Title:

Concurrent assessment of urban environment and cardiometabolic risk over ten years in a middle-aged population-based cohort

Short title/Running head:

10-year evaluation of predictive impacts (40 characters, with spaces)

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None

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Abstract

Inference regarding the impact of urban areas on health is limited by cross-sectional studies concurrently assessing few dimensions and not accounting for area-level socio-economic status. This study simultaneously assessed several dimensions of the built environment against incident cardiometabolic risk (CMR) arising over 10 years. It tested the hypothesis that, accounting for local area relative wealth, features of the built environment would *not* predict incident CMR. Initially disease-free adults in a biomedical cohort in Adelaide, Australia provided address and clinical data over three waves of follow-up. CMR was defined as the count of five clinical CMR factors. Built environment measures were derived for the urban form (walkability), natural (public open space (POS) and normalised difference vegetation index), and food (healthful and unhealthful) environments. Local area wealth was expressed using the Relative Locational Factor (RLF) index. Poisson growth models accounting for within-suburb clustering, age, sex, and education were used to estimate associations between built environment measures and increasing CMR. Fitted linear trajectories had statistically significant mean values of intercepts and slopes. CMR trajectories were associated with age, male sex and low education. In models including measures of the food, natural, and urban form environments, per standard deviation increase, only POS count predicted incident CMR (RR=0.965, 95% CI: 0.933–0.998, $p=0.038$) which was more strongly predicted by RLF (RR=0.931, 95% CI: 0.906–0.955, $p<0.0001$). Not accounting for local-area socioeconomic status may overestimate the strength of relationships between health and the built environment. Inequity in accessible POS is robustly related to incident CMR.

Keywords

built environment; walkability; public open space; food environment; area-level wealth; cardiometabolic risk

Introduction

Cardiometabolic diseases (CMD) are a leading cause of morbidity and premature mortality worldwide, and among the most important global public health challenges of the century. It is estimated that CMD, specifically, type 2 diabetes mellitus (T2DM) and cardiovascular disease (CVD), currently accounts for 33.9 per cent (19.4 million) of all global deaths annually and that this figure will increase to 35.2 per cent (24.7 million) by 2030 (WHO, 2015). Public health strategies to prevent CMD have largely targeted individual-level, behavioural risk factors (WHO, 2011). Such strategies, when implemented without attention to the ecological context of disease, have had limited success in the primary prevention of CMD (Greaves *et al.*, 2011). Contextual initiatives to enable healthful lifestyles include strategic attention to land use, zoning, urban planning, public transportation, open areas, green space, and healthful food availability. Environmental interventions are increasingly viewed as essential to prevent CMD at the population level (Mozaffarian, 2016; Sallis *et al.*, 2012).

A growing body of evidence indicates that adverse features of urban environments affect health via behavioural, psychosocial, and stress-related pathways. Such features act as risk conditions, promoting the development of individual risk factors and worsening underlying disease vulnerabilities for exposed individuals (Daniel *et al.*, 2008). Review articles report consistent inverse associations between area socio-economic status (SES) and CMD and cardiometabolic risk (CMR) after accounting for individual-level factors (Chaix, 2009; Leal & Chaix, 2011). Such environmental features can be objectively measured, for example, can be constructed using a geographic information system and available spatial data, or assessed as individually self-reported environmental perceptions. Correspondence between objective and perceived environmental measures is low although both may influence health and behaviour (Gebel *et al.*, 2009; Boehmer *et al.*, 2006).

The built environment is the human-made or human-modified space in which people live out their lives (Renalds *et al.*, 2010). Studies evaluating the built environment in relation to CMD propose that it affects individual energy balances by providing opportunities around physical activity and healthful dietary behaviour (Feng *et al.*, 2010). Dietary behaviour is thought to be shaped by the availability of healthful versus unhealthful food sources (for example, green grocers or produce markets versus convenience stores or fast-food outlets) (Caspi *et al.*, 2012; Black *et al.*, 2014), and physical activity is shaped by the accessibility of public open space (POS)—parks and green space, and urban form—density, street connectivity, land use, sprawl, and infrastructure for walking/cycling (Durand *et al.*, 2011; Kaczynski & Henderson, 2008; Malambo *et al.*, 2016; Sallis *et al.*, 2012).

