 out-of-scope contacts (i.e. deceased, no longer at the address, unable to participate for health-related reasons) 11,035 usable surveys were returned yielding a baseline response rate of 68.3%: the corresponding response rates from in-scope and contactable participants in 2009, 2011, and 2013 were 72.6% (n = 7866), 67.3% (n = 6900), and 67.1% (n = 6520) respectively.

2.5. Measurements

2.5.1. Exposure and outcome

2.5.1.1. Main transport mode. Participants were asked "On most weekdays (Monday to Friday), which type of transport do you mainly use to get to and from places?" Response options included 'Public transport', 'Car or motorcycle', 'Walk', 'Bicycle' or 'Other (please specify)'. Unlike some cohort studies (Martin et al., 2015; Flint et al., 2016), which have combined active transport modes, we keep them separate (despite small numbers) for two reasons: first, the energy expenditure of each active travel mode is likely to be different and hence each may show a different pattern of association with BMI; second, previous research has found that the socioeconomic characteristics of people who walk or cycle for transport are different, with the latter being more likely to come from advantaged backgrounds (Rachele et al., 2015).

2.5.1.2. Bodyweight. Participants reported their weight (in kilograms or stones and pounds) and height (in centimetres or feet and inches): these were used to calculate body mass index ($weight_{kg}$ / $height_{m}^{2}$) (BMI).

2.5.2. Covariates

Exploratory data analyses showed that choice of transport mode and BMI were each associated with the following individual-, household- and neighbourhood-level characteristics: age, education level, occupation, household income, neighbourhood disadvantage, country of birth, physical activity, health status, and private motor vehicle access. These characteristics were therefore likely to confound the relationship between transport mode and BMI and hence were treated as covariates in our analyses. Our preliminary analyses also showed that both the cross-sectional and longitudinal associations between transport mode and BMI differed for men and women thus we present gender stratified results.

2.5.2.1. Neighborhood disadvantage. Each of the 200 neighborhoods was assigned a socioeconomic score using the ABS' Index of Relative Socioeconomic Disadvantage (IRSD) (Australian Bureau of Statistics, 2008): the Index reflects each area's overall level of disadvantage based on 17 socioeconomic attributes, including education, occupation, income, unemployment, and household tenure. For analysis, the 200 neighborhoods were grouped into quintiles based on their IRSD scores with Q1 denoting the 20% (n = 40) most disadvantaged areas in Brisbane and Q5 the least disadvantaged 20% (n = 40).

2.5.2.2. Education. Highest educational qualification completed was coded as bachelor degree or higher (including post graduate diploma, Masters, or doctorate); diploma (associate or undergraduate); vocational (trade or business certificate, or apprenticeship), or; no post-school qualifications.

2.5.2.3. Occupation. Respondents reported their employment status at the time of the survey, and if employed, their job title and main tasks and duties performed. This information was coded in accordance with the ABS' Australian and New Zealand Standard Classification of Occupations (ANZSCO)(Australian Bureau of Statistics, 2013). For analysis, ANZSCO was re-coded into 3 categories: managers and professionals (managers and administrators, professionals and associate professionals); white collar employees (clerical, sales and service); and blue collar workers (trades, production workers, labourers). Two additional categories were also created; Other (students, unemployed, retired, home duties, and permanently unable to work); and Not easily classified (insufficient information for their employment status and/or occupation to be reliably ascertained).

2.5.2.4. Household income. Respondents were asked to estimate the total pre-tax income for their household using a single question comprising 13 income categories. For analysis, these were re-coded into six categories: AUS$130,000pa or more; $129,999 – 72,800; $72,799 – 52,000; $51,999 – 26,000; $25,999 – 0; and Missing (i.e. left the income question blank, ticked 'Don't know' or 'Don't want to answer this').

2.5.2.5. Country of birth. Responses were initially categorised into 10 regions using the Standard Australian Classification of Countries (Australian Bureau of Statistics, 2016). For analyses, these were subsequently grouped as Australia, Oceania, Europe, Asia, or Other.

