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# Residential location, commute distance, and body size: Cross-sectional observational study of state and territory capital cities in Australia

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ABSTRACT:

*Introduction:* Body size, a key risk factor for chronic diseases, is associated with longer commutes. This study assessed associations between residential proximity to capital city central business district (CBD), area-level commute distance, and individual-level body size (body mass index [BMI] and waist circumference [WC]), and whether commute distance partially explains associations between residential proximity and body size.

*Methods:* This study used 2017-18 National Health Survey (NHS) data for working adults (aged ≥15 years, n = 6394) residing in Australian capital cities. Measures included individual-level sociodemographic information and measured body size (BMI, WC), area-level (SA1) disadvantage, average commute distance, and population density. SA1-centroid distances to CBDs were calculated and grouped into tertiles. Multilevel linear regression models estimated city-specific associations between commute distance and body size, and residential proximity and body size, accounting for area clustering and sequentially adjusting for covariates.

*Results:* Commute distance was positively associated with BMI except in Adelaide and Darwin, and with WC in all cities except Darwin. Associations were largely unaffected by covariate adjustment in Sydney (β = 0.039, 95%CI: 0.004, 0.074) and Melbourne (β = 0.083, 95%CI: 0.045, 0.121) for BMI; and in Melbourne (β = 0.169, 95%CI: 0.074, 0.265) and Perth (β = 0.082, 95%CI: <0.001, 0.166) for WC. For other cities, associations were nullified. Distance to CBD was positively associated with BMI and WC in most cities, but robust to covariate adjustment (including commute distance) only in Darwin (BMI: middle tertile β = 1.60, 95%CI: 0.39, 2.81; WC: middle tertile β = 4.10, 95% CI: 0.45, 7.75) and Adelaide (WC: outer tertile β = 7.67, 95%CI: 2.65, 121.69).

*Conclusion:* Living in middle and outer areas of Australia's capital cities is associated with greater body size. Longer commute distance partially accounts for this association in some cities. Integrated multisector planning may help to reduce the association between residential distance to CBD and commute distance on body size and thus health.

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## 1. Introduction

During recent decades, cities in Australia and many other countries have experienced rapidly increasing urbanisation and associated population growth (Infrastructure Australia, 2018; McCulley et al., 2019; Sun et al., 2020). These changes present city planners and policy makers with numerous challenges such as the equitable provision of features of built environments that promote and support population health. Such features include walkable neighbourhood design, and provision of public transport, public open space, local amenities including social and community facilities, and accessible employment (Giles-Corti et al., 2016). These challenges are acute in cities characterised by a monocentric metropolis (i.e., with a central business district [CBD]) surrounded by lower density suburban development, a pattern typical of Australian capital cities (Slavko et al., 2020) and cities elsewhere. Residing closer to a city's CBD often means living in a higher density area (i.e., apartment buildings and smaller homes), with more shared space, more walkable neighbourhoods, and closer employment and destinations such as shopping centres, thus facilitating the use of public transport and active travel (e.g., cycling) and shorter commute times. This contrasts with the experience of residing in an outer, lower density suburb where residences might be larger and initially more affordable, but less convenient and more costly over time as a result of restricted access to community amenities, an employment market, and public transport, necessitating a greater reliance on private motor vehicles and longer commute times (Badland et al., 2014). Socioeconomically disadvantaged individuals, therefore, often reside in disadvantaged areas farther from the CBD which may feature poorer urban design. Thus, there is a need to account for potential confounding by area disadvantage in studies assessing associations between the built environment and health outcomes (Chaix et al., 2010).

In this study, we characterise Australia's capital cities using the monocentric metropolis model and examine associations between area-level commute distance (a proxy for job proximity (White et al., 2019)) and individual body size (body mass index [BMI], and waist circumference), a key risk factor for preventable chronic diseases such as type 2 diabetes, cardiovascular disease, and some cancers (Ng et al., 2014; World Health Organization, 2013). There is now a well-established literature documenting positive associations between duration or distance spent travelling in a motor vehicle and weight status (McCormack and Virk, 2014). A parallel literature suggests these associations are due in part to longer commutes which can displace opportunities for physical activity and increase time spent sitting (Christian, 2012b; Künn-Nelen, 2016) and increase exposure to an unhealthful food environment and the consumption of takeaway food (Burgoine et al., 2014). However, no known study has examined the association between area-level commuting and individual body size within the broader context of how cities are spatially structured, and more specifically, where people live in relation to the CBD. Importantly, Australia's capital cities (among others) vary considerably on factors that might influence commute distance (and hence body size) such as geographic area, population density, public transport networks, built environments, employment and industry profiles, and extent of greenfield development on the urban fringes (among others). Therefore, we assess area-level commute distance and body size for each of Australia's state and territory capital cities. We evaluate: (i) whether residential proximity to a capital city's CBD is associated with area-level commute distance to work, and with individual body size expressed as BMI and waist circumference; (ii) whether area-level commute distance to work is associated with body size; and (iii) whether commute distance contributes to the relationship between residential proximity and body size.

## 2. Methods

Data were drawn from the 2017-18 Australian National Health Survey (NHS), designed, and implemented by the Australian Bureau of Statistics (ABS). Full details of the survey's scope and coverage, its research design, sampling procedures and data collection methods have been documented elsewhere (Australian Bureau of Statistics, 2019). Only a brief overview is provided here.

### *2.1. Sampling*

The NHS was conducted over a 12-month period (July 2017 to June 2018) accounting for possible seasonal effects. The NHS used a stratified multistage area sample of private dwellings (n = 25,109) from across the whole Australian population resident in private dwellings, excluding those living in a remote location or Indigenous community, and was designed to provide detailed estimates for capital cities. After excluding out-of-scope dwellings (e.g., vacant), the number of sampled dwellings was reduced to 21,544, and of these, 16,384 responded to the survey (76.1% response rate). Within each responding dwelling, one adult aged 18 years and over, and one child 0–17 years (where applicable) were randomly selected, resulting in a total sample of 21,315 persons.

### *2.2. Data collection*

Data were collected by trained ABS personnel using face-to-face Computer Assisted Personal Interviews. Information collected included prevalence of long-term health conditions, disability status, mental health and psychological wellbeing, medication use, health literacy, health-related behaviours and risk factors, and household demographic and socioeconomic characteristics. Indicators of each respondent's physical and social environment were also included as part of the NHS dataset and those of relevance for this present study were area-level socioeconomic disadvantage, population density, and commuting distance.

### *2.3. Geographic scope and units of analyses for this study*

Using combinations of geographic indicators available in the NHS dataset, we identified areas corresponding to each of the eight state and territory capital cities in Australia: Sydney, Melbourne, Brisbane, Adelaide, Perth, Hobart, Darwin, and Canberra. Within each city, we then identified all Statistical Areas Level 1 (SA1) containing sampled dwellings. SA1s were the primary area-units used by this study (analyses were conducted at the individual level). In capital cities, SA1s typically have a population of 200–800 persons (average 400) and a residential density of over 200 persons per km$^2$ (Australian Bureau of Statistics, 2016a).