Studies in support of relationships between context and CMD and/or CMR have linked fast-food outlet access and availability to unhealthful diet, obesity, and diabetes (Bodicoat *et al.*, 2015; Moore *et al.*, 2009; Reitzel *et al.*, 2014). Others indicate access to and availability of fruit and vegetables—grocers or supermarkets—are associated with healthful diet and lower odds, prevalence, and incidence of obesity (Auchincloss *et al.*, 2013; Bodor *et al.*, 2008; Bodor *et al.*, 2010; Morland *et al.*, 2006; Rose & Richards, 2004). The ratio of unhealthful food stores to healthful or total food stores is related to T2DM incidence and prevalence (California Centre for Public Health Advocacy, 2008; Mezuk *et al.*, 2016). Other studies have observed no link between food stores or fast-food outlets, and diet, obesity, or CVD risk factors (Black *et al.*, 2014; Rahmanian *et al.*, 2014).

Physical activity has been linked to the proximity, availability, size, and quality of POS, and to elements of walkable urban form such as residential and intersection densities (Kaczynski *et al.*, 2011; Malambo *et al.*, 2016; Sallis *et al.*, 2016) while lack of available neighbourhood parks and green space predicts obesity (Rundle *et al.*, 2009), CVD (Tamosiunas *et al.*, 2014) and T2DM (Bodicoat *et al.*, 2014). Other studies have reported no associations between accessibility to POS and physical activity (Foster *et al.*, 2009; Hillsdon *et al.*, 2006) and CMR (Potestio *et al.*, 2009; Richardson *et al.*, 2010) or between walkability and T2DM incidence (Sundquist *et al.*, 2015). Several reviews report uneven findings in research examining the relationships between the built environment and CMD/CMR (Feng *et al.*, 2010; Leal & Chaix, 2011).

The extent of contradictory research on the built environment and CMD/CMR is notable vis-à-vis the consistency of studies that link neighbourhood SES to CMD/CMR. It is paradoxical, then, that the rising prevalence of CMD is increasingly attributed to the built environment. Studies on the built environment and CMD/CMR can be criticised for several limitations, particularly a primary reliance on cross-sectional designs (Feng *et al.*, 2010; Leal & Chaix, 2011; Malambo *et al.*, 2016) and short follow-ups of just one to three years for a small number with longitudinal designs (Leal & Chaix, 2011). Features of the built environment that may shape CMR and CMD are likely to have induction periods beyond one to three years, hence short follow-up may be insufficient (Ben Shlomo, 2014). Such studies could also wrongly implicate factors that, at a later point in the induction period, are associated only with having CMR or CMD, rather than predicting a causal pathway (Ben Shlomo *et al.*, 2014; Daniel *et al.*, 2008).

Other limitations extend to how built environment and CMD/CMR relationships have been analysed. Most studies do not simultaneously evaluate different dimensions of the built environment within the same model. Estimating single dimensions of the built environment is akin to estimating individual risk factors one at a time. Seeming links between the built environment and CMD/CMR could be specious if a given “effect” were weaker or eclipsed when other relevant features are accounted for (Black & Macinko, 2008). Similarly, some studies also limit analyses to a single form of a dimension, where different but related expressions could provide a more informative representation (for example, analysing the food environment in terms of healthful food outlets *as well as* fast-food outlets).

Another criticism involves not accounting for local-area SES as a confounder of built environment–CMD relationships (Leal & Chaix, 2011). Neighbourhood SES is reliably related to CMD/CMR; it also correlates with the built environment (Daniel *et al.*, 2009). Thus, any apparent “effects” of the built environment can be confounded if neighbourhood SES is not controlled by design or analysis (Chaix *et al.*, 2010). In research regarding place influences on health, neighbourhood SES has typically been expressed as aggregated socio-demographic information (income, education, or employment) from census surveys and defined within census (or like) units. This finding corresponds to estimating individual-averaged risks for areas in multilevel analysis that model local area SES expressed for

administrative areas. Parameter estimates for built environment measures are, on the other hand, largely expressed at the individual level, not at the area level. This inconsistency in the form of risk estimates can be overcome, however, if neighbourhood SES is expressed for the actual location of the individual whose health is being modelled, not using the average SES for the area in which he or she resides.

This study sought to evaluate the relationships between the built environment and CMR to address the limitations of previous research. The hypothesis tested was that, in a population-based cohort tracked across 10 years, accounting for local area SES at the location of each participant, the urban form, food, and natural environments would not predict incident CMR.