2.5.2.6. Total physical activity. Using a modified version of the Active Australia Survey (Australian Institute of Health and Welfare AIHW 2003), participants estimated the total time spent in the previous week walking "continuously for 10 minutes for recreation, exercise, or to get to or from places"; doing vigorous activity (excluding household chores, gardening, or yard work) that "made you breathe harder or puff or pant" (e.g. jogging, aerobics); and doing moderate physical activities (excluding household chores, gardening, or yard work) 'that you have not already mentioned' (e.g. gentle swimming, golf). The three questions were combined to derive a measure of total MET.minutes/week - an estimate of energy expenditure - as follows: ([walking minutes * 3.33METS] + [moderate minutes * 3.33 METS] + [vigorous minutes * 6.66 METS]). Total activity was categorized as: none/negligible (< 33); very low (> 33 < 250); low (≥250 < 500); moderate (> 500 < 1000); high (≥1000 < 2000); or very high (≥2000).

2.5.2.7. Self-rated health. This was measured by asking respondents to rate their health as Excellent, Very Good, Good, Fair, or Poor. For analysis, these options were categorised as 'Excellent-Very Good' and 'Fair-Poor'.

2.5.2.8. Private motor vehicle access. This was measured with a single question which asked "Do you have a motor vehicle available for your personal use?' Response options were 'Yes, always', 'Yes, sometimes', 'No', and 'Do not drive'.

2.6. Data analysis

The baseline HABITAT sample comprised 11,035 respondents aged 40–65. For this study, we excluded respondents who moved outside of the Brisbane area (n = 593), respondents who were not the same person from the previous wave (n = 313), and those who had missing data at all four waves for transport mode, BMI, education, physical activity, private motor vehicle access or self-rated health (n = 197). As this paper focuses on prospective trends in the relationship between transport mode and BMI among respondents who consistently used the same mode between 2007 and 2013, we also excluded those who changed their main mode of transport between any of the four waves (n = 1410). Restricting the analysis to people who did not change their transport mode allowed us to reliably estimate trends in BMI for consistent users of inactive and active travel, and this is an important issue that hasn't been examined in previous research: investigating temporal trends would have been less straightforward and less clear if we had also included those who changed their transport mode. After these exclusions, the analytic samples in 2007, 2009, 2011, and 2013 for men were 3750, 2428, 2071, and 1949 respectively; and for women, 4772, 3313, 2835, and 2669 respectively. Table 1 presents the characteristics of the analytic samples for men and women, arrayed beside the characteristics of the HABITAT baseline sample which was representative of the wider Brisbane population (Turrell et al., 2010).

Exploratory analyses and data preparation were conducted using Stata 14 (Stata Corporation, 2016) and the regression models were fitted using MLwiN V2.35 (Rasbash et al., 2009). The longitudinal analyses were undertaken using random-effects linear regression. A three-stage modelling strategy was used. Model 1 included main transport mode, baseline age (mean centred), and wave (0 = 2007, 1 = 2009, 2 = 2011, and 3 = 2013). This model also included a random term for 'wave' to test for heterogeneity in the rate of BMI change between 2007 and 2013. The 'heterogeneity of change' coefficient captures the extent of between-individual variation in BMI change: a statistically significant coefficient indicates that the rate of change in BMI (i.e. the time x BMI slope) is not the same for everyone and is substantially different from the overall (average) rate of change. Model 2 added the hypothesised confounders: physical activity, self-rated health, private motor vehicle access, country of birth, individual- and household-level SEP, and neighbourhood disadvantage. Model 3 extends Model 2 by including a transport-wave interaction to assess whether the rate of change in BMI differed significantly by transport mode. The regression output for each Model is expressed as a β coefficient that quantifies the difference in BMI (kg/m^2) between consistent private motor vehicle users and those who mainly used public transport, walking, or cycling. The temporal trends in BMI by main transport mode are plotted graphically: these graphs also include a trend-line for all men and all women (irrespective of the main type of transport used) to represent BMI trajectories in the mid- to older-age population.

3. Results

Table 2 presents bivariate associations between body weight (kg), BMI, and main transport mode for men and women in 2007 and 2013. Irrespective of gender or wave, walkers and cyclists weighed less on average and had a lower BMI than their counterparts who mainly used a PMV or public transport; and women who reported that public transport was their main mode of travel weighed more and had higher BMI than women who consistently used other modes.

The results of the random effects models that regressed BMI on main transport mode are presented in Table 3.