### 2.4. *Directed Acyclic Graph (DAG)*

A DAG was constructed based on the literature to make explicit our conceptualisation of the associations between residential location, commute distance, and body size, and to guide analysis (Fig. 1). The depicted pathways in the DAG inform our study in four ways. First, proximity of one's residential neighbourhood to the city's CBD will be associated with distance travelled to work. Second, the probability of living in a neighbourhood that is proximate to, or distal from, the CBD will be influenced by demographic characteristics and socioeconomic position (SEP), and these factors will also differentiate the body size of people living close to, or further from, the CBD; hence, demographic factors and SEP are conceptualised as possible confounders. Third, neighbourhoods at varying proximities to the city's CBD will differ in their population densities and levels of neighbourhood disadvantage, and these factors will also differentiate inner and outer areas in terms of built environments that influence body size; hence, population density and neighbourhood disadvantage are conceptualised as further possible confounders of the association between residential location and body size. Fourth, commute distance will influence body size by displacing time available for physical activity, by requiring people to be sedentary for extended periods, by increasing the likelihood of exposure to unhealthful food environments and the consumption of takeaway food, or a combination of these, and beyond a certain threshold, will govern the transport mode, impacting active transport opportunities, which have downstream effects on physical activity levels and sedentary behaviours. Importantly, whilst physical activity, sedentary behaviour, and diet are depicted in the DAG as being prior proximal causes of body size, these behavioural factors are presented only for completeness and to demonstrate the biological plausibility of the DAG; they are not included in our analysis, as doing so would arguably constitute over-adjustment.

### 2.5. *Measures*

#### 2.5.1. *Residential location (i.e., distance from CBD)*

The 2017-18 NHS did not include residential distance from the CBD. Hence, for each capital city, using MapInfo RouteFinder [MapInfo Pro v2019.1, RouteFinder v6.01, Precisely, Pearl River, New York] we calculated Euclidean distances (km) from SA1 centroids to the relevant CBD (defined as the location of the city's General Post Office – co-ordinates extracted from Google Maps [Google Inc, Mountain View, California]) and incorporated this into the NHS dataset by merging on the SA1 identifier common to both datasets. Capital cities in Australia vary markedly in their population-size and geographic coverage. To account for this (and other) variation and provide a basis for comparing cities, a standardised measure of residential location was created. SA1s within each city were grouped into tertiles using their Euclidean distance to the CBD: 'inner areas' - SA1s relatively close to the CBD; 'middle areas' – SA1s at an intermediate distance; and 'outer areas' – SA1s farther away from the CBD.

### 2.6. *Commute distance*

The NHS dataset includes an ecologic measure of average distance travelled between a person's neighbourhood of residence and their place of work derived using data collected at the 2016 Census of Population and Housing. The measure was calculated by the ABS and is described in detail elsewhere (Australian Bureau of Statistics, 2019). In brief, for census participants who identified as employed,

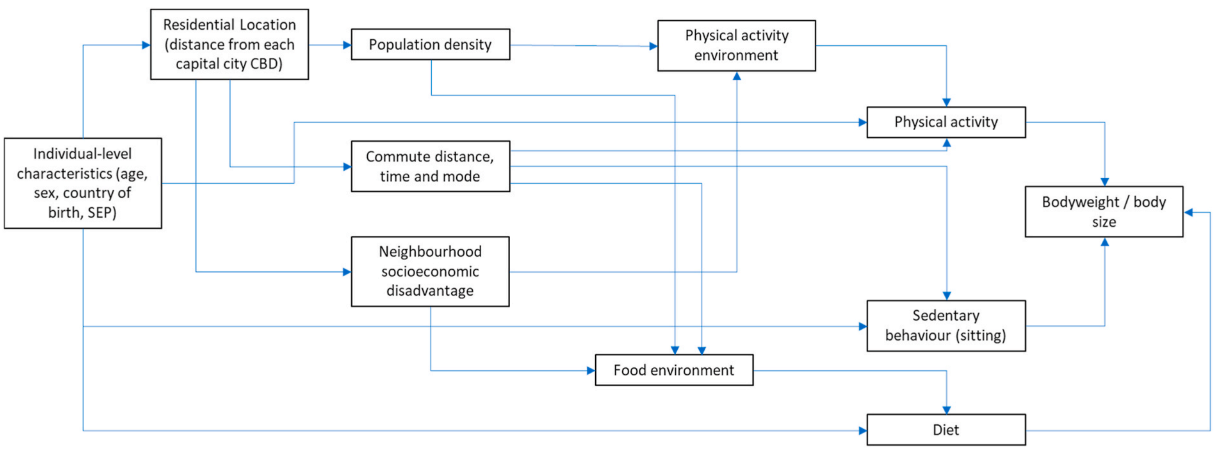


**Fig. 1.** Directed Acyclic Graph depicting relationships between residential location, commute distance, and body size (body mass index and waist circumference).

commute distance was calculated as the shortest road-network distance between the SA1 centroid for their usual place of residence to the SA1 centroid for their place of work. Where road-network distance could not be calculated a straight-line Euclidean distance was calculated. Individual-level distance information was averaged for each SA1 and this averaged commute distance measure was appended to the NHS data by the ABS using SA1 identifiers. For this present study, commute distance was operationalised as a continuous variable representing a round trip (i.e., to work and back).

#### 2.6.1. Body size

Two measures of body size were obtained by direct physical measurement using standard procedures by trained ABS personnel: (1) body mass index (BMI) (calculated as weight $[kg]^2$ divided by height [m]); and (2) waist circumference (cm). Interviewers used a digital scale to measure weight, a stadiometer to measure height, and a non-extensible metal tape measure to measure waist circumference (at the height midway between the lowest palpable rib and the iliac crest) (Australian Bureau of Statistics, 2019; World Health Organization, 2011). Given respondent sensitivities about providing these physical measures, non-response rates were high: 33.8% for BMI, and 35.4% for waist circumference. The ABS imputed missing values for these physical measures using the Hot Deck method (Andridge and Little, 2010) whereby a 'recipient' (a record with missing physical data) was matched with a 'donor' (a non-missing record) with similar characteristics based on sex, age-group, location, self-perceived body mass, level of exercise, cholesterol status as a long-term condition, and BMI collected from self-report height and weight.

Sensitivity tests conducted by the ABS showed negligible differences between 'measured only' and 'measured and imputed' data, with the latter deemed by the ABS to be of 'suitable quality' (Australian Bureau of Statistics, 2019). This study used 'measured and imputed' body size data. Sensitivity analyses were conducted to assess potential bias related to analysis of imputed data. We performed three sets of analyses for each outcome measure (BMI and WC) using the following analytic samples: 1) measured data only; 2) measured and imputed data; and 3) imputed data only (see Supplementary files, Table S1). The results of these analyses indicate that the effect estimates we report based on the inclusion of imputed data are weaker and thus biased toward the null rather than favouring positive associations.