Methods

Study Sample

Part of the Place and Metabolic Syndrome (PAMS) Project, this study aimed to evaluate environmental factors and cardiometabolic health in Adelaide, South Australia. PAMS used the North West Adelaide Health Study (NWAHS), a population-based cohort providing behavioural and clinical data on chronic conditions and risks for northwest Adelaide. This region accounts for 38 per cent of the city's metropolitan area and 28 per cent of the South Australian population (ABS, 2001b). Three waves of data were collected between 2000 and 2010. Details of data collection protocols are described elsewhere (Grant *et al.*, 2009). This study used data from all three waves across 10 years.

At Wave 1 (2000–03), adults (≥ 18 years) from the north-west of Adelaide were randomly selected from the Electronic White Pages directory and recruited by telephone interview. Socio-demographic, behavioural, and psychosocial information was obtained using questionnaire or Computer Assisted Telephone Interview. Anthropometric, blood pressure, and fasting blood samples were obtained at clinic visits. Current prescription medication use was obtained by linking participant Medicare numbers to the Australian Pharmaceutical Benefits Scheme. At Wave 1 (baseline), 4056 individuals (49.4 per cent of the eligible

sample) completed all modes of data collection. Cohort retention rates at Wave 2 (2005–06; $n=3564$) and Wave 3 (2008–10; $n=2597$) were 79 per cent and 64 per cent, relative to baseline participation.

The NWAHS study region was limited to urban areas representing Census Collection Districts (CD) classified by the Australian Bureau of Statistics (ABS) as having a population density of at least 200 persons per square kilometre (ABS, 2001c). The CD is the smallest spatial unit used to report Census data, accounting for 225 dwellings in the 2001 Australian Census (ABS, 2001a). A geographic information system was used to geocode residential addresses for cohort participants, and the Spatial Analyst extension of ArcGIS (Version 9.3.1; ESRI, 2010) used to calculate baseline environmental measures—urban form, natural, and food environments, and local-area SES—for 1,600 metre road-network distance buffers from each participants' residence, corresponding to 15 to 18 minute walk (Morris & Hardman, 1997).

Written consent was provided by participants at each wave of data collection. Ethics approval was granted by the University of South Australia, Queen Elizabeth Hospital, Central Northern Adelaide Health Service, and South Australian Department for Health and Ageing.

Measures

Outcome Measure. A CMR score was calculated as the count of five CMR factors, including:

- (i) abdominal adiposity (that is, waist circumference ≥ 94 cm for Europic men, and ≥ 90 cm for men of other ethnic groups, and ≥ 80 cm for all women);
- (ii) hypertriglyceridemia (that is, high levels of blood triglycerides [fatty molecules] ≥ 1.7 mmol/L [millimoles per litre], or prescription treatment);
- (iii) low high-density lipoprotein (HDL) cholesterol (≤ 1.03 mmol/L for men, ≤ 1.29 mmol/L for women, or prescription treatment);
- (iv) hypertension ($\geq 130/85$ mmHg [millimetre of mercury], or prescription treatment); and
- (v) high fasting plasma glucose (FPG) (≥ 5.6 mmol/L) or previously diagnosed T2DM.

Each CMR factor was scored “1” if it met or exceeded the cut-off value; otherwise, “0.”

Scores were summed for a scale of 0–5. These five risk factors tend to cluster and are used to

define the metabolic syndrome (ATPIII, 2002; IDF, 2006). Their summative score has previously been used to express CMR (see Paquet *et al.*, 2010).

Contextual measures. Contextual measures were defined at baseline and pertained to the urban form, natural, and food environments within 1,600m road-network distance for each participant.

Urban form environment. “Walkability” was operationalised as a measure of urban form (Saelens *et al.*, 2003) using a composite index with four components: intersection density (connectivity), dwelling density, land use mix, and net retail area (proximity). Data were derived from the 2001 South Australian Digital Cadastral Database, Land Ownership and Tenure System database, 2001 Dwelling Count, 2001 Generalised Land Use and 1999 Retail Database from the Land Services Group, Department of Planning, Transport & Infrastructure, Government of South Australia, and 2001 Adelaide StreetPro© road data provided by Pitney Bowes Business Insight. The formulation of each component is described elsewhere (Leslie *et al.*, 2007). To calculate the index, deciles were derived for each of the four components, one representing the lowest value for the component’s frequency distribution and 10 the highest. Decile values were summed to form a total walkability score (ranging from four to 40) for each buffer. A low score indicates low walkability and a high score indicates high walkability. This index has been validated for the Adelaide Metropolitan Area (Leslie *et al.*, 2007) and is similar to that used in other studies (Carlson *et al.*, 2015; Sundquist *et al.*, 2015). Our walkability score did not, however, include other environmental aspects such as footpath condition and route aesthetics that may relate to walking behaviour (Sugiyama *et al.*, 2012).