In 2007, mean BMI for men was 27.6 kg/m^2 (after adjustment for baseline age) and this increased significantly by an average of 0.087 kg/m^2 per wave; and there was statistically significant between-person heterogeneity in BMI change. Averaged over the four waves, men who consistently walked or cycled for transport had significantly lower BMI than men who mainly travelled by PMV: this finding was observed before and after adjustment for the covariates. Mean BMI for women was 26.3 kg/m^2 in 2007, and this increased significantly by an average of 0.213 kg/m^2 per wave; between-person heterogeneity in BMI change was statistically significant. Women who consistently walked or cycled as their main mode of transport had lower average BMI than those who mainly used a PMV; however, the differences only reached statistical significance for walking. Women who used public transport as their main mode had significantly higher average BMI than PMV users.

Fig. 1 shows temporal trends in BMI by main transport mode for men and women; and for all men and all women irrespective of mode. For men, no significant interactions were found between transport mode, wave, and average BMI: between 2007 and 2013, BMI trended upward at a similar rate for all four modes, and for men overall. Average BMI for women showed an upward trend for consistent users of PMVs, public transport, cyclists, and all women, and the rate of increase was similar for each of these groups. By contrast, compared with consistent users of PMVs, women who mainly walked for transport experienced a statistically significant

Table 1
Sample and panel characteristics: Total HABITAT sample, and the analytic panels for men and women in 2007 (Wave 1) and 2013 (Wave 4).

	Total sample in 2007 (n = 11,035)		Panel used for analysis			
	Men	Women	Men		Women	
			2007	2013	2007	2013
Number	4849	6186	3750	1949	4772	2669
	%	%	%	%	%	%
Main transport mode						
Private motor vehicle	80.0	80.7	86.4	87.6	88.2	87.9
Public transport	11.3	11.5	8.4	6.3	8.0	5.7
Walking	2.8	3.4	1.8	1.2	1.6	1.0
Cycling	2.5	0.4	1.5	1.3	0.2	0.2
Missing [a]	3.4	3.9	2.0	3.5	2.0	5.3
Age						
40 – 44	26.4	20.2	26.9	–	20.7	–
45 – 49	21.9	21.3	22.2	16.9	21.2	14.7
50 – 54	20.0	21.7	20.2	22.4	21.2	20.9
55 – 59	17.9	19.6	17.6	22.0	19.2	20.3
60 – 65	13.8	17.2	13.1	22.5	17.7	24.9
66 – 70	–	–	–	15.3	–	18.4
71 – 72	–	–	–	1.0	–	0.8
Neighbourhood disadvantage [c]						
Q5 (Least disadvantaged)	29.9	29.3	29.7	21.5	30.4	21.9
Q4	19.2	19.9	19.1	26.0	20.4	26.4
Q3	17.8	16.3	18.2	20.6	16.2	19.0
Q2	20.3	20.6	20.4	18.6	19.7	19.1
Q1 (Most disadvantaged)	12.8	13.9	12.7	13.3	13.3	13.6
Education level						
Bachelor degree or higher	33.7	29.5	32.6	34.8	29.7	33.8
Diploma/Associate diploma	11.9	11.2	11.9	12.2	11.0	11.4
Certificate (trade/business)	21.7	14.5	22.3	22.8	14.4	13.9
School	32.4	44.3	33.3	30.2	44.9	41.0
Missing	0.3	0.5	–	–	–	–
Occupation[b]						
Managers & professionals	39.6	28.6	38.9	36.3	29.5	31.1
White collar	13.2	29.0	13.0	12.8	28.3	24.1
Blue collar	23.8	6.9	25.2	21.0	7.2	5.0
Other	12.8	24.6	12.5	18.9	24.8	23.2
Not easily classifiable	10.6	11.0	10.4	10.9	10.3	16.8
Household income						
$130,000 pa or more	20.3	14.6	20.1	26.4	15.3	17.1
$72,800 - $129,999	28.9	23.4	28.6	25.0	23.2	22.7
$52,000 - $72,799	15.2	14.4	15.2	12.8	14.4	11.1
$26,000 - $51,999	16.6	19.3	17.1	17.1	18.9	19.9
$0 - $25,999	7.3	11.2	7.3	8.2	10.4	11.0
Don't know/refused/missing	11.8	17.2	11.7	10.5	17.9	18.2
Country (region) of birth[d]						
Australia	73.5	75.7	73.1	75.5	76.2	78.4
Oceania	3.9	4.2	3.9	3.8	4.2	3.9
Europe	13.6	10.5	13.9	12.9	10.3	10.0
Asia	4.6	5.3	4.9	3.9	5.5	4.1
Other/Missing	4.4	4.4	4.3	4.0	4.0	3.6
Total physical activity (MET.minutes/ week)[e]						
None/negligible (< 33.3)	13.7	14.7	14.8	13.7	16.0	14.7
Very low (> = 33.3 - < 250)	12.5	12.6	13.0	13.0	13.1	12.7
Low (> = 250 - < 500)	11.8	14.9	12.1	12.0	14.3	14.5
Moderate (> = 500 - < 1000)	16.5	19.1	16.2	18.2	19.1	20.3
High (> = 1000 - < 2000)	20.7	19.3	19.8	20.0	18.7	18.3
Very high (> = 2000)	22.1	16.4	21.5	20.5	16.1	16.6
Missing	2.7	3.0	2.6	2.6	2.8	2.9