### 2.7. Covariates

Potential confounders of the associations between place of residence, commute distance, and body size were identified according to our DAG. At the individual-level these included: age (years); sex (male or female); country of birth (Australian-born or overseas-born); highest educational qualification completed (four categories: bachelor's degree or higher; diploma; certificate; or high school or less); occupation (four categories: manager and professional; white collar employee; blue collar worker; and 'not in the labour market'); and total equalised household income (quintiles, with households in Q5 being in the lowest income category).

At the area-level, potential confounders included: neighbourhood disadvantage (SA1), expressed using the ABS' Index of Relative Socioeconomic Disadvantage (IRSD) (Australian Bureau of Statistics, 2011) operationalised as a continuous variable with lower scores denoting more disadvantaged areas; and population density, measured as density at 1 $km^2$ grid-cells, and calculated by the ABS by spatially intersecting the longitude and latitude associated with all household addresses with the Australian Population Grid 2017 (Australian Bureau of Statistics, 2018).

### 2.8. Analytic dataset and analytic approach

Limiting the study sample to residents of state and territory capital cities reduced the sample from n = 21,315 to n = 13,078. Of this portion, we retained persons of working age (i.e., 15 years and over) who were active in the paid labour market at the time of the 2017-18 NHS (n = 6757). Further, we excluded women who reported being pregnant (n = 31) and persons with missing data for one or more of measured confounding variables (n = 332). The final analytic sample comprised 6394 persons residing across 2913 SA1s.

Analyses were conducted in three stages for each capital city. Firstly, study participants' body size and socio-demographic characteristics were described using univariate statistics. Secondly, bivariate statistics were used to examine associations between place of residence, commute distance, and body size. Finally, multilevel linear regression models were used to estimate city-specific associations between commute distance and body size, and residential location and body size, adjusting for covariates and accounting for clustering of individuals within SA1s. A multistage modelling strategy was used: Model 1 adjusted for age, sex, and country of birth; Model 2 further adjusted for individual-level SEP; Model 3 added neighbourhood disadvantage; and Model 4 added population density. When estimating the association between residential location and body size we also adjusted for commute distance (Model 5). Model outputs are expressed as β coefficient and 95% confidence interval. All data preparation and analyses were conducted using Stata version 16.0 for Windows (StataCorp, 2019).

### 2.9. Ethics

This study received ethics approval from the University of Canberra's Human Research Ethics Committee (UC HREC-2313). This study has been conducted in compliance with relevant laws and institutional guidelines and in accordance with the requirements of the Declaration of Helsinki.

## 3. Results

Table 1 presents univariate statistics describing participants' body size and sociodemographic characteristics by capital city. Brisbane residents had the highest average BMI (28.1 kg/m$^2$) and the largest average waist circumference (93.0 cm), and residents of Sydney had the lowest average BMI (26.7 kg/m$^2$) and the smallest average waist circumference (89.3 cm). There were substantial differences between the cities in residents' country of birth, educational attainment, occupation, and household income. Neighbourhoods in Canberra were the most socioeconomically advantaged and neighbourhoods in Hobart the most disadvantaged. Population density was highest in Sydney (4147 persons/km$^2$) and lowest in Hobart (1262 persons/km$^2$).

Table 2 differentiates, for each capital city, residential proximity to the CBD according to commute distance to work (round trip), BMI, and waist circumference. Distance to CBD tertiles varied by city. In Sydney, neighbourhoods categorised as 'closest' were on average 6.7 km (95%CI 6.4–7.0) from the CBD, and those categorised as 'farthest' were an average of 35.6 km (95%CI 34.6–36.7) from the CBD. The corresponding distances for the closest and farthest neighbourhoods in Hobart were 2.7 km (95%CI 2.6–2.9) and 12.8 km (95%CI 12.2–13.3) respectively. Commute distances within these distance to CBD tertiles also varied by city. For example, residents of Perth who lived closer to the CBD commuted an average of 18 km (95%CI 17.6–18.5) and those living farther from the CBD commuted an average of 38.4 km (95%CI 37.3–39.6). The corresponding round-trip commute distances within Hobart were 9.3 km (95%CI 8.8–9.8) for residents in the closest distance tertile to the CBD and 26.1 km (95%CI 25.1–27.7) for those living in the farthest tertile from the CBD. For body size measures, there was a positive graded association between residential proximity to the CBD and both BMI and waist circumference which tended to be smallest in neighbourhoods closer to the CBD, intermediate in middle-distance neighbourhoods, and greatest in neighbourhoods farthest from the CBD. This pattern was evident for all capital cities except Darwin, where BMI and waist circumference were greatest for residents of the middle-distance neighbourhoods.

Table 3 presents the results of regression models estimating associations between area commute distance and individual body size by capital city. Significant positive associations were found between commute distance and BMI in Sydney, Melbourne, Brisbane,