Natural environment. The natural environment was operationalised as public open space (POS) area and count, and Normalised Difference Vegetation Index (NDVI) (“greenness”). POS data were derived from the South Australian 2001 Digital Cadastral Database and Land Ownership and Tenure System database, provided by the Land Services Group, Department of Planning, Transport & Infrastructure, Government of South Australia. POS was defined as publicly-accessible (enclosed or unenclosed) land of 150 square metres or more: parks, gardens, wetlands, conservation reserves, undeveloped land, sporting grounds, and recreation facilities (Parks & Leisure Australia, 2013). POS was classified *active* if it had at least one sporting ground or facility (sports field, outdoor arena, or tennis court); otherwise, *passive*.

Most POS has unrestricted access, but some such as community gardens or golf courses can have semi-restricted access, requiring membership or entrance fees. Such spaces were included within the definition of POS.

POS count was measured as the number of active POS either partially or completely contained within each buffer. Active rather than all POS was used as passive POS includes disused land not suited to physical or recreational activity. Hence active POS was deemed more sensitive. POS area was measured as the square metre area of all (that is, both active and passive) POS either partially or completely contained within each buffer. Greenness was measured as the NDVI (estimate of the photo-synthetic activity of plant life using Landsat satellite imaging) (Defries & Townshend, 1994). Greenness was expressed as the median NDVI of all POS within any buffer. The image used for this analysis was captured February of 2001 (summer). The satellite image resolution was set at 25 metres and each grid cell was assigned a single NDVI value. For further details on the formation of POS NDVI values are given elsewhere (Paquet *et al.*, 2008). This study considers POS in terms of count, area, and greenness; it does not include other specific features pertaining to POS quality—beyond greenness—that may influence behaviour and health outcomes (Sugiyama *et al.*, 2015).

Food environment. The food environment was operationalised as fast-food restaurant density and count, and Retail Food Environment Index (RFEI). Food outlet locations were obtained via the 1999 South Australian Retail Database (Planning SA, South Australian Government); coded *healthful* (greengrocers, butchers, health food stores, supermarkets, and healthful take-away) or *unhealthful* (bakeries, sweet food retailers, convenience stores, chain and non-chain fast-food restaurants, and service station “foodmarts”).

Fast-food restaurant count was measured as the total number of chain and non-chain fast-food restaurants within each buffer. Fast-food density was measured by applying density estimations to fast-food outlets across the study region. Density was expressed as the count of outlets divided by the sum of land parcel square kilometre area (that is, each land parcel with a frontage) within each buffer. The “unhealthfulness” of the food environment was given by the RFEI (California Centre for Public Health Advocacy, 2008) as the ratio of unhealthful to healthful food outlets within each buffer.

Local area SES. Local area SES was operationalised as the locational value of each participant's residential area calculated as the Relative Location Factor (RLF) (Lockwood *et al.*, 2018). The RLF is a locational value index providing a socio-spatial expression of wealth and *individual-level* alternative to conventional averaged aggregated neighbourhood SES measures. The RLF is derived from a hedonic global ordinary least squares regression model predicting residential property sale price. The model uses dwelling structural characteristics (land area, dwelling age, size, style, condition, roof, and wall construction), omitting the non-structural attributes (location) contained in the error term. Therefore, RLF reflects “where you live” rather than “what you live in”. Property characteristics were obtained from the transaction data of all valid sales of single detached residential properties occurring within the study region for the period from May to October, 2001 provided by the South Australian Valuer General. Transactions for this period were used as the residential property market price did not undergo any major fluctuations. This process yielded a sales data set of 4,917 properties. The RLF is calculated as the ratio of actual sale price to the predicted sale price. This value is used to interpolate a continuous ordinary kriging surface across the study region. The interpolated surface was 35 metres resolution to estimate each residential property value. From the interpolated surface values were extracted for each dwelling point location for each participant. RFL values less than one indicate where location defines lesser property value; values greater than one indicate where location defines greater property value.