(*continued on next page*)

Table 1 (*continued*)

	Total sample in 2007 (n = 11,035)		Panel used for analysis			
	Men	Women	Men		Women	
			2007	2013	2007	2013
Self-rated health						
Excellent/Very Good/Good	81.5	81.3	81.9	79.6	81.5	79.7
Fair/Poor	17.8	17.6	17.6	19.0	17.8	19.2
Missing	0.7	1.2	0.5	1.3	0.7	1.2
Private motor vehicle access						
Always	90.5	87.3	92.3	92.4	90.0	89.1
Sometimes	4.7	5.4	3.7	3.8	4.3	5.0
Never	2.4	2.8	2.1	2.0	2.2	2.5
Don't drive	1.6	3.5	1.4	1.4	2.9	2.4
Missing	0.9	1.1	0.5	0.6	0.5	1.1

[a] Respondents who had missing data for all four waves were excluded from the study (n = 197). The missing cases presented in the Table were retained in the analysis because they provided usable data for at least one wave.
[b] Neighbourhoods were assigned a socioeconomic score using the Australian Bureau of Statistics Index of Relative Socioeconomic Disadvantage (Australian Bureau of Statistics, 2008).
[c] Occupation information was coded and categorised in accordance with the Australian and New Zealand Classification of Occupations (ANZCO)(Australian Bureau of Statistics, 2013).
[d] Respondents were categorised into countries and regions using the Standard Australian Classification of Countries (Australian Bureau of Statistics, 2016).
[e] Measure based on questions from the Active Australia Survey (Australian Institute of Health and Welfare AIHW 2003).

Table 2
Body weight (kg) and BMI (kg/m^2) characteristics of men and women in 2007 (Wave 1) and 2013 (Wave 4): by main transport mode.

	Weight (mean, 95%CI)		BMI (mean, 95%CI)	
	2007	2013	2007	2013
Men[a]				
Private motor vehicle	87.1 (86.5, 87.7)	87.9 (87.1, 88.7)	27.6 (27.4, 27.8)	27.8 (27.6, 28.0)
Public transport	86.2 (84.4, 88.0)	89.2 (85.9, 92.5)	27.5 (27.0, 28.0)	28.3 (27.3, 29.3)
Walking	78.4 (75.2, 81.6)	76.7 (72.2, 81.2)	24.8 (23.8, 25.8)	25.6 (23.7, 27.5)
Cycling	80.8 (77.6, 84.0)	80.9 (75.9, 85.9)	25.3 (24.4, 26.2)	25.4 (23.9, 26.9)
Women[b]				
Private motor vehicle	70.1 (69.6, 70.6)	71.9 (71.2, 72.6)	26.2 (26.0, 26.4)	26.8 (26.6, 27.0)
Public transport	74.0 (71.9, 76.1)	74.4 (71.4, 77.4)	28.0 (27.2, 28.8)	28.2 (27.1, 29.3)
Walking	63.4 (60.3, 66.5)	61.5 (57.0, 66.0)	24.4 (23.2, 25.6)	23.4 (21.7, 25.1)
Cycling	64.2 (55.9, 72.5)	58.7 (52.5, 64.9)	22.9 (20.2, 25.6)	9. (19.8, 24.0)

[a] The number of men included in the analyses for 2007 and 2013 was 3750 and 1949 respectively
[b] The number of women included in the analyses for 2007 and 2013 was 4772 and 2669 respectively

decline in BMI.