**Table 1**
Body size and sociodemographic characteristics of study participants, by Australian capital city.

| | Sydney | Melbourne | Brisbane | Adelaide | Perth | Hobart | Darwin | Canberra |
|---|---|---|---|---|---|---|---|---|
| Individuals (n) | 1116 | 1177 | 960 | 655 | 786 | 340 | 575 | 785 |
| Areas (n) | 576 | 548 | 459 | 379 | 368 | 146 | 122 | 315 |
| ***Body size*** | | | | | | | | |
| Body mass index | | | | | | | | |
| Mean (SD) | 26.7 (5.2) | 27.3 (5.5) | 28.1 (5.9) | 27.8 (5.5) | 27.2 (5.4) | 27.4 (5.4) | 27.2 (5.9) | 27.5 (6.0) |
| *10/90pct* | 20.7/33.7 | 21.2/34.5 | 21.3/36.0 | 21.5/34.8 | 21.0/34.6 | 21.1/34.1 | 20.9/34.7 | 21.3/35.4 |
| Waist circumference | | | | | | | | |
| Mean (SD) | 89.3 (14.6) | 90.4 (15.1) | 93.0 (16.0) | 91.8 (15.7) | 90.4 (14.8) | 90.6 (14.7) | 89.8 (16.1) | 91.2 (15.8) |
| *10/90pct* | 71.0/107.3 | 71.6/110.0 | 73.0/114.5 | 72.0/112.0 | 72.0/110.0 | 73.0/109.0 | 70.0/110.0 | 72.0/112.0 |
| ***Covariates*** | | | | | | | | |
| Age (mean, SD) | 41.1 (13.6) | 40.8 (13.9) | 40.2 (13.4) | 42.9 (14.3) | 41.9 (14.5) | 43.0 (14.2) | 40.1 (13.6) | 40.4 (13.5) |
| Sex (% men) | 50.7 | 50.1 | 50.5 | 49.0 | 51.5 | 43.8 | 50.9 | 45.7 |
| Country of birth (%) | | | | | | | | |
| Australia | 52.4 | 62.7 | 68.8 | 72.3 | 58.6 | 79.7 | 65.3 | 68.9 |
| Overseas | 47.5 | 37.3 | 31.1 | 27.6 | 41.3 | 20.2 | 34.6 | 31.0 |
| *Education (%)* | | | | | | | | |
| Bachelor's degree+ | 47.5 | 46.0 | 35.5 | 33.7 | 34.9 | 35.2 | 32.5 | 49.4 |
| Diploma | 11.8 | 12.2 | 13.5 | 12.2 | 13.1 | 12.3 | 11.1 | 11.7 |
| Certificate | 14.7 | 14.0 | 23.8 | 21.5 | 20.6 | 24.1 | 24.8 | 13.3 |
| High school or less | 25.9 | 27.7 | 27.0 | 32.5 | 31.3 | 28.2 | 31.4 | 25.4 |
| *Occupation (%)* | | | | | | | | |
| Managers and professionals | 43.2 | 42.9 | 35.4 | 40.3 | 37.2 | 37.6 | 29.7 | 50.4 |
| White collar | 30.7 | 31.1 | 33.4 | 32.8 | 29.1 | 34.1 | 37.0 | 32.3 |
| Blue collar | 22.4 | 22.3 | 26.7 | 23.8 | 29.0 | 22.9 | 27.8 | 15.0 |
| Unemployed | 3.4 | 3.5 | 4.3 | 3.0 | 4.5 | 5.2 | 5.3 | 2.2 |
| *Household income (quintiles) (%)* | | | | | | | | |
| Q1 (highest) | 5.3 | 3.8 | 6.0 | 8.0 | 5.8 | 7.0 | 5.2 | 3.5 |
| Q2 | 7.5 | 12.0 | 11.4 | 14.6 | 9.4 | 15.8 | 9.5 | 7.2 |
| Q3 | 16.0 | 19.3 | 22.2 | 21.9 | 20.7 | 23.8 | 18.9 | 15.2 |
| Q4 | 22.7 | 21.8 | 21.3 | 24.2 | 22.6 | 23.5 | 23.1 | 24.2 |
| Q5 (lowest) | 31.8 | 22.3 | 24.5 | 21.9 | 25.5 | 20.5 | 32.3 | 38.4 |
| Missing | 16.4 | 20.5 | 14.2 | 9.0 | 15.7 | 9.1 | 10.7 | 11.2 |
| *Area-level disadvantage* | | | | | | | | |
| Mean (SD) | 1035.8 (90.2) | 1028.0 (77.9) | 1022.8 (82.5) | 1003.7 (83.5) | 1029.7 (70.1) | 991.9 (103.3) | 1038.4 (69.7) | 1065.7 (53.2) |
| *10/90pct* | 915/1123 | 932/1109 | 911/1110 | 881/1091 | 934/1108 | 838/1096 | 962/1111 | 991/1125 |
| *Population density* | | | | | | | | |
| Mean (SD) | 4147.9 (3200.2) | 3029.3 (2135.0) | 2006.5 (1194.6) | 2023.6 (746.6) | 1759.7 (956.6) | 1262.8 (858.5) | 1438.2 (790.2) | 1698.8 (825.7) |
| *10/90pct* | 1056/8229 | 1017/4994 | 471/3376 | 951/2839 | 494/3050 | 115/2362 | 245/2383 | 724/2747 |

**Table 2**

Residential proximity to each city's Central Business District, commute distance (km), and body size.

| City | Residential location[a] | Areas per location | Participants per location | Distance to CBD (Euclidian, km)[b] | | Commute distance to work (km)[c] | | Body mass index (kg/m$^2$) | | Waist circumference (cm) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Mean | 95% CI | Mean | 95% CI | Mean | 95%CI | Mean | 95%CI |
| **Sydney** | (Inner) | 188 | 347 | 6.7 | 6.4–7.0 | 16.1 | 15.7–16.6 | 25.9 | 25.4–26.4 | 87.7 | 86.1–89.2 |
| | (Middle) | 197 | 381 | 17.0 | 16.7–17.3 | 25.0 | 24.6–25.4 | 26.7 | 26.2–27.2 | 89.4 | 88.1–90.8 |
| | (Outer) | 191 | 388 | 35.6 | 34.6–36.7 | 38.8 | 37.9–39.7 | 27.3 | 26.8–27.9 | 90.6 | 89.1–92.1 |
| **Melbourne** | (Inner) | 181 | 401 | 7.2 | 6.9–7.5 | 16.5 | 16.1–16.9 | 26.9 | 26.4–27.4 | 89.4 | 87.9–90.8 |
| | (Middle) | 183 | 362 | 17.3 | 17.0–17.6 | 26.8 | 26.2–27.4 | 27.7 | 26.1–27.2 | 88.8 | 87.4–90.3 |
| | (Outer) | 184 | 414 | 35.3 | 34.4–36.3 | 36.7 | 35.9–37.4 | 28.3 | 27.7–28.8 | 92.7 | 91.2–94.3 |
| **Brisbane** | (Inner) | 154 | 301 | 6.2 | 5.8–6.5 | 16.9 | 16.4–17.3 | 27.8 | 27.2–28.5 | 92.4 | 90.5–94.2 |
| | (Middle) | 156 | 317 | 16.2 | 15.9–16.6 | 27.8 | 27.4–28.3 | 28.0 | 27.3–28.6 | 93.1 | 91.4–94.8 |
| | (Outer) | 149 | 342 | 28.5 | 27.9–29.1 | 37.1 | 36.3–37.8 | 28.5 | 27.8–29.2 | 93.4 | 91.7–95.2 |
| **Adelaide** | (Inner) | 129 | 227 | 4.9 | 4.7–5.1 | 13.6 | 13.2–13.9 | 27.5 | 26.7–28.2 | 89.9 | 87.9–91.9 |
| | (Middle) | 127 | 230 | 10.4 | 10.2–10.7 | 20.3 | 19.9–20.6 | 27.6 | 26.8–28.3 | 90.9 | 88.8–92.9 |
| | (Outer) | 123 | 198 | 20.6 | 19.8–21.4 | 30.0 | 29.2–30.8 | 28.5 | 27.7–29.3 | 95.0 | 92.8–97.1 |
| **Perth** | (Inner) | 129 | 242 | 7.1 | 6.8–7.4 | 18.0 | 17.6–18.5 | 26.7 | 26.0–27.4 | 89.3 | 87.4–91.2 |
| | (Middle) | 119 | 258 | 14.0 | 13.7–14.3 | 24.7 | 24.2–25.2 | 27.3 | 26.7–27.9 | 90.8 | 89.1–92.6 |
| | (Outer) | 120 | 286 | 31.2 | 29.7–32.6 | 38.4 | 37.3–39.6 | 27.6 | 26.9–28.3 | 91.0 | 89.3–92.8 |
| **Hobart** | (Inner) | 50 | 105 | 2.7 | 2.6–2.9 | 9.3 | 8.8–9.8 | 26.6 | 25.5–27.6 | 88.6 | 85.6–91.5 |
| | (Middle) | 49 | 108 | 6.2 | 6.0–6.5 | 16.2 | 15.3–17.1 | 27.6 | 26.5–28.7 | 90.9 | 88.2–93.5 |
| | (Outer) | 47 | 127 | 12.8 | 12.2–13.3 | 26.1 | 25.1–27.1 | 28.0 | 27.1–29.0 | 92.0 | 89.4–94.5 |
| **Darwin** | (Inner) | 41 | 188 | 4.6 | 4.2–5.1 | 17.0 | 16.5–17.6 | 26.6 | 25.8–27.3 | 88.3 | 86.1–90.5 |
| | (Middle) | 39 | 188 | 10.8 | 10.7–11.0 | 18.9 | 18.4–19.3 | 27.8 | 26.9–28.7 | 92.2 | 89.7–94.7 |
| | (Outer) | 42 | 199 | 16.1 | 15.9–16.3 | 28.0 | 27.6–28.4 | 27.2 | 26.4–28.1 | 88.9 | 86.7–91.1 |
| **Canberra** | (Inner) | 104 | 235 | 5.1 | 4.9–5.4 | 14.1 | 13.6–14.6 | 27.2 | 26.4–28.1 | 90.5 | 88.4–92.6 |
| | (Middle) | 104 | 258 | 10.1 | 10.0–10.3 | 22.4 | 22.0–22.7 | 27.3 | 26.6–28.0 | 90.9 | 89.0–92.8 |
| | (Outer) | 107 | 292 | 15.0 | 14.8–15.1 | 30.1 | 29.6–30.5 | 28.0 | 27.3–28.7 | 92.0 | 90.2–93.8 |