Covariates. Individual-level covariates included participant age, sex, and education at baseline. Age was continuously measured, sex was dichotomous (male or female), and education was categorical for three levels of educational attainment; low ($\leq 9^{\text{th}}$ grade), middle ($9^{\text{th}}-12^{\text{th}}$ grade and/or technical training) and high ($\geq$ baccalaureate degree).

Data analysis

Descriptive statistics were computed for baseline values of socio-demographic and environmental measures. Poisson growth models accounting for participant age, sex, and

education were fitted to estimate the associations between baseline measures of context, RLF, and change in CMR across the 10-year follow up. Inferential analyses were conducted using the SAS procedure GLIMMIX with a random intercept.

The Poisson growth models included three levels to account for participant repeat measures and spatial clustering within suburbs. The sample was restricted to State Suburbs where at least five NWAHS participants resided ($n=138$). The State Suburb is a spatial unit calculated by the ABS, used to approximate suburban areas by the aggregation of CDs (ABS, 2001c). The magnitude of spatial clustering was not quantified given the use of Poisson models, where the random effects are at a different scale than that of the observations. As the variance is a function of the mean, the ICC would be computed for a range of values of the predictors, and its interpretation would be conditional upon the explanatory variables entering in each model (Goldstein *et al.*, 2002). Previous studies within this cohort and region using a normally distributed continuous outcome (HbA_{1c}) reported ICCs for spatial clustering of 0.01 (see Carroll *et al.*, 2016). Analysis was performed for participants who were disease free at baseline and having at least some data at each wave of data collection ($n=2530$).

Some 2,530 participants provided at least some data at each wave of data collection, but not all had full sets of observations for all measures at each wave. Incomplete records were accounted for using the full information maximum likelihood approach. This method deals directly with missing data and yields asymptotically efficient estimates under the assumed model, with standard errors of estimates that account for the incomplete nature of the data (Armitage & Berry, 1994). The approach assumes that parameters vary from individual to individual, with heterogeneity caused by unmeasured factors and those related to “missingness” (individual age, sex, and education) modelled as covariates to support the assumption of observations missing at random. This procedure conserves power and provides a better estimate of the response profile for an individual, borrowing strength from information provided by other individuals with similar characteristics (Greenland & Finkle, 1995).

Results

Socio-demographic characteristics of the study sample are presented in Table 1. At baseline, participant mean age was 50.5 years. Slightly more than 50 per cent were women. Fewer than 15 per cent held a bachelor's degree or greater and 46 per cent had an education of less than grade 9.

Characteristics of participants' urban form, natural, and food environments, and locational value index are presented in Table 2. The median walkability score was 22. The median POS count was three, median POS area was 115,299 m², and median greenness was 17. The median fast-food count was six; the median RFEI was two. The mean RLF was one.

Poisson growth models with time as the sole covariate indicated that fitted linear trajectories had statistically significant mean values of intercepts and slopes ($p < 0.0001$, $p = 0.01$, respectively). Inter-individual variations in the growth curve parameters were significant only for the intercepts. As shown in Table 3, Model I, this change remained significant after accounting for age, sex, and education (relative risk (RR)=1.036, 95% CI: 1.011-1.061, $p = 0.005$, per 5 years).

A consistent effect of RLF was observed across Models II-IV (Table 3). This effect remained strong after adjusting for individual-level covariates as well as measures of the urban form, natural and food environments (RR=0.931, 95% CI: 0.906-0.955, $p < 0.0001$) (Model IV). Of the food, natural, and urban form environments, POS count alone predicted change in CMR (RR=0.965, 95% CI: 0.933-0.998, $p = 0.038$) (Model IV).

Discussion

This study assessed the relationships between the built environment and evolution of CMR in a population-based biomedical cohort followed up over 10 years. It addressed many limitations of prior studies. It was longitudinal, with a follow up far exceeding the one to three year periods used in the few other longitudinal studies of the built environment and health. Other strengths include a concurrent assessment of several dimensions of the built environment and an outcome based on five clinical variables. The strength of the outcome is noteworthy as most studies on CMR use only overweight and/or obesity as an outcome. Less

is known about the influence of the built environment on clinical risks. Importantly, this study unlike many others examining the built environment, also accounted for local area SES (RLF) in estimating the influence of the built environment on incident CMR.