4. Discussion

This longitudinal study examined prospective trends in BMI for mid- and older-aged men and women who used the same main mode of transport (irrespective of purpose) over a seven year period. The cross-sectional data showed that in both 2007 and 2013, those who mainly walked or cycled weighed less and had a lower BMI than their counterparts who mainly travelled by PMV. These results support the findings of previous cross-sectional studies of commuting to work using both self-reported (e.g. Laverty et al., 2013) and objectively measured (Flint et al., 2014; Flint and Cummins, 2016; Millett et al., 2013) anthropometric data.

The longitudinal evidence showed that overall BMI increased significantly for both men and women, with the rate of increase being greater for women. The absolute value of BMI at each of the four time-points, and its rate of increase over time, were almost identical for both the overall sample (i.e. all men and women) and those who mainly used a PMV: this was unsurprising given that more than 85% of this older population reported using a car or motorcycle as their main mode of travel. Between 2007 and 2013, men and women who consistently walked or cycled maintained a lower average BMI relative to PMV users, and for women who consistently walked their average BMI showed a significant downward trend. These results are broadly similar to those reported by Mytton et al. (2016) who found that commuters who consistently cycled to work had significantly lower BMI at one-year follow-up than those who never cycled. Taken together, the findings of these two studies, and those showing consistently high rates of BMI in the overall sample, suggest that the regular use of active travel for daily living may help to mitigate the increased levels of overweight

Table 3
Main transport mode by body mass index: men and women who did not change their mode between 2007 and 2013.

	Model 1[a]	Model 2[b]	Model 3[c]
Men			
Intercept	27.6 (0.08)	27.6 (0.18)	27.6 (0.18)
Wave (0 = 2007)	0.087 (0.04, 0.13)	0.059 (0.01, 0.11)	0.051 (0.02, 0.10)
Heterogeneity of change	0.207 (0.042)	0.195 (0.041)	0.195 (0.041)
Transport mode			
Private motor vehicle	Referent	Referent	Referent
Public Transport	0.12 (−0.38, 0.61)	−0.15 (−0.66, 0.36)	−0.20 (−0.73, 0.33)
Walking	−2.94 (−4.03, −1.86)	−3.20 (−4.28, −2.12)	−3.33 (−4.46, −2.20)
Cycling	−2.13 (−3.22, −1.04)	−2.15 (−3.22, −1.08)	−2.27 (−3.41, −1.13)
*Transport mode*wave*			
Private motor vehicle			Referent
Public Transport * wave			0.06 (−0.13, 0.24)
Walking * wave			0.15 (−0.23, 0.54)
Cycling * wave			0.13 (−0.27, 0.52)
Women			
Intercept	26.3 (0.09)	27.2 (0.26)	27.2 (0.26)
Wave (0 = 2007)	0.213 (0.16, 0.26)	0.182 (0.13, 0.23)	0.195 (0.14, 0.25)
Heterogeneity of change	0.407 (0.052)	0.385 (0.052)	0.380 (0.052)
Transport mode			
Private motor vehicle	Referent	Referent	Referent
Public Transport	1.43 (0.87, 1.98)	1.06 (0.51, 1.62)	1.16 (0.58, 1.74)
Walking	−2.09 (−3.38, −0.80)	−2.42 (−3.66, −1.18)	−2.11 (−3.38, −0.83)
Cycling	−3.35 (−7.07, 0.38)	−2.44 (−5.98, 1.11)	−2.35 (−6.02, 1.31)
*Transport mode*Wave*			
Private motor vehicle			Referent
Public Transport * wave			−0.11 (−0.31, 0.08)
Walking * wave			−0.44 (−0.87, −0.01)
Cycling * wave			−0.11 (−1.32, 1.10)

[a] Model 1: Usual transport, baseline age (centred), wave.
[b] Model 2: Model 1 plus neighbourhood disadvantage, education, occupation, household income, country of birth, total physical activity, self-rated health, and private motor vehicle access.
[c] Model 3: Model 2 plus an interaction between wave and main transport mode.

and obesity that have been observed in Australia and elsewhere during the last few decades (Australian National Preventive Health Agency, 2014; Ng et al., 2014; Feng and Wilson 2015; Department of Health, 2013).