[a] Participants' residential neighbourhood (Statistical Area 1) grouped into tertiles on the basis of their Euclidean distance to the capital city's central business district.

[b] Euclidean distance from centroid of the area (Statistical Area 1) to the capital city's central business district.

[c] Area-level (average), round -trip distance travelled between SA1 centroid for a person's place of usual residence and SA1 centroid for their place of work.

**Table 3**
Association between commute distance (km) and body size, by capital city (regression coefficients and 95% confidence intervals).

| | Model 1[a] | | Model 2[b] | | Model 3[c] | | Model 4[d] | |
|---|---|---|---|---|---|---|---|---|
| Body Mass Index (kg/m$^2$) | β | 95% CI | β | 95% CI | β | 95% CI | β | 95% CI |
| **Sydney** | **0.043** | **0.014, 0.072** | **0.042** | **0.013, 0.071** | **0.040** | **0.011, 0.070** | **0.039** | **0.004, 0.074** |
| **Melbourne** | **0.071** | **0.042, 0.100** | **0.064** | **0.033, 0.095** | **0.063** | **0.032, 0.094** | **0.083** | **0.045, 0.121** |
| **Brisbane** | **0.050** | **0.012, 0.088** | 0.031 | −0.005, 0.068 | 0.016 | −0.021, 0.054 | 0.015 | −0.028, 0.058 |
| **Adelaide** | 0.029 | −0.021, 0.080 | 0.002 | −0.054, 0.058 | 0.001 | −0.054, 0.057 | 0.004 | −0.054, 0.064 |
| **Perth** | **0.041** | **0.009, 0.074** | **0.034** | **0.001, 0.067** | 0.030 | −0.002, 0.064 | 0.026 | −0.008, 0.060 |
| **Hobart** | **0.077** | **0.019, 0.135** | 0.060 | −0.001, 0.121 | 0.060 | −0.001, 0.121 | 0.040 | −0.030, 0.112 |
| **Darwin** | 0.026 | −0.058, 0.111 | 0.018 | −0.064, 0.101 | 0.016 | −0.063, 0.096 | 0.012 | −0.069, 0.095 |
| **Canberra** | **0.069** | **0.016, 0.122** | 0.048 | −0.007, 0.104 | 0.048 | −0.008, 0.104 | 0.048 | −0.007, 0.104 |
| **Waist circumference (cm)** | | | | | | | | |
| **Sydney** | **0.090** | **0.018, 0.161** | **0.087** | **0.016, 0.157** | **0.082** | **0.011, 0.153** | 0.057 | −0.032, 0.147 |
| **Melbourne** | **0.156** | **0.081, 0.231** | **0.136** | **0.060, 0.213** | **0.133** | **0.056, 0.209** | **0.169** | **0.074, 0.265** |
| **Brisbane** | **0.102** | **0.007, 0.197** | 0.044 | −0.047, 0.136 | −0.009 | −0.105, 0.085 | −0.030 | −0.039, 0.077 |
| **Adelaide** | **0.146** | **0.009, 0.284** | 0.084 | −0.062, 0.232 | 0.080 | −0.065, 0.226 | 0.118 | −0.032, 0.268 |
| **Perth** | **0.122** | **0.045, 0.199** | **0.112** | **0.031, 0.193** | **0.100** | **0.017, 0.183** | **0.082** | < **0.001, 0.166** |
| **Hobart** | **0.228** | **0.083, 0.373** | **0.198** | **0.038, 0.358** | **0.198** | **0.041, 0.355** | 0.156 | −0.026, 0.338 |
| **Darwin** | 0.048 | −0.187, 0.284 | 0.029 | −0.209, 0.269 | 0.023 | −0.210, 0.256 | 0.026 | −0.208, 0.261 |
| **Canberra** | **0.146** | **0.002, 0.289** | 0.106 | −0.042, 0.255 | 0.105 | −0.042, 0.253 | 0.107 | –0.039, 0.254 |

[a] Model 1: adjusted for age, sex, country of birth.
[b] Model 2: model 1 plus adjustment for education, occupation, and household income.
[c] Model 3: model 2 plus adjustment for neighbourhood disadvantage.
[d] Model 4: model 3 plus adjustment for population density.

Perth, Hobart, and Canberra: longer average area round-trip commute distance to work was associated with greater individual BMI. In Sydney and Melbourne, the association between commute distance and BMI was largely unaffected by adjustment for sociodemographic factors, neighbourhood disadvantage, and population density, whereas in Brisbane, Perth, Hobart, and Canberra, adjustment for these factors attenuated the associations to the null. There were no significant associations between commute distance and BMI in Adelaide and Darwin.