The hypothesis that measures of the urban form and natural and food environments would *not* predict incident CMR, was partly rejected. POS count was inversely related to incident CMR in models accounting for local area SES. Other measures of the natural environment, POS area and greenness, were not related to incident CMR. What it is about POS count that underlies its link with CMR requires research. As POS count was based on active POS, the relationship could be mediated by physical activity involving locally accessible POS. This is a key avenue for investigation (Leal & Chaix, 2011; Mackenbach *et al.*, 2014). Other researchers assessing the relationships between green space and health have highlighted the quality of green space, experiences afforded by different green space, and individual orientations that may influence use of green space (Bell *et al.*, 2014). Such information is needed to provide evidence for planning to support physical activity and reduce population risk of chronic disease (Lachowycz & Jones, 2013). Despite strengths, this study did not provide the means to explore use and person-specific factors driving use patterns of locally accessible POS. On the other hand, that POS count predicts the evolution of CMR has implications for urban planning for equity in the provision of greater numbers of locally accessible POS (Lachowycz & Jones, 2013).

The built environment is important as it can underpin unhealthful diet and physical activity patterns representing the greatest percentages of preventable factors causing premature mortality (Woolf & Aron, 2013). Of features other than POS count, neither urban form (walkability) nor the food environment predicted incident CMR in this study. Insofar as CMR arises from health-related behaviour, our results would run counter to the notions that neighbourhood walkability supports greater *physical activity* and unhealthful food environment supports *unhealthful diet*, but the studies supporting such views are largely cross-sectional (Caspi *et al.*, 2012; Durand *et al.*, 2011; Malambo *et al.*, 2016). Of the few longitudinal studies reporting temporal relationships between environments and behaviour, such associations may not extend to reducing CMR. This finding could apply to reports of inverse relationships between obesity/overweight, and walkability and/or healthful food

environments. For example, the finding from a longitudinal study that positive land use mix, including density of recreational services, street network, and landscape slope, is inversely related to residents' body mass index (Sarkar *et al.*, 2013) might be valid, yet its impact insufficient to inhibit the development of CMR.

Insufficient strength of an effect of the food environment on CMR is also supported by a study indicating a lack of specificity in the magnitude of food environment associations with CVD mortality (Daniel *et al.*, 2010). This study observed a greater risk of CVD death associated with greater fast-food outlet density, but this risk did not differ from that associated with non-CVD death. Insofar as behavioural pathways influence cardiovascular mortality, the associations between fast-food outlet density and CVD mortality should be stronger than those for non-CVD mortality (Daniel *et al.*, 2010). This observation is not to suggest that promoting healthful food environments is not worthwhile, or that positive local food environments might not have other positive effects. It is likely that good access to healthful food resources supports healthful diets by enabling opportunities to purchase quality healthful foods for those individuals predisposed towards healthier diets (Green & Kreuter, 1999). Moreover, the influence of healthful urban form and food environments on health behaviour and outcomes may be very small but when accrued across the life course they may have substantial impact in reducing risk of CMR (Green & Kreuter, 1999). Hence, even the 10-year follow-up in this study may not adequately capture a benefit of positive urban form and healthful food environments. Life course studies of the built environment and CMR and CMD are needed before concluding that such positive features of places have no impact on chronic disease.

Another concern is the construct validity and content validity of the measures used to represent environmental constructs. Several reviews have criticised built environment–CMD research for heterogeneity in the definition and operationalisation of built environment measures (Gascon *et al.*, 2016; Leal & Chaix, 2011). There is a lack of systematic investigation into constructs that warrant assessment, how they should be operationalised, and what data sources to use. For example, studies have employed a variety of measures of the food environment including the count, ratio, density, availability, and accessibility of sources (Feng *et al.*, 2010; Daniel *et al.*, 2008). The impact of heterogeneous measurement is

worsened as food sources are often categorised and sub-categorised prior to measurement, not always reliably or accurately—for example in relation to supermarkets versus speciality markets (Paquet *et al.*, 2008). Data sources for objective measures range from commercial and public directories, residence surveys, and ground-level observation (Feng *et al.*, 2010; Paquet *et al.*, 2008). Lack of standardisation yields difficulty comparing results across studies, as does spatial scale for the size of buffers—for instance, 500m, 1,000m, or 1,600m, their nature of expression as road networks or Euclidian spaces, and zonation effects (Coffee *et al.*, 2013; Vernez Moudon *et al.*, 2011). The construct and content validity of built environment measures, and their sensitivity requires investigation before interpreting that the urban form and food environments do not have predictive validity in reducing risk of CMR.