Cross-sectional research and natural experiment studies have tended to find that bodyweight, BMI, and percentage body fat, are lower among those who travel or commute by public transport, although the evidence is not entirely consistent. Wen and Rissel (2008) and Lindstrom (2008) for example found that men who used public transport had significantly lower odds of being overweight and obese than PMV users; however no significant differences were evident for women. Laverty et al. (2013) observed that public transport users (men and women combined) had lower odds of overweight and obesity than PMV users, and Millett et al (2013) found a similar result but only prior to adjustment for confounders. The only known longitudinal study found that switching from PMV to public transport was not associated with change in BMI; however, this study did not examine data from men and women separately (Martin et al., 2015). In this present study we found no cross-sectional or temporal differences in BMI between men who mainly used a PMV and those who used public transport. Among women however, public transport users at baseline weighed more and had higher BMI than PMV users. Moreover, women who used public transport had significantly higher BMI averaged over the four waves of the study, and at each separate wave. The explanation for this is unknown; however, the finding might reliably reflect the characteristics of a general-population sample of mid- and older-aged women (with all of its social and economic heterogeneity) rather than a commuter sample of younger employed workers, which is necessarily socially circumscribed, and which nearly all previous studies have used. Commuter samples might only capture some of the dimensions of the relationship between public transport use and bodyweight. This issue should be explored in future research, ideally using sex-stratified samples of both commuters and the general population, where associations between transport mode and bodyweight in each sample can be directly compared.

The robustness of this study's findings to sample attrition (i.e. drop-out) and bias were examined in two ways. First, using a multilevel logistic regression model with lagged variables, we investigated whether values of transport mode, the covariates, and BMI at one wave predicted drop-out at a subsequent wave. Drop-out is considered to be ‘missing at random’ (MAR) when it is unrelated to prior values of the outcome conditional on adjustment for the predictor and covariates (Knuiman et al., 2014). We found that drop-out was related to transport mode and a number of the covariates (e.g. SES, self-rated health); however, it was unrelated to prior values of BMI conditional on the other variables, hence the random effect regression estimates are unbiased under a MAR assumption

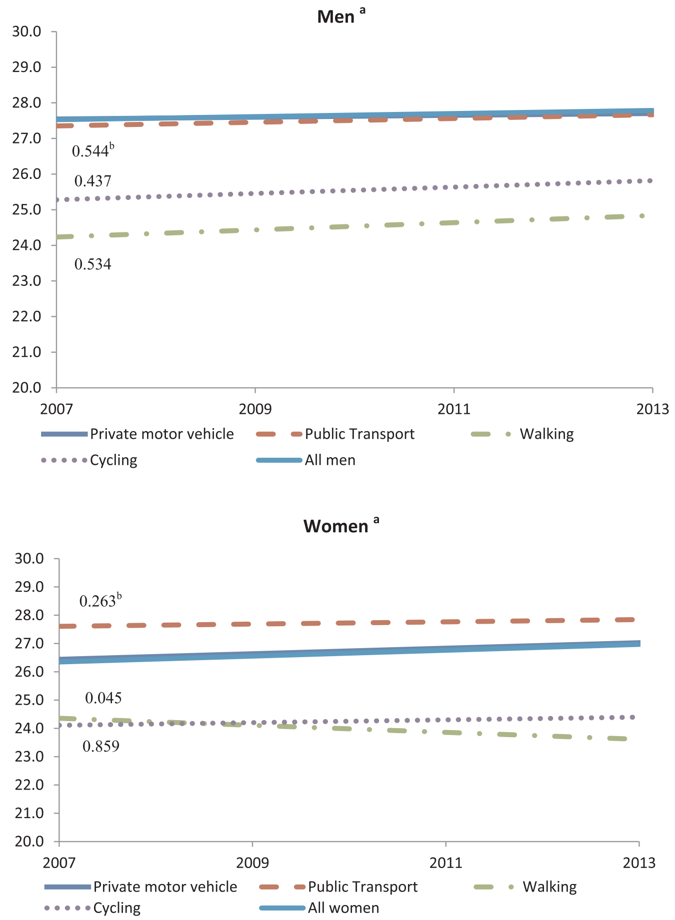

Fig. 1. Plotting the association between main transport mode and body mass index: men and women, 2007 – 2013 [a]Models adjusted for neighbourhood disadvantage, education, occupation, household income, country of birth, total physical activity, self-rated health, and private motor vehicle access [b]P-value for the test of the difference in the steepness of the regression slopes between private motor vehicle and each of the other transport modes: a statistically significant p-value is indicative of a faster rate of change in BMI relative to consistent users of private motor vehicles.