**Table 4**
Residential proximity to each city's Central Business District and body mass index (multilevel linear regression coefficients and 95% confidence intervals).

| | | Model 1[a] | | Model 2[b] | | Model 3[c] | | Model 4[d] | | Model 5[e] | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Location | β | 95% CI | β | 95% CI | β | 95% CI | β | 95% CI | β | 95% CI |
| **Sydney** | (Inner) | – | | – | | – | | – | | – | |
| | (Middle) | **0.80** | **0.09, 1.52** | **0.92** | **0.21, 1.63** | **0.77** | **0.07, 1.47** | 0.76 | −0.24, 1.55 | 0.50 | −0.38, 1.39 |
| | (Outer) | **1.23** | **0.48, 1.97** | **1.24** | **0.49, 1.98** | **1.05** | **0.29, 1.81** | **1.04** | **0.12, 1.96** | 0.35 | −1.10, 1.81 |
| **Melbourne** | (Inner) | – | | – | | – | | – | | – | |
| | (Middle) | −0.08 | −0.82 0.65 | −0.19 | −0.94, 0.55 | −0.33 | −1.08, 0.42 | −0.21 | −1.11, 0.67 | −1.07 | −2.03, 0.11 |
| | (Outer) | **1.34** | **0.56, 2.13** | **1.10** | **0.27, 1.94** | **1.00** | **0.16, 1.84** | **1.14** | **0.11, 2.17** | −0.66 | −2.04, 0.70 |
| **Brisbane** | (Inner) | – | | – | | – | | – | – | – | |
| | (Middle) | 0.21 | −0.65, 1.08 | 0.03 | −0.84, 0.92 | −0.20 | −1.13, 0.72 | −0.36 | −1.36, 0.64 | −0.80 | −1.98, 0.37 |
| | (Outer) | 0.89 | −0.06, 1.85 | 0.45 | −0.49, 1.40 | −0.01 | −0.98, 0.94 | −0.22 | −1.34, 0.90 | −1.07 | −2.79, 0.65 |
| **Adelaide** | (Inner) | – | | – | | – | | – | – | – | |
| | (Middle) | 0.01 | −0.96, 0.99 | −0.22 | −1.18, 0.74 | −0.20 | −1.16, 0.75 | −0.15 | −1.14, 0.83 | 0.10 | −1.04, 1.26 |
| | (Outer) | 0.86 | −0.11, 1.84 | 0.33 | −0.75, 1.41 | 0.29 | −0.79, 1.37 | 0.37 | −0.76, 1.52 | 1.03 | −0.89, 2.95 |
| **Perth** | (Inner) | – | | – | | – | | – | – | – | |
| | (Middle) | 0.63 | −0.30, 1.58 | 0.42 | −0.52, 1.37 | 0.34 | −0.61 1.29 | 0.28 | −0.68, 1.24 | 0.13 | −0.83, 1.10 |
| | (Outer) | **1.10** | **0.14, 2.06** | 0.78, | −0.20, 1.77 | 0.68 | −0.29, 1.67 | 0.55 | −0.47, 1.58 | 0.08 | −1.12, 1.29 |
| **Hobart** | (Inner) | – | | – | | – | | – | – | – | |
| | (Middle) | 0.96 | −0.40, 2.32 | 0.66 | −0.88, 2.21 | 0.27 | −1.20, 1.75 | −0.11 | −1.80, 1.56 | −0.93 | −2.78, 0.91 |
| | (Outer) | 1.12 | −0.23, 2.48 | 0.80 | −0.68, 2.30 | 0.45 | −1.00, 1.92 | −0.07 | −1.71, 1.57 | −2.02 | −4.53, 0.48 |
| **Darwin** | (Inner) | – | | – | | – | | – | – | – | |
| | (Middle) | **1.51** | **0.25, 2.78** | **1.68** | **0.47, 2.89** | **1.57** | **0.36 2.79** | **1.56** | **0.35, 2.71** | **1.60** | **0.39, 2.81** |
| | (Outer) | **1.17** | **0.11, 2.24** | **1.09** | **0.05, 2.13** | 0.98 | −0.04, 2.00 | 0.93 | −0.13, 2.00 | 1.13 | −0.32, 2.59 |
| **Canberra** | (Inner) | – | | – | | – | | – | – | – | |
| | (Middle) | 0.32 | −0.73, 1.39 | 0.07 | −1.00, 1.15 | 0.03 | −1.03, 1.10 | 0.04 | −0.10, 1.13 | −0.57 | −2.11, 0.96 |
| | (Outer) | 0.96 | −0.08, 2.00 | 0.58 | −0.49, 1.65 | 0.58 | −0.49, 1.66 | 0.58 | −0.49, 1.65 | −0.65 | −2.91, 1.60 |

[a] Model 1: adjusted for age, sex, country of birth.
[b] Model 2: model 1 plus adjustment for education, occupation, and household income.
[c] Model 3: model 2 plus adjustment for neighbourhood disadvantage.
[d] Model 4: model 3 plus adjustment for population density.
[e] Model 5: model 4 plus adjustment for commute distance.

Statistically significant positive associations between area commute distance and individual waist circumference were observed for all capital cities except Darwin: longer average area commute distance was associated with larger waist circumference. In Melbourne and Perth, the association between commute distance and waist circumference remained statistically significant after adjustment for all covariates; in Sydney and Hobart, the associations attenuated to the null after adjustment for population density; and in Brisbane, Adelaide, and Canberra, associations between commute distance and waist circumference were nullified after adjustment for individual-level socioeconomic factors.

Associations between proximity of one's residential neighbourhood to the CBD and BMI are presented in Table 4. Significant positive associations were observed for tertiles in Sydney, Melbourne, Perth, and Darwin: living farther from the CBD was associated with greater BMI. For Perth, Sydney and Melbourne, these associations were attenuated on inclusion of other measures: in Perth, the association was no longer statistically significant after adjustment for individual-level socioeconomic factors; in Sydney and Melbourne, the association was nullified after adjustment for commute distance. However, in Darwin the association between proximity to the CBD and BMI observed for middle-distance neighbourhoods was largely unaffected by adjustment for individual sociodemographic factors, neighbourhood-level SEP, population density, and commute distance. There were no statistically significant associations between residential proximity to the CBD and BMI in Brisbane, Adelaide, Hobart, and Canberra.

Table 5 presents associations between proximity of one's residential neighbourhood to the CBD and waist circumference. Significant positive associations were found in Sydney, Melbourne, Adelaide, Perth, Hobart, and Darwin. In Adelaide (farthest tertile) and Darwin (middle tertile) these associations remained statistically significant after adjustment for each of the covariates, including commute distance. In Sydney, the association between proximity to the CBD and waist circumference was attenuated to the null after adjustment for population density; in Melbourne, the association was nullified after adjustment for neighbourhood disadvantage, and in Perth and Hobart similarly nullified upon adjustment for individual-level SEP. In Brisbane and Canberra, there were no statistically significant associations between residential proximity to the CBD and waist circumference.

## 4. Discussion

This study responds to calls from international health authorities including the World Health Organization (WHO) (World Health Organization, 2008) and the Organization for Economic Cooperation and Development (OECD) (International Transport Forum, 2011), and from leading public health advocates and researchers (Giles-Corti et al., 2016), who stress the importance of integrated multisector city planning to combat the growing prevalence of non-communicable disease.