Limited support in this study for a role of adverse built environment features relating to worsening CMR aligns with some (Auchincloss *et al.*, 2009; Christine *et al.*, 2015; Hirsch *et al.*, 2014; Li *et al.*, 2009b), but not all (Eid *et al.*, 2008; Hirsch *et al.*, 2014; Li *et al.*, 2009a) findings from other longitudinal studies examining the built environment and CMD/CMR. This study is the first to test several dimensions of the built environment, accounting for local area SES specific to the individuals observed. Results align with earlier multi-level studies that observed inverse relationships between neighbourhood SES, clinical risk factors (Leal & Chaix, 2011), morbidity (Lisabeth *et al.*, 2007; Menec *et al.*, 2010; Sundquist *et al.*, 2004), and mortality (Meijer *et al.*, 2012). Yet few studies have directly assessed both local area SES *and* built environment measures. This study shows that local area SES is more strongly related to CMD/CMR than is the built environment. However, in the current study, the built environment was expressed only at one time-point. This allows for assessment of a lag-effect of the built environment on health, yet it does not account for the effect of potential changes in the built environment occurring during the follow-up period.

A novel finding was that the RLF based on area-level wealth data but expressed at the individual level for the participant's location, was a robust predictor of CMR. Commonly, area SES is based on aggregated data expressed for administrative areas for which Census data are available (Feng *et al.*, 2010). In Australia, unit record level Census data are not available and spatial aggregation is used by the ABS to preserve privacy. The CD was designed to provide a complete coverage of Australia without omission or overlap (ABS,

2001c). While it is common to use the smallest unit for which population census data are available (CD), a reliance on aggregated area data is not necessary or invariably appropriate. The RLF is a sensitive measure with its expression at the finest spatial scale (point location in space) based on proximal properties (Lockwood *et al.*, 2018). Derivation from an interpolated surface enables representation of the environment yet supports consistent modelling of individual-level risk, rather than averaged area-level risk as when modelling census-based SES for administrative areas.

The RLF overcomes other problems related to aggregated spatial data obtained from census and other governmental statistics that are available only for pre-defined administrative areas which can yield results tainted with the Modifiable Areal Unit Problem (MAUP) (Vernez Moudon *et al.*, 2011). Based on local property sales data, the RLF has a further benefit as a composite measure of wealth potentially reducing measurement error, co-linearity, and over-adjustment in analysis, and conferring ease of explanation (Drewnowski *et al.*, 2017; Feng *et al.*, 2010). Property values have been found to be a stronger predictor of health over traditional measures of SES (Vernez Moudon *et al.*, 2011; Rehm *et al.*, 2012). Little place and health research thus far has examined individual-level property value as a metric of wealth and as a substitute for conventional SES-based measures of neighbourhood deprivation.

In summary, this study sought to assess the relationships between the built environment and CMR in a manner that addressed the limitations of previous research. The hypothesis that, accounting for area-level SES, the urban form, natural and food environments would not predict incident CMR was partially rejected. Only the count of active POS located within a 1,600m network buffer from participants' residences predicted CMR. This finding supports urban planning for equity in provision of accessible POS. Given the lack of support for other urban form (walkability) and food environment measures, a 10-year follow-up may be insufficient to capture a benefit of these influences of CMR. Life course studies of the built environment and chronic disease are required with research to assess the construct validity and content validity of built environment measures, and their sensitivity, before concluding that the urban form and food environments have no impact on CMR. Overall, this study supports earlier multilevel studies indicating that local area SES is inversely related to

individual-level CMR. There was, however, only limited support for the influence of the built environment on CMR development.

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None.

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Table 1. Socio-demographic characteristics of sample ^a

	Sample Size	Mean or %	Standard Deviation
Age (Years)	2530	50.5	14.6
Sex (Male) (%)	1158	45.8	-
Sex (Female) (%)	1372	54.2	-
Level of Education (Low) ^b (%)	1161	45.9	-
Level of Education (Middle) ^c (%)	1059	41.9	-
Level of Education (High) ^d (%)	310	12.2	-

Note. ^aVariables measured at individual level. ^bLow: <9th grade; ^cMedium: 9th-12th grade and/or technical training; ^dHigh: ≥Bachelor's degree.