(Fitzmaurice et al., 2011). Second, this study's analysis was based on an unbalanced panel. These panels use all available data at each time-point and allow participants to exit and re-enter the panel irrespective of wave and item non-response: because of this, unbalanced panels do not contain exactly the same participants at every wave hence estimates of transport mode trends in BMI might partially reflect self-selection into or out of the panel. To test for this, the data were re-analysed using a balanced panel that comprised participants who returned a survey at every wave and had complete data for transport mode and BMI at all four waves: thus balanced panels contain exactly the same participants at each wave. Our reanalysis using a balanced panel showed that associations and trends between transport mode and BMI were similar irrespective of panel-type, thus providing further confidence in the robustness of the study's findings. The results of the balanced panel analyses are included in the online appendix.

4.1. Study limitations

Several methodological and analytical issues need to be considered when interpreting and understanding this study's findings. BMI is likely to have been systematically underestimated because it was based on self-reported height and weight (Yun et al., 2006). Our assessment of transport mode and travel did not capture duration or frequency of trips or distances travelled, and we did not measure the purpose of travel or travel on the weekend. Further, the measurement of main transport mode did not allow for mixed-mode travel (e.g. walking to the bus); hence an amount of within-mode heterogeneity in transport-related physical activity probably went unmeasured (Flint et al., 2014) resulting in an underestimation of the relationship between transport mode and BMI. This underestimation may have been exacerbated because physical activity was self-reported and based on retrospective accounts of time-based activities, and our measure of activity captured total activity from four different domains (i.e. leisure, occupation, domestic, and transport) (Fuller and Pabayo, 2014).

Comparing the findings of this study with previous research was difficult: some studies measured transport mode using highly specific and sensitive categories (Flint and Cummins 2016; Laverty et al., 2013; Millett et al., 2013) whereas others used crude measures that combined walking and cycling (Lindstrom 2008; Flint et al., 2014; Martin et al., 2015) or walking, cycling and public transport (Flint et al., 2016). Some researchers analysed data from men and women separately (Lindstrom 2008; Flint et al., 2014; Wen and Rissel, 2008) and others presented sex-combined results (Laverty et al., 2013; Martin et al., 2015; Millett et al., 2013). Some studies were based on all-age samples (Lindstrom, 2008; Wen and Rissel 2008; Martin et al., 2015), samples of mid-to-older aged adults (Flint and Cummins 2016; Flint et al., 2016) and samples of the working-aged (Laverty et al., 2013). Finally, the number and type of confounders used varied greatly between studies. Study heterogeneity in samples and methods has both negative and positive implications: negative in that directly and precisely comparing results via synthesising techniques such as systematic reviews or meta analyses is challenging, thus limiting the scope of the evidence to inform interventions or policy; and positive in that the reproducibility of findings based on different study designs and across diverse research settings and contexts attests to the reliability and generalisability of the association between transport mode and bodyweight (Krieger and Davey Smith, 2016).

5. Conclusion

This study confirms that active travel – and walking and cycling in particular – should be promoted as a way of incorporating physical activity into everyday life to address the global burden of overweight and obesity and related chronic disease (ARUP, 2016; Sallis et al., 2016; Stevenson et al., 2016). The focus of these intervention strategies should be on the use of active travel for all daily living activities (employment and non-employment related) that are within a walkable or cycling distance (Cole et al., 2017). Importantly, for maximum reach and effectiveness, these efforts would be facilitated by joined-up, inter-sectoral partnerships between health authorities and all sectors involved in the design, planning and (re)development of our cities and communities (Kleinert and Horton, 2016; Giles-Corti et al., 2016). Given this study's findings in relation to public transport and BMI, and the less-than-consistent evidence reported elsewhere, it remains an open question about when and under what circumstances using public transport is sufficient to influence weight status, and further research is needed. Finally, and more broadly, heavy reliance on PMVs underpins several problems confronting cities in most countries, including fossil fuel dependency, rising greenhouse gas emissions, traffic congestion, road trauma, and air and noise pollution (Giles-Cort et al., 2010). Reducing reliance on PMVs and facilitating greater use of active travel modes will therefore produce significant co-benefits - social, economic, environmental and health – across multiple sectors and for all societies (Woodcock et al., 2009; Jarrett et al., 2010).

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.jth.2017.12.004.

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