Australia, like many other high-income countries, experienced rapidly rising rates of overweight and obesity during the last few

**Table 5**
Residential proximity to each city's Central Business District and waist circumference (multilevel linear regression coefficients and 95% confidence intervals).

| | | Model 1[a] | | Model 2[b] | | Model 3[c] | | Model 4[d] | | Model 5[e] | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Location | β | 95% CI | β | 95% CI | β | 95% CI | β | 95% CI | β | 95% CI |
| **Sydney** | (Inner) | – | | – | | – | | – | | – | |
| | (Middle) | **1.88** | **< 0.01, 3.76** | **2.17** | **0.28, 4.06** | 1.71 | −0.17, 3.60 | 1.22 | −0.99, 3.44 | 0.80 | −1.60, 3.21 |
| | (Outer) | **2.68** | **0.77, 4.59** | **2.75** | **0.85, 4.65** | **2.19** | **0.25, 4.13** | 1.51 | −0.98, 4.01 | 0.41 | −3.38, 4.22 |
| **Melbourne** | (Inner) | – | | – | | – | | – | | – | |
| | (Middle) | 0.27 | −1.66, 2.21 | −0.11 | −2.05, 1.83 | −0.60 | −2.58, 1.37 | −0.46 | −2.81, 1.89 | −2.29 | −4.77, 0.18 |
| | (Outer) | **3.08** | **1.03, 5.13** | **2.39** | **0.28, 4.50** | 2.02 | −0.10, 4.14 | 2.19 | −0.46, 4.86 | −1.63 | −5.08, 1.80 |
| **Brisbane** | (Inner) | – | | – | | – | | – | – | – | |
| | (Middle) | 1.40 | −0.80, 3.60 | 0.85 | −1.33, 3.03 | 0.01 | −2.28, 2.29 | −0.43 | −2.85, 1.99 | −0.54 | −3.43, 2.34 |
| | (Outer) | 2.34 | >-0.01, 4.70 | 1.05 | −1.27, 3.38 | −0.58 | −2.93, 1.76 | −1.15 | −3.85, 1.54 | −1.37 | −5.66, 2.90 |
| **Adelaide** | (Inner) | – | | – | | – | | – | – | – | |
| | (Middle) | 1.00 | −1.64, 3.66 | 0.46 | −2.12, 3.05 | 0.49 | −0.92, 0.92 | 0.99 | −1.62, 3.60 | 2.37 | −0.71, 5.46 |
| | (Outer) | **4.60** | **2.10, 7.11** | **3.54** | **0.80, 6.27** | **3.40** | **0.66, 6.15** | **4.23** | **1.37, 7.09** | **7.67** | **2.65, 12.69** |
| **Perth** | (Inner) | – | | – | | – | | – | – | – | |
| | (Middle) | 1.96 | −0.42, 4.36 | 1.65 | −0.76, 4.08 | 1.42 | −1.01, 3.86 | 1.17 | −1.25, 3.60 | 0.59 | −1.79, 2.99 |
| | (Outer) | **2.80** | **0.41, 5.20** | 2.39 | −0.08, 4.87 | 2.08 | −0.36, 4.52 | 1.50 | −0.97, 3.98 | −0.43 | −3.45, 2.58 |
| **Hobart** | (Inner) | – | | – | | – | | – | – | | |
| | (Middle) | 2.32 | −1.01, 5.66 | 1.82 | −1.84, 5.50 | 1.23 | −2.38, 4.84 | 0.20 | −3.93, 4.33 | −2.73 | −7.17, 1.69 |
| | (Outer) | **2.66** | **−0.69, 6.02** | 2.03 | −1.82, 5.89 | 1.49 | −2.41, 5.39 | 0.10 | −4.22, 4.43 | −6.91 | −12.76, 1.05 |
| **Darwin** | (Inner) | – | | – | | – | | – | – | – | |
| | (Middle) | **4.31** | **0.56, 8.06** | **4.57** | **0.92, 8.23** | **4.25** | **0.58, 7.91** | **4.26** | **0.59, 7.93** | **4.10** | **0.45, 7.75** |
| | (Outer) | 2.31 | −0.86, 5.49 | 2.01 | −1.22, 5.25 | 1.66 | −1.52, 4.85 | 1.71 | −0.15, 4.93 | 0.71 | −3.94, 5.36 |
| **Canberra** | (Inner) | – | | – | | – | | – | – | – | |
| | (Middle) | 1.43 | −1.23, 4.10 | 0.90 | −1.76, 3.57 | 0.84 | −1.79, 3.48 | 0.89 | −1.77, 3.57 | −0.31 | −4.23, 3.60 |
| | (Outer) | 2.14 | −0.53, 4.82 | 1.46 | −1.26, 4.18 | 1.45 | −1.26, 4.18 | 1.44 | −1.27, 4.16 | −0.92 | −6.72, 4.86 |

[a] Model 1: adjusted for age, sex, country of birth.
[b] Model 2: model 1 plus adjustment for education, occupation, and household income.
[c] Model 3: model 2 plus adjustment for neighbourhood disadvantage.
[d] Model 4: model 3 plus adjustment for population density.
[e] Model 5: model 4 plus adjustment for commute distance.

decades (Australian National Preventive Health Agency, 2014; Ng et al., 2014). This has contributed to chronic conditions such as CVD, diabetes, and some cancers becoming increasingly common, and it has placed a large and growing burden on both the health sector and economy (Australian Institute of Health and Welfare, 2017). The findings of this study suggest that the way our cities are structured may have contributed to these public health and economic problems. Mean commute times have also increased for each mainland Australian capital city during the last two decades (Wilkins et al., 2019). Residents of middle and outer areas of Australia's capital cities commuted further to work and had greater BMI and waist circumference than residents of areas located closer to the CBD. Moreover, consistent with previous research (McCormack and Virk, 2014), longer commutes were positively associated with body size, and for some cities (e.g. Sydney and Melbourne) commute distance to work contributed to associations between residential proximity to the CBD, greater BMI, and larger waist circumference.

Statistically significant associations between residential location, commute distance, and body size were not observed for all cities; where significant associations were found, they differed in magnitude across cities; and there were notable between-city differences in the extent to which adjustment for covariates attenuated associations between residential proximity to the CBD and body size. This suggests spatial variation in these covariates (i.e., individual sociodemographic characteristics, neighbourhood disadvantage, and/or population density) accounts for some of the spatial variation in body size. Taken together, these results show that the relationship between residential location, commute distance, and body size in any given Australian capital city is not necessarily generalisable to other capital cities. Moreover, these results support our decision to stratify the analysis to take account of likely city differences on measured and unmeasured factors that might influence commute distance and hence body size, such as the extent of greenfield development, built and social environments, population density, public transport networks, and spatially patterned socioeconomic inequity (Australian Institute of Health and Welfare, 2020; Giles-Corti et al., 2016; Sallis et al., 2020).