Table 2. Contextual (urban form, natural and food environments) and compositional measures^a

	Sample	Mean	Standard			
	Size	or %	Deviation	Median	Minimum	Maximum
Walkability Score	2530	21.83	6.66	22.00	3.00	39.00
POS ^b Count (per buffer)	2519	3.67	2.56	3.00	0.00	14.00
POS ^b Area (Total area m ² per buffer)	2519	225575	296807	115299	0.00	1834169
Greenness (Median NDVI ^c per buffer)	2304	14.83	8.67	17.00	-9.50	33.00
Fast-food Count (per buffer)	2530	6.90	4.57	6.00	0.00	28.00
Fast-food Density (per buffer area)	2530	0.98	0.83	0.82	0.00	4.67
Retail Food Environment Index (RFEI) (per buffer)	2530	2.28	1.57	2.00	0.00	15.00
Locational Value Index (RLF) ^d	2483	1.03	0.25	0.95	0.49	1.99

^aVariables were measured within a 1600 metre network buffer. ^bPublic Open Space.

^cNormalised Difference Vegetation Index. ^dRelative Location Factor.

Table 3. Poisson regression parameter estimates for contextual and compositional measures predicting change over time in cardiometabolic risk score, accounting for individual-level locational value index ($n=2530$)^a

	Model I	Model II	Model III	Model IV
	AIC=22894.42	AIC=22417.48	AIC=20170.75	AIC= 20175.40
Years from Baseline Clinic Visit [5]	1.036 ^{**} (1.011-1.061)	1.037 ^{**} (1.012-1.063)	0.988 (0.961-1.015)	0.988 (0.961-1.015)
Age (Years) [1]	1.315 ^{****} (1.283-1.347)	1.326 ^{****} (1.294-1.359)	1.281 ^{****} (1.247-1.315)	1.281 ^{****} (1.247-1.315)
Sex ^b (Male)	2.005 ^{****} (1.930-2.083)	2.015 ^{****} (1.940-2.093)	1.895 ^{****} (1.818-1.974)	1.895 ^{****} (1.819-1.974)
Level of Education ^c (Low)	1.987 ^{****} (1.917-2.059)	1.970 ^{****} (1.900-2.042)	1.831 ^{****} (1.762-1.904)	1.831 ^{****} (1.762-1.904)
Level of Education ^c (Medium)	1.849 ^{****} (1.782-1.918)	1.848 ^{****} (1.781-1.918)	1.711 ^{****} (1.644-1.781)	1.710 ^{****} (1.643-1.780)
Locational Value Index (RLF) [1]		0.926 ^{****} (0.904-0.948)	0.929 ^{****} (0.905-0.954)	0.931 ^{****} (0.906-0.955)

Walkability Score [1]	0.977 (0.953-1.001)	0.979 (0.951-1.009)	0.976 (0.944-1.008)
POS Area (Total m ² area per buffer) [1]		1.004 (0.974-1.035)	1.008 (0.977-1.039)
POS Count (No. per buffer) [1]		0.966* (0.934-0.998)	0.965* (0.933-0.998)
Greenness (Median NDVI per buffer) [1]		0.987 (0.960-1.015)	0.988 (0.960-1.016)
Fast-food Density (Density per buffer) [1]			1.018 (0.982-1.056)
Fast-food Count (No. per buffer) [1]			0.993 (0.953-1.033)
Retail Food Environment Index ^d (RFEI per buffer) [1]			1.006 (0.981-1.032)

Note. ^aAge, Sex, Level of Education, and Locational Value Index (RLF; Relative Location Factor) were measured at the individual-level.

Walkability, Public Open Space (POS) Size, Public Open Space (POS) Count, Greenness (NDVI; Normalised Difference Vegetation

Index), Fast-food Density, Fast-food Count, and Retail Food Environment Index (RFEI) were measured with a 1600 metre network buffer.

^bSex-Male, Female (Reference Group). ^cEducation-Low: $\leq$ 9th grade, Middle: 9th-12th grade and/or technical training, High: $\geq$ Bachelor's degree (Reference group). ****: p -value <0.0001 . ***: p -value <0.001 . **: p -value <0.01 . *: p -value <0.05 . [No. of SD unit increase].

Figure 1. Study Region – North-Western Adelaide, South Australia

Source: Australian Bureau of Statistics Australian Standard Geographic Classification 2001

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