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Review Article

The Association between Urban Form and Ischemic Heart Disease: Evidence from Brisbane, Australia

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Abstract

We measured the association between urban form and hospitalisation rates for Ischemic Heart Disease (IHD), stratified by age and sex, and controlling for ethnicity, socio economic status, proximity to hospital and neighbourhood walk ability. This was a retrospective cohort study of the proportion of people within the Brisbane area of Australia who were hospitalised between 2006 to 2011 with a primary diagnosis of IHD. There were strong spatial patterns in the incidence of IHD. The importance of predictor variables differed by sex and age. Urban form was generally not a strong predictor. This study suggests no strong relationship was identified between urban form factors and ischemic heart disease using this research approach.

Keywords: Ischemic heart disease; Urban form and structure; Spatial analysis

Introduction

Ischemic Heart Disease (IHD) is characterised by reduced blood supply to the heart. It is one of the most common causes of mortality world-wide, resulting in 11.2% of deaths globally in 2011 [1]. In Australia, IHD accounts for 16% of all deaths [2], placing it 9th internationally in terms of contribution to national burden of disease. Major risk factors of this disease include family history of coronary artery disease, diabetes, high blood pressure or atherosclerosis, smoking, poor nutrition (especially dietary fat intake), previous heart attack or stroke, obesity, hypertension, elevated cholesterol and/or low level of High Density Lipoprotein (HDL) [3].

The built environment is highlighted as a factor determining health outcomes, as part of a broader social determinants model of health [4], yet very little is known about the effects of urban form on IHD. It has recently been proposed that urban form (the physical shape and structure of a city that influences daily activity) is an important behaviour a determinant [5]. Previous studies have related urban form to travel behaviour, walking and other forms of physical activity [6,7], air pollution [8] and obesity [9,10]. These effects may be of some significance for IHD. The aim of this paper is to test for an association between urban form and the incidence of IHD in Brisbane, Australia's third largest city. We also control for the effects of age, sex, ethnicity, socioeconomic status, proximity to hospital and neighbourhood walk ability.

Methodological approach, design and settings

This study was a retrospective cohort study of spatial variation in the incidence of hospitalizations due to IHD in southern metropolitan Brisbane, Australia (Figure 1) from 1 January 2006 to 31 December 2011.Brisbane is the third largest city in Australia, with a population of 2.07 million in 2011 [11]. The spatial units were Statistical Local Areas (SLAs), as defined by the Australian Bureau of Statistics [11]. Hereafter the term "study area" refers to the 118 SLAs used for analysis (Figure 2) was based on three phases: 1.

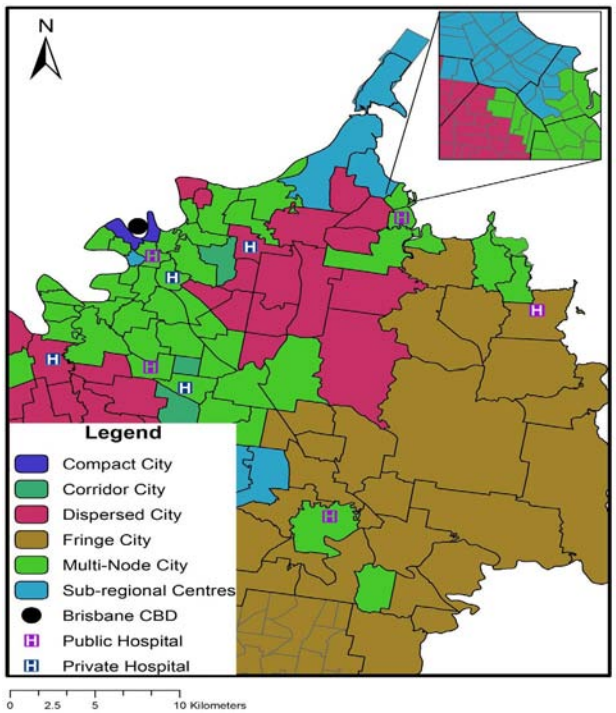

Figure 1: Area of the study with assigned urban form categories by Statistical Local Areas (SLAs).

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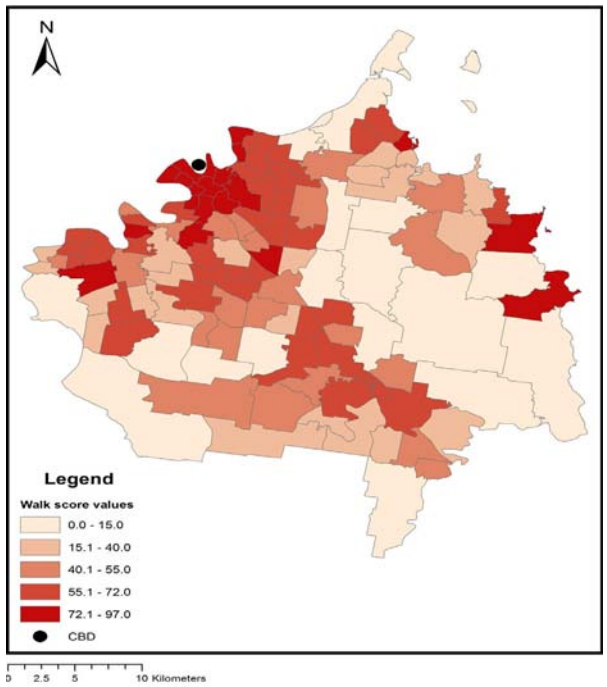

Figure 2: Walkability index map for the 118 SLAs in the area of study.

The analysis was stratified by age and sex. Our methodological approach) Adoption of methods suggested by [5, 12]. The data collection and the categories of the data aggregation were replicated by [5] within Brisbane; 2) Aggregation of the total IHD hospitalizations between 2006 and 2011 into Statistical Local Areas (SLAs) level; and 3) Bayesian modeling was undertaken in order to understand the relationships between the urban form categories and IHD hospital admission measures, which simultaneously allowed urban form to be evaluated as a risk predictor. This model also accounted for socioeconomic status, including proximity to public and private hospitals, ethnicity and walk ability index. The following sections provide detailed information about our methodological approach, design and settings.

Urban form classification

We assigned each Statistical Local Area one of six urban form categories (Table 1), following Grosvenor and O'Neill [5]. We initially assigned this classification at the finer spatial scale of Statistical Areas Level 1 (ABS 2011) and then determined the urban form category for each SLA.

Ethnicity

The following cultural groups (categories are based on place of birth) were accounted for in the model based on the Australian Bauru of Statistics (ABS's) main categories in 2006 [13] and 2011 [14] censuses, and the categories provided in our data set Americas, North Africa and the Middle East, North-east Asia, North-west Europe, Oceania (mostly people who were born in Australia, New Zealand, Melanesia, Micronesia, and Polynesia excluding Hawaii etc.), South-east Asia, Southern and central Asia, Southern and eastern Europe, Sub-Saharan, Africa and Not stated (Table 2).

Socioeconomic status

Socio Economic Status (SES) was based on the 2006 Australian Bureau of Statistics' Index of Relative Socio economic Advantage/ Disadvantage [15]. This index, which is generated for each five-yearly national census, summarises the presence of both positive and negative social and economic factors (e.g. income, educational attainment and unemployment) of people and households within specific geographical areas. In deriving the Index, the Australian Bureau of Statistics used a Principal Components Analysis to assign each variable a weighting. Individual census areas are then given a score based on the sum of their variable weightings.

Neighbourhood walk ability

One way that built environment elements are organised and measured in research for active travel is with a *'walk ability index'*. One measure that has become popular in recent years is the Walk

Table 1: Urban form classification in Brisbane, Queensland (derived from: Grosvenor & O'Neill, 2012(5).

Urban form category	Description	GIS criteria / process
Compact City	General increase in accessibility to public transport, employment, retail and essential services with a mixture of housing choice.	1500m from Brisbane CBD.
Multi-Node City	Highly accessible to public transport, employment, retail and essential services as the Compact City but dominated by apartments.	Within 800 m of "Principal Regional Activity Centres" of South East Queensland Regional Plan (SEQRP) and within 800m proximity to railway and bus way stations
Sub-regional Centres	SA1 s located within 800m of railway stations (proxy for centroid) located within designated secondary centres: Sub-regional centres have similar characteristics to the Multi-Node City on a smaller scale with less employment opportunities.	SA1 s in the suburbs within 800 m buffer of "Major regional" and "Specialist" Activity Centres (See South East Queensland regional Plan 2009-2031 report) and within 800m proximity to railway and bus way stations.
Corridor City	Any SA1 s outside the previous categories that are located within 800m walking distance of a railway station within the rest of the metropolitan area or 400m of a high-order bus corridor. This area characterised by good accessibility to local shopping precincts with a mixture of housing choice (other than four-storey and above apartments).	SA1 within 400 m buffer of the bus stops on the road ways and major bus routes (Grosvenor & O'Neill (2012)and within 800m of railway stations which are not assigned a urban form definition category previously
Dispersed City	Any other areas left within what is considered the traditional Brisbane suburban environment. Generally comprises a mixture of old and contemporary detached dwellings dominated by car access and local bus services.	All SA1 s within 400m vicinity of all bus stops (from the remaining SA1s from the previous steps).
Fringe City	Designated areas beyond traditional suburban environments (primarily contemporary build) with poor public transport and local service accessibility.	All other SA1 s which are not selected in any previous steps

Table 2: Proportion of people hospitalised with ischaemic heart disease as a primary diagnosis.

40-44 years old						
	Female			Male		
Ethnic category	Cases	Pop.	Prop.	Cases	Pop.	Prop.
Oceania and Antarctica	146	22644	0.0064	394	21416	0.0184
South-east Asia	3	2103	0.0014	17	1530	0.0111
Southern and Central Asia	6	629	0.0095	9	707	0.0127
North-east Asia	1	1310	0.0008	2	905	0.0022
Southern and Eastern Europe	6	894	0.0067	9	780	0.0115
North-west Europe	7	2769	0.0025	47	2949	0.0159
Sub-Saharan Africa	2	879	0.0023	15	837	0.0179
North Africa and Middle East	1	369	0.0027	7	514	0.0136
Americas	3	518	0.0058	4	470	0.0085
Not stated	5	1576	0.0032	12	1794	0.0067
TOTAL	180	33691	0.0053	516	31902	0.0162
50-54 years old						
	female			male		
Ethnic category	cases	population	proportion	cases	population	proportion
Oceania and Antarctica	431	19701	0.0219	983	18571	0.0529
South-east Asia	24	1893	0.0127	28	1394	0.0201
Southern and Central Asia	10	529	0.0189	31	505	0.0614
North-east Asia	4	1196	0.0033	10	937	0.0107
Southern and Eastern Europe	13	1127	0.0115	57	1120	0.0509
North-west Europe	51	2634	0.0194	109	2870	0.0380
Sub-Saharan Africa	7	499	0.0140	30	628	0.0478
North Africa and Middle East	3	161	0.0186	12	251	0.0478
Americas	11	461	0.0239	13	462	0.0281
Not stated	13	1371	0.0095	17	1488	0.0114
TOTAL	567	29572	0.0192	1290	28226	0.0457
60-64 years old						
	female			male		
Ethnic category	cases	population	proportion	cases	population	proportion
Oceania and Antarctica	666	13818	0.0482	1514	13074	0.1158
South-east Asia	25	1070	0.0234	36	823	0.0437
Southern and Central Asia	11	205	0.0537	28	406	0.0690
North-east Asia	15	665	0.0226	25	601	0.0416
Southern and Eastern Europe	38	867	0.0438	97	1033	0.0939
North-west Europe	128	3051	0.0420	310	3358	0.0923
Sub-Saharan Africa	5	259	0.0193	22	340	0.0647
North Africa and Middle East	2	53	0.0377	15	101	0.1485
Americas	11	215	0.0512	20	374	0.0535
Not stated	10	1005	0.0100	27	1071	0.0252
TOTAL	911	21208	0.0430	2094	21181	0.0989
70-74 years old						
	female			male		
Ethnic category	cases	population	proportion	cases	population	proportion
Oceania and Antarctica	735	7561	0.0972	1142	6209	0.1839
South-east Asia	33	515	0.0641	14	400	0.0350
Southern and Central Asia	11	89	0.1236	24	68	0.3529
North-east Asia	7	377	0.0186	21	379	0.0554
Southern and Eastern Europe	64	782	0.0818	122	795	0.1535
North-west Europe	136	1792	0.0759	287	1887	0.1521
Sub-Saharan Africa	8	52	0.1538	14	43	0.3256
North Africa and Middle East	9	24	0.3750	11	22	0.5000
Americas	6	57	0.1053	10	69	0.1449
Not stated	11	647	0.0170	9	614	0.0147
TOTAL	1020	11896	0.0857	1654	10486	0.1577

80-84 years old						
	female			male		
Ethnic category	cases	population	proportion	cases	population	proportion
Oceania and Antarctica	906	5665	0.1599	783	3356	0.2333
South-east Asia	23	177	0.1299	15	93	0.1613
Southern and Central Asia	13	58	0.2241	13	12	0.9900
North-east Asia	9	214	0.0421	10	143	0.0699
Southern and Eastern Europe	80	571	0.1401	95	525	0.1810
North-west Europe	150	1245	0.1205	179	1017	0.1760
Sub-Saharan Africa	11	25	0.4400	3	11	0.2727
North Africa and Middle East	5	32	0.1563	8	15	0.5333
Americas	11	22	0.5000	8	22	0.3636
Not stated	9	729	0.0123	15	522	0.0287
TOTAL	1217	8738	0.1393	1129	5716	0.1975

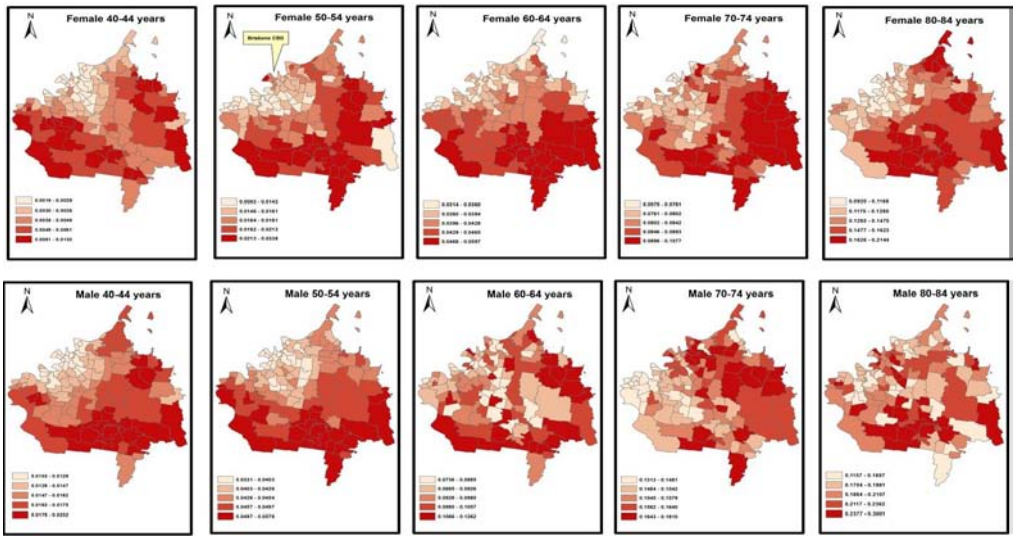

Figure 3: The Bayesian smoothed probability of IHD for each SLA stratified by age group and gender.

Score® [16] (http://www.walkscore.com) which uses Google Maps and distance-based algorithms to measure and score accessibility on foot to a range of amenities (destinations) in a certain neighbourhood. In this study we used the Walk Score website [17] to apply these metrics in our area of study. In each of the 118 SLAs we located the geographic centeroids and then extracted the associated walking score as appropriate. Figure 2 for the walk ability index by SLAs.

Distance to the nearest cardiology centre

The distance to cardiology centres (based on public and private hospitals) was identified by de An dade et al. [18] as an important measure. For example they found a positive association between IHD mortality rates and the geographic distances between patient's city of residence and their corresponding regional cardiology centres.

Hospitalisation data

Hospitalisation data were sourced from the Queensland Health Statistics Unit, in the form of a database of hospitalisation records in the south metro Brisbane area of Queensland, dating back to 2006. For each SLA, we calculated the total number of people, stratified by age, sex and ethnicity, which had one or more hospitalisations from the first of January 2006 to the 31st of December 2011, with a primary diagnosis of IHD (ICD-10 codes I20-I25). This approach ignored information pertaining to the number of different hospitalisation events per person, and length of stay. We restricted the analysis to people over 39 years of age given that ischemic heart disease is uncommon below 40 years [19,20], and to people under 85 years of age due to low numbers of people older than 84.

Stratification by age and sex

Stratification was undertaken by grouping the sample by age and sex to allow for demographic diversity in the spatial distribution of IHD. Such differences may arise if there are demographic discrepancies in the relative importance of different risk factors, including urban form. The population was grouped into five-year age categories given that there is a steep relationship between age and heart disease [19,20]. Further, we restricted the analysis to the first five years of every decade, so that there were a manageable number of age categories while still covering a wide distribution of ages. Thus we analysed the data for the following age categories: 40-44, 50-54, 60-64, 70-74 and 80-84 years. For each individual who had more than one hospitalisation with a primary diagnosis of ischemic heart disease in the period 2006 to 2011, we based their age category on the time of their first hospitalisation.

Population denominators

We used population census data [14] for population denominators

Table 3: Univariable and multivariable results for all urban form measures.

Measure	Model	F40	F50	F60	F70	F80	M40	M50	M60	M70	M80
URB1		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
URB2	Uni	0.59 (0.10 to 4.61)	1.14 (0.44 to 3.63)	1.27 (0.62 to 2.8)	1.57 (0.69 to 4.48)	0.99 (0.53 to 1.98)	1.4 (0.52 to 4.66)	0.76 (0.42 to 1.43)	0.66 (0.43 to 0.96)	1.21 (0.69 to 2.14)	1 (1 to 1)
	Multi	0.14 (0.01 to 1.87)	1.01 (0.29 to 4.04)	1.04 (0.44 to 2.66)	1.46 (0.55 to 4.4)	0.81 (0.36 to 1.88)	1.05 (0.35 to 3.86)	0.6 (0.32 to 1.19)	0.6 (0.34 to 1.11)	1.35 (0.67 to 2.89)	0.66 (0.3 to 1.4)
URB3	Uni	0.85 (0.26 to 6.40)	1.18 (0.51 to 3.16)	1.18 (0.66 to 2.44)	1.51 (0.71 to 3.86)	0.93 (0.54 to 1.77)	1.38 (0.58 to 4.42)	0.9 (0.57 to 1.57)	0.68 (0.5 to 0.98)	1.26 (0.78 to 2.1)	0.55 (0.2 to 1.6)
	Multi	0.23 (0.03 to 2.62)	1.06 (0.39 to 3.98)	1.01 (0.44 to 2.35)	1.33 (0.52 to 3.59)	0.73 (0.36 to 1.58)	0.94 (0.36 to 3.23)	0.67 (0.38 to 1.21)	0.6 (0.38 to 0.99)	1.43 (0.77 to 2.72)	0.69 (0.36 to 1.35)
URB4	Uni	1.02 (0.31 to 6.89)	1.56 (0.67 to 4.37)	1.42 (0.81 to 2.95)	1.94 (0.92 to 5.08)	1.06 (0.61 to 1.99)	1.72 (0.7 to 5.71)	1.02 (0.65 to 1.72)	0.78 (0.56 to 1.08)	1.22 (0.77 to 2.02)	0.63 (0.24 to 1.76)
	Multi	0.16 (0.02 to 1.58)	1.01 (0.33 to 3.96)	1.17 (0.51 to 2.85)	1.78 (0.67 to 4.79)	0.69 (0.33 to 1.54)	1.11 (0.41 to 3.65)	0.66 (0.36 to 1.18)	0.66 (0.39 to 1.14)	1.38 (0.71 to 2.67)	0.76 (0.4 to 1.49)
URB5	Uni	0.65 (0.19 to 4.59)	1.22 (0.52 to 3.33)	1.1 (0.63 to 2.21)	1.53 (0.7 to 4.01)	0.73 (0.41 to 1.36)	1.2 (0.5 to 3.86)	0.86 (0.54 to 1.49)	0.65 (0.47 to 0.92)	1.19 (0.74 to 2.04)	0.67 (0.23 to 2.03)
	Multi	0.18 (0.02 to 1.81)	1.09 (0.40 to 3.91)	0.98 (0.47 to 2.23)	1.47 (0.58 to 3.97)	0.6 (0.29 to 1.25)	0.92 (0.35 to 3.06)	0.68 (0.39 to 1.19)	0.58 (0.36 to 0.94)	1.33 (0.73 to 2.51)	0.83 (0.44 to 1.62)
URB6	Uni	0.6 (0.14 to 4.51)	1.42 (0.53 to 4.08)	1.54 (0.81 to 3.23)	1.65 (0.73 to 4.43)	1.43 (0.76 to 2.59)	2.08 (0.78 to 6.99)	1.25 (0.75 to 2.16)	0.76 (0.52 to 1.14)	0.98 (0.6 to 1.76)	0.76 (0.28 to 2.11)
	Multi	0.16 (0.01 to 1.99)	0.88 (0.27 to 3.8)	1.13 (0.46 to 2.76)	1.53 (0.56 to 4.5)	0.96 (0.42 to 2.32)	1.28 (0.45 to 4.91)	0.84 (0.42 to 1.58)	0.64 (0.36 to 1.12)	1.08 (0.56 to 2.17)	0.82 (0.39 to 1.68)

and estimated the population denominator for each SLA, stratified by age, sex and ethnicity, as the average number of people for the 2006 and 2011 censuses [13,14]. Fractional averages were rounded to integer values, using a random number generator to determine whether to round up or down.

Statistical Analyses

Ri ~Binomial (Ni,pi)

$\text{logit}(pi) = \beta 0$ (1) null model

where, for area i, R_i is the number of people who were hospitalised at least once for ischemic heart disease as the primary diagnosis, N_i is the total number of people of age and sex category, and p_i is the probability of being hospitalised for ischemic heart disease. The constant β_0 is the log odds of the mean probability of being hospitalised.

We used a random effects model to allow for variation between areas in the probability of ischemic hospitalisation:

$\text{Logit}(p_i) = \beta_0 + u_i + v_i$ (2) random effects model

where u_i is a spatially-correlated random effect and v_i is a spatially-uncorrelated random effect, following [21]. The uncorrelated random effect was specified as being normally distributed with a mean of zero, and no constraint of correlation among neighbouring areas.

The spatially correlated random effect u_i was based on a Conditional Autoregressive (CAR) term, with the constraint of following a normal distribution that is conditional on the local mean of CAR random effect estimates among neighbouring areas:

$$\left[u_i \middle| u_j, i \neq j, \sigma_u^2\right] \sim N\left(\overline{u_i},\right)$$

$$\left[u_i \middle| u_j, i \neq j, \sigma_u^2\right] \sim N\left(\overline{u_i}, \sigma_i^2\right)$$

Where $\overline{u_i} = \frac{\sum_j u_j \omega_{ij}}{\sum_j \omega_{ij}}$

$$\sigma_i^2 = \frac{\sigma_u^2}{\sum_j \omega_{ij}}$$

$\omega_{ij} = 1$ if areas i and j are neighbours; otherwise 0

Neighbours were defined as those areas immediately adjacent to the area in question, including neighbours that share only one vertex.

Standardisation for ethnicity

We used an offset term to standardise the models by ethnicity:

$\text{logit}(p_i) = \beta_0 + \text{logit}(e_i)$ (3) ethnically-adjusted null model

and

$\text{logit}(p_i) = \beta_0 + \text{logit}(e_i) + u_i + v_i$

(4) ethnically-adjusted random effects model

where e_i is the expected proportion of people hospitalised in area i based on the proportion of different ethnic groups within that area, and the global (all-of-study-area) proportion of people hospitalised for each ethnic group. This standardisation was calculated separately for each age-sex demographic class (Table 2), and it shows the proportion of people hospitalised with ischemic heart disease as a primary diagnosis, by ethnic group, stratified by demographic class.

We used a mixed model to allow for the effects of urban form and other covariates, while standardising for ethnicity and allowing for spatially-correlated and spatially-uncorrelated random effects:

$\text{legit}(p_i) = \beta_0 + \text{legit}(e_i) + \beta_1.X_1 + \ldots + \beta_n.X_n + u_i + v_i$

(5) ethnically-adjusted mixed model

where $\beta_1 \ldots \beta_n$ are covariate effects. We ran uni variable versions of this model, plus a full model that included effects of all covariates.

Each model was run as a Bayesian analysis. Bayesian techniques have a proven ability to solve disease mapping problems through the use of Markov Chain Monte Carlo sampling methods [23]. We specified uninformative normal prior distributions (= 0; σ = 1000) for each of $\beta_0, \beta_1 \ldots \beta_n$, and following [24] we specified uninformative half-normal prior distributions (μ = 0; σ = 100) for the standard deviation of each of the random effects u, v and d. We used Win BUGS 1.4 software [25], which uses Markov Chain Monte Carlo sampling to generate posterior distributions. For each model we used a burn-in

Table 4: Demographic groups and their associated covariate estimates that were found to be statistically significant.

Demographic group	Covariate	Odds Ratio (95% credible interval)
Female 40-44 years	WLK4[a]	0.52 (0.34 to 0.77)
Female 50-54 years	SES5[b] DISPUB (distance to public hospitals)	0.70 (0.52 to 0.98) 0.97 (0.94, to 0.99)
Female 60-64 years	WLK5[a]	0.58 (0.42 to 0.78)
Female 80-84 years	SES5[b] WLK5[a]	0.69 (0.54 to 0.90) 0.73 (0.59 to 0.90)
Male 40-44 years	WLK4[a] WLK5[a]	0.77 (0.62 to 0.94) 0.59 (0.40 to 0.85)
Male 50-54 years	WLK5[a]	0.75 (0.59 to 0.95)
Male 60-64 years	URB2[c](Corridor City)	0.66 (0.43 to 0.96)
Male 80-84 years	WLK1[a] WLK2[a] WLK4[a]	0.68 (0.51 to 0.87) 0.80 (0.65 to 0.98) 0.80 (0.69 to 0.94)

[a]Relative to WLK3 (reference category for walkability).
[b]Relative to SES3 (reference category for socioeconomic status).
[c]Relative to URB1 (reference category for urban form).

Table 5: Covariate effects for univariable and multivariable models, for all demographic categories.

a	Model	F40	F50	F60	F70	F80	M40	M50	M60	M70	M80
URB1	Uni	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
URB1	Multi	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
URB2	Uni	0.59 (0.1 to 4.61)	1.14 (0.44 to 3.63)	1.27 (0.62 to 2.8)	1.57 (0.69 to 4.48)	0.99 (0.53 to 1.98)	1.4 (0.52 to 4.66)	0.76 (0.42 to 1.43)	0.66 (0.43 to 0.96)	1.21 (0.69 to 2.14)	0.66 (0.3 to 1.4)
URB2	Multi	0.14 (0.01 to 1.87)	1.01 (0.29 to 4.04)	1.04 (0.44 to 2.66)	1.46 (0.55 to 4.4)	0.81 (0.36 to 1.88)	1.05 (0.35 to 3.86)	0.6 (0.32 to 1.19)	0.6 (0.34 to 1.11)	1.35 (0.67 to 2.89)	0.55 (0.2 to 1.6)
URB3	Uni	0.85 (0.26 to 6.4)	1.18 (0.51 to 3.16)	1.18 (0.66 to 2.44)	1.51 (0.71 to 3.86)	0.93 (0.54 to 1.77)	1.38 (0.58 to 4.42)	0.9 (0.57 to 1.57)	0.68 (0.5 to 0.98)	1.26 (0.78 to 2.1)	0.69 (0.36 to 1.35)
URB3	Multi	0.23 (0.03 to 2.62)	1.06 (0.39 to 3.98)	1.01 (0.44 to 2.35)	1.33 (0.52 to 3.59)	0.73 (0.36 to 1.58)	0.94 (0.36 to 3.23)	0.67 (0.38 to 1.21)	0.6 (0.38 to 0.99)	1.43 (0.77 to 2.72)	0.63 (0.24 to 1.76)
URB4	Uni	1.02 (0.31 to 6.89)	1.56 (0.67 to 4.37)	1.42 (0.81 to 2.95)	1.94 (0.92 to 5.08)	1.06 (0.61 to 1.99)	1.72 (0.7 to 5.71)	1.02 (0.65 to 1.72)	0.78 (0.56 to 1.08)	1.22 (0.77 to 2.02)	0.76 (0.4 to 1.49)
URB4	Multi	0.16 (0.02 to 1.58)	1.01 (0.33 to 3.96)	1.17 (0.51 to 2.85)	1.78 (0.67 to 4.79)	0.69 (0.33 to 1.54)	1.11 (0.41 to 3.65)	0.66 (0.36 to 1.18)	0.66 (0.39 to 1.14)	1.38 (0.71 to 2.67)	0.67 (0.23 to 2.03)
URB5	Uni	0.65 (0.19 to 4.59)	1.22 (0.52 to 3.33)	1.1 (0.63 to 2.21)	1.53 (0.7 to 4.01)	0.73 (0.41 to 1.36)	1.2 (0.5 to 3.86)	0.86 (0.54 to 1.49)	0.65 (0.47 to 0.92)	1.19 (0.74 to 2.04)	0.83 (0.44 to 1.62)
URB5	Multi	0.18 (0.02 to 1.81)	1.09 (0.4 to 3.91)	0.98 (0.47 to 2.23)	1.47 (0.58 to 3.97)	0.6 (0.29 to 1.25)	0.92 (0.35 to 3.06)	0.68 (0.39 to 1.19)	0.58 (0.36 to 0.94)	1.33 (0.73 to 2.51)	0.76 (0.28 to 2.11)
URB6	Uni	0.6 (0.14 to 4.51)	1.42 (0.53 to 4.08)	1.54 (0.81 to 3.23)	1.65 (0.73 to 4.43)	1.43 (0.76 to 2.59)	2.08 (0.78 to 6.99)	1.25 (0.75 to 2.16)	0.76 (0.52 to 1.14)	0.98 (0.6 to 1.76)	0.82 (0.39 to 1.68)
URB6	Multi	0.16 (0.01 to 1.99)	0.88 (0.27 to 3.8)	1.13 (0.46 to 2.76)	1.53 (0.56 to 4.5)	0.96 (0.42 to 2.32)	1.28 (0.45 to 4.91)	0.84 (0.42 to 1.58)	0.64 (0.36 to 1.12)	1.08 (0.56 to 2.17)	0.98 (0.34 to 3.39)
SES1	Uni	1.52 (0.81 to 2.8)	1.58 (1.1 to 2.2)	1.39 (1.06 to 1.87)	1.2 (0.91 to 1.56)	0.94 (0.7 to 1.29)	1.8 (1.29 to 2.61)	1.36 (1.1 to 1.72)	1.06 (0.87 to 1.3)	1.28 (1 to 1.64)	0.87 (0.65 to 1.19)
SES1	Multi	1.42 (0.59 to 3.42)	1.57 (0.99 to 2.53)	1.35 (0.96 to 1.92)	1.2 (0.82 to 1.79)	0.87 (0.6 to 1.34)	1.8 (1.22 to 2.72)	1.29 (0.97 to 1.69)	1.03 (0.77 to 1.33)	1.3 (0.95 to 1.78)	0.77 (0.45 to 1.27)
SES2	Uni	1.89 (0.82 to 4.02)	1.25 (0.8 to 1.98)	1.46 (1.01 to 2.03)	1.08 (0.76 to 1.54)	0.9 (0.63 to 1.25)	1.29 (0.77 to 2.06)	1.32 (0.97 to 1.76)	1.17 (0.92 to 1.51)	1.39 (1.02 to 1.87)	0.96 (0.68 to 1.32)
SES2	Multi	1.71 (0.55 to 5.08)	1.32 (0.7 to 2.55)	1.54 (1 to 2.33)	1.21 (0.78 to 1.89)	0.92 (0.58 to 1.5)	1.42 (0.8 to 2.43)	1.3 (0.93 to 1.85)	1.23 (0.87 to 1.71)	1.43 (0.99 to 2.13)	1.17 (0.7 to 2.12)
SES3	Uni	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
SES3	Multi	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
SES4	Uni	1.15 (0.71 to 1.99)	0.94 (0.7 to 1.27)	0.98 (0.76 to 1.24)	1.05 (0.82 to 1.33)	0.87 (0.7 to 1.11)	0.98 (0.73 to 1.34)	0.94 (0.78 to 1.15)	0.9 (0.77 to 1.07)	1.19 (0.97 to 1.48)	0.77 (0.62 to 0.98)
SES4	Multi	1.17 (0.56 to 2.56)	0.96 (0.61 to 1.45)	1.01 (0.72 to 1.39)	1.07 (0.78 to 1.49)	1.11 (0.82 to 1.54)	1.07 (0.77 to 1.55)	0.99 (0.78 to 1.26)	0.86 (0.69 to 1.09)	1.19 (0.91 to 1.58)	0.79 (0.52 to 1.25)
SES5	Uni	0.67 (0.38 to 1.24)	0.7 (0.52 to 0.98)	0.86 (0.67 to 1.11)	0.96 (0.75 to 1.23)	0.7 (0.55 to 0.91)	0.78 (0.57 to 1.12)	0.83 (0.69 to 1.03)	0.86 (0.73 to 1.02)	1.24 (0.99 to 1.55)	0.93 (0.74 to 1.22)
SES5	Multi	0.52 (0.21 to 1.24)	0.71 (0.45 to 1.11)	0.95 (0.67 to 1.33)	1.09 (0.77 to 1.57)	0.92 (0.69 to 1.32)	0.89 (0.62 to 1.37)	0.84 (0.65 to 1.08)	0.84 (0.66 to 1.08)	1.26 (0.95 to 1.69)	1.03 (0.65 to 1.67)
DISPUB	Uni	1 (0.96 to 1.05)	0.97 (0.95 to 1)	0.99 (0.97 to 1.01)	1 (0.98 to 1.02)	1 (0.98 to 1.02)	1 (0.97 to 1.02)	1.01 (0.99 to 1.02)	1 (0.99 to 1.01)	1 (0.98 to 1.02)	0.98 (0.96 to 1)
DISPUB	Multi	0.97 (0.88 to 1.06)	0.98 (0.94 to 1.03)	0.99 (0.96 to 1.02)	1.01 (0.98 to 1.05)	0.98 (0.95 to 1.02)	1.01 (0.97 to 1.05)	1 (0.98 to 1.03)	1.01 (0.98 to 1.03)	1 (0.98 to 1.04)	0.99 (0.94 to 1.04)
DISPRV	Uni	1.02 (1 to 1.05)	1.03 (1.01 to 1.04)	1.02 (1.01 to 1.03)	1.01 (0.99 to 1.02)	1.03 (1.02 to 1.04)	1.02 (1.01 to 1.04)	1.01 (1.01 to 1.03)	1.01 (1 to 1.01)	1 (0.99 to 1.01)	1.01 (1 to 1.02)
DISPRV	Multi	1.01 (0.94 to 1.08)	1 (0.96 to 1.03)	1 (0.97 to 1.02)	1 (0.97 to 1.02)	1.03 (1 to 1.05)	0.99 (0.97 to 1.02)	1 (0.98 to 1.02)	0.99 (0.98 to 1.01)	1 (0.98 to 1.02)	1.02 (0.99 to 1.07)

WLK1	Uni	1.03 (0.62 to 1.55)	0.91 (0.69 to 1.19)	0.94 (0.72 to 1.16)	0.87 (0.67 to 1.13)	1.16 (0.92 to 1.53)	0.78 (0.56 to 1.03)	1.09 (0.92 to 1.3)	0.97 (0.83 to 1.12)	0.9 (0.75 to 1.09)	0.68 (0.52 to 0.88)
WLK1	Multi	1.34 (0.63 to 2.88)	1.14 (0.75 to 1.72)	0.93 (0.66 to 1.32)	0.76 (0.53 to 1.09)	1.13 (0.79 to 1.58)	0.81 (0.58 to 1.19)	1.1 (0.87 to 1.38)	0.93 (0.75 to 1.17)	0.89 (0.68 to 1.17)	0.5 (0.31 to 0.77)
WLK2	Uni	0.94 (0.6 to 1.48)	0.88 (0.66 to 1.16)	1 (0.81 to 1.2)	0.87 (0.71 to 1.05)	1.03 (0.84 to 1.26)	1.05 (0.81 to 1.35)	0.99 (0.83 to 1.18)	0.95 (0.81 to 1.1)	0.99 (0.84 to 1.17)	0.8 (0.65 to 0.98)
WLK2	Multi	0.86 (0.45 to 1.63)	0.83 (0.56 to 1.17)	0.95 (0.71 to 1.25)	0.83 (0.62 to 1.1)	0.98 (0.71 to 1.29)	1.09 (0.8 to 1.47)	0.96 (0.8 to 1.18)	0.91 (0.74 to 1.12)	0.97 (0.78 to 1.21)	0.59 (0.41 to 0.87)
WLK3	Uni	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
WLK3	Multi	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
WLK4	Uni	0.52 (0.35 to 0.77)	0.84 (0.68 to 1.02)	0.96 (0.82 to 1.13)	0.89 (0.77 to 1.05)	0.91 (0.78 to 1.07)	0.78 (0.62 to 0.94)	0.93 (0.81 to 1.06)	0.92 (0.82 to 1.03)	0.93 (0.82 to 1.06)	0.81 (0.69 to 0.94)
WLK4	Multi	0.59 (0.33 to 1.11)	0.92 (0.68 to 1.25)	0.98 (0.8 to 1.21)	0.94 (0.75 to 1.18)	0.9 (0.72 to 1.11)	0.82 (0.64 to 1.06)	0.92 (0.77 to 1.08)	0.94 (0.79 to 1.1)	0.98 (0.82 to 1.18)	0.76 (0.57 to 1)
WLK5	Uni	0.57 (0.29 to 1.05)	0.76 (0.54 to 1.07)	0.59 (0.42 to 0.79)	0.87 (0.68 to 1.12)	0.74 (0.6 to 0.91)	0.6 (0.41 to 0.85)	0.75 (0.6 to 0.96)	1.01 (0.85 to 1.18)	1.03 (0.85 to 1.24)	0.86 (0.67 to 1.11)
WLK5	Multi	0.71 (0.25 to 1.94)	0.77 (0.45 to 1.3)	0.64 (0.42 to 0.9)	0.87 (0.6 to 1.25)	0.77 (0.54 to 1.07)	0.72 (0.47 to 1.09)	0.81 (0.62 to 1.08)	1.08 (0.84 to 1.41)	1.04 (0.79 to 1.41)	0.85 (0.54 to 1.35)

of 1000,000 iterations, with posterior distributions generated from an additional 1000,000 iterations, thinned to 1000 samples. Convergence was confirmed using the Geweke diagnostic [26].

Findings

We identified high levels of spatial variation in the probability of IHD occurrence, which led us to examine each of the associated risk factors. For instance, Figure 3 below shows the smoothed probability of IHD incidence for each SLA stratified by age and gender. In general, the probability of being admitted with IHD for males and females between the ages of 50-54 is greater in outer suburban areas than in the inner-suburbs of Brisbane at the same time suggesting that the outlying spatial clusters are more noticeable.

Urban form was only weakly associated with the incidence of IHD (Table 3). There was no urban form categories associated with consistently high or low incidence of IHD across age and sex categories. Few other covariates had statistically significant effects on the incidence of IHD, and covariate effects were highly inconsistent between age and sex categories (Tables 4 & 5).

There were generally strong patterns of residual spatial variation after accounting for the combined effects of urban form, ethnicity, socioeconomic status, walk ability and distance to local hospitals. Figure 4 shows the odds ratios (residual variation) from the fully adjusted model versus the odds ratios from random effects model (model that did account for the covariates) [bottom]. The findings suggest that after accounting for the covariates, the inter quartile difference between the demographic categories decreases (smaller inter quartile range). For instance, before accounting for the covariates within the Male 50-54 age group (Odds of IHD hospitalisation), the inter quartile ranges were between 0.89 to 1.14. After accounting for the covariates, the inter quartile ranges for the same groups were between 0.97 to 1.05, see also (Figure 5). We can therefore surmise from these findings that after accounting for the covariates the inter quartile differences between demographic groups were predominantly more noticeable for male's between50-54 and 40-44 years of age, spatial pattern identified the odds of IHD

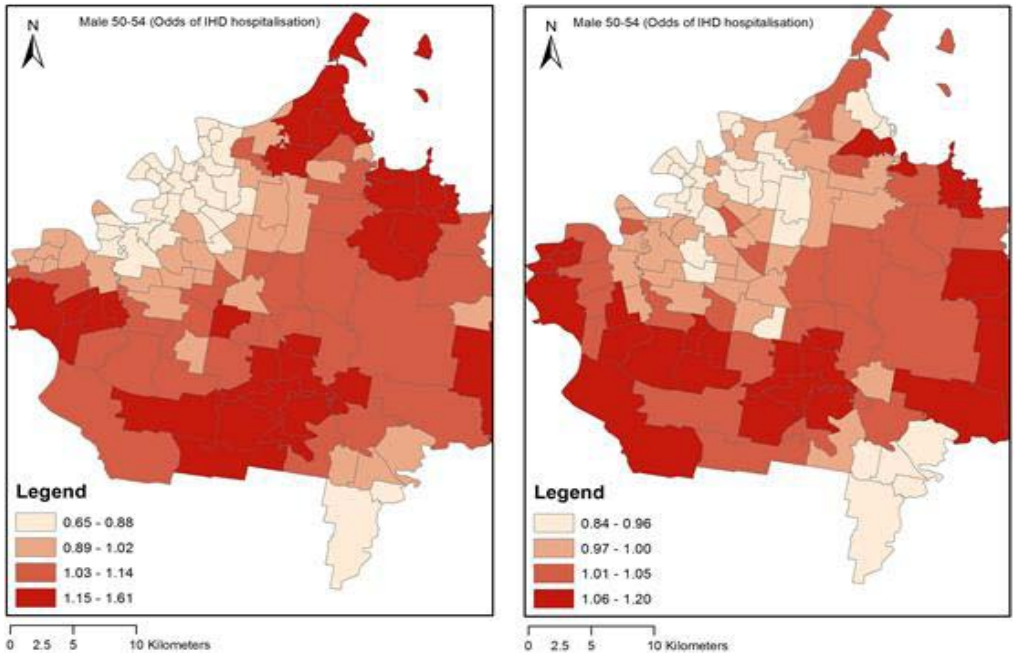

Figure 4: Odds ratios from random effects model (no covariates) [top], and fully-adjusted model (residual variation) [bottom].