Most of Australia's capital-city workforce commutes to work by private motor vehicle (PMV). In 2016, this ranged from 66.8% in Sydney to 85.4% in Hobart, and in the outer areas of some Australian capital cities commuting by PMV was often upwards of 90% or more (Australian Bureau of Statistics, 2016b). Commute mode data were not collected as part of the 2017-18 NHS; however, it is likely that similar proportions of NHS participants residing in each capital city used a PMV for commuting purposes. Hence, the measure of commute distance used in the NHS can be broadly viewed as a proxy for time spent travelling to work in a PMV. There are several possible reasons for the observed associations between residential location, commute distance (and likely PMV use), and body size, and specifically, for the finding that residents living in the outer areas of Australia's capital cities had higher levels of adiposity. First, outer areas of cities often have land use patterns, transport systems, and a built environment that necessitates long commutes, travel by PMV and automobile dependence (Rachele et al., 2018), and mitigates against using more active forms of transport. These include distant separation between home and work, limited public transport, low residential density, and a less connected street network, among others (James et al., 2013). Second, cross-sectional (Christian, 2012b; Hoehner et al., 2012) and longitudinal (Halonen et al., 2020) studies show that longer commutes and more time spent travelling in a PMV are associated with lower levels of physical activity, a key risk factor for poor cardiometabolic health including greater BMI and waist circumference (Warburton and Bredin, 2017). Third, residents of outer areas of capital cities who are required to spend significant amounts of time sitting and sedentary whilst commuting to work are at greater risk of overweight and obesity (Sugiyama et al., 2016) and associated chronic disease (Hoehner et al., 2012), even among the physically active (Sugiyama et al., 2013). Fourth, commuting to work has been associated with higher levels of exposure to takeaway food outlets and the consumption of takeaway food (Burgoine et al., 2014) and both are linked with greater BMI and waist circumference (Burgoine et al., 2018; Pieroni and Salmasi, 2014). Further, poorer anthropometric outcomes associated with long commutes are only one a growing list of negative consequences of living in suburbs that are distant from employment. At the individual level, greater commuting time is also linked with poorer mental health and subjective stress (Milner et al., 2017), increased divorce risk (Presser, 2000), shorter sleep duration and lesser sleep quality (Christian, 2012b; Petrov et al., 2018), less time spent with family and friends (Christian, 2012a; Putnam, 2000) and less time available for home-based meal preparation and cooking (White et al., 2019). At a societal level, more time spent commuting – especially in a PMV – has been associated with increased motor vehicle accidents, traffic congestion, and road trauma (e.g. pedestrian injuries and fatalities) (Yiannakoulias et al., 2014), and health care utilisation (Künn-Nelen, 2016), and greater absenteeism at work and lower employee productivity (Ma and Ye, 2019).

City structure arises from historical settlement patterns and subsequent multiple forms of migration and resettlement (Slavko et al., 2020) as well as formal (or lack of formal) planning and design. Reducing commute distances and time spent travelling in PMVs, and mitigating their negative health, social, environmental, and economic impacts will require a rethink of the way we plan and (re)design our cities (Giles-Corti et al., 2016). Urban and transport planning and urban design, housing policy, and all levels of government and the private sector, should ideally collaborate in integrated partnerships around multi-sector planning. These would shape, post hoc from established communities as well as for developing regions, environments characterised by diverse employment opportunities, affordable housing, and readily accessible services and facilities, distributed equitably across inner, middle and outer areas of our capital cities. At present, the built and social environments that make a city liveable, healthy, and environmentally sustainable are disproportionately the preserve of those who can afford to reside and work near the CBD (Badland and Pearce, 2019). Ideally, future distributed employment opportunities directed at reducing commute distances would be centralised (e.g., suburban nodes) rather than spatially dispersed, thus facilitating greater use of public transport (and where possible, walking and cycling) and lessening dependence on PMVs (Infrastructure Australia, 2018). To achieve this, the evidence suggests that cities will need to increase in density and become more compact, rather than expanding their geographic boundaries (Rachele et al., 2018; Sallis et al., 2016). The provision of flexible work options such as working from home may also assist in reducing commute-related health issues though such options are likely predominantly available to white-collar workers and may increase health inequities (Chatterjee et al., 2020). Alternately, there is the possibility that monocentric cities will transition into a polycentric structure (Crosato et al., 2021) with the potential for reductions in commute times for some workers. The associations between distance to work and obesity-related measures may be different in polycentric cities. Establishing these relationships represents an opportunity for future, important work in this area.

Several methodological issues (strengths and limitations) are relevant to interpreting and understanding the findings of our study. The 2017-18 NHS data were collected from all Australian states and territories, thus facilitating city-specific analysis and improving study generalisability relative to earlier Australian research on commuting and body size which was restricted to one capital city (Sugiyama et al., 2013). Another strength of this study are the outcome measures, BMI, and waist circumference, which were measured rather than self-reported. Most previous studies have relied on self-reported body size which is influenced by social desirability bias (Krul et al., 2011). Where NHS participants did not consent to being measured, body size data were imputed by the ABS based on self-reported body size and other information, and these derived estimates closely reflected age- and sex-matched body-size values produced by the objective measurement. The NHS achieved a relatively high response rate of 76.1%; however, based on previous research (Turrell et al., 2020; Turrell et al., 2003), it is likely that the 23.9% non-response disproportionately underrepresented people from socioeconomically disadvantaged areas and backgrounds, thus our findings may overestimate the true magnitude of the relationships examined. Given the cross-sectional design of the NHS, assumptions about causality should be made with caution: longitudinal research examining residential location, commute distance, and body size over time would provide stronger evidence for causal inference. The NHS did not collect data on different modes of commuting; however, because most commuters in Australian capital cities commute to work by PMV it seems reasonable to assume that the results of our study reflect car use. Commute distance was measured using an ecologic indicator derived from the Australian Bureau of Statistics, 2016b Census of Population and Housing which captured area-level averages of distance travelled that were matched to the usual area of residence for participants in the NHS. Not having an individual-level measure of commute distance or travel time (ideally objectively assessed) meant that our study was subject to the usual limitations of an ecologic analysis (Freedman, 1999; Loney and Nagelkerke, 2014).

## 5. Conclusion

Living in middle and outer areas of Australia's capital cities is associated with longer commute distance, and those who travel further to work are more likely to have greater BMI and waist circumference. These health-related consequences of greater commute distance form part of a growing list of negative social, economic, and environmental impacts associated with time spent travelling to work. Integrated multisector planning is increasingly seen as relevant to tackling these problems, and therefore constitutes a potential solution to Australia's overweight and obesity epidemic and associated rising rates of chronic disease.

## Data statement/availability of data and materials

The data that support the findings of this study are available from the Australian Bureau of Statistics. Restrictions may apply to the availability of these data, which may require applicants to undertake ABS directed training to ensure the maintenance of confidentiality. Application may be made via: www.abs.gov.au/websitedbs/D3310114.nsf/home/How+to+Apply+for+Microdata.

## Authors contributions

**Suzanne Carroll:** Conceptualisation, Methodology, Writing-Original Draft, Writing-Review and Editing. **Gavin Turrell:** Conceptualisation, Methodology, Data Curation, Formal analysis, Writing-Original Draft, Writing-Review and Editing. **Michael Dale:** Conceptualisation, Methodology, Visualisation, Writing-Review and Editing. **Mark Daniel:** Conceptualisation, Methodology, Writing-Review and Editing.

## Declaration of competing interest

The Authors declare no Conflicts of Interest.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jth.2021.101122.

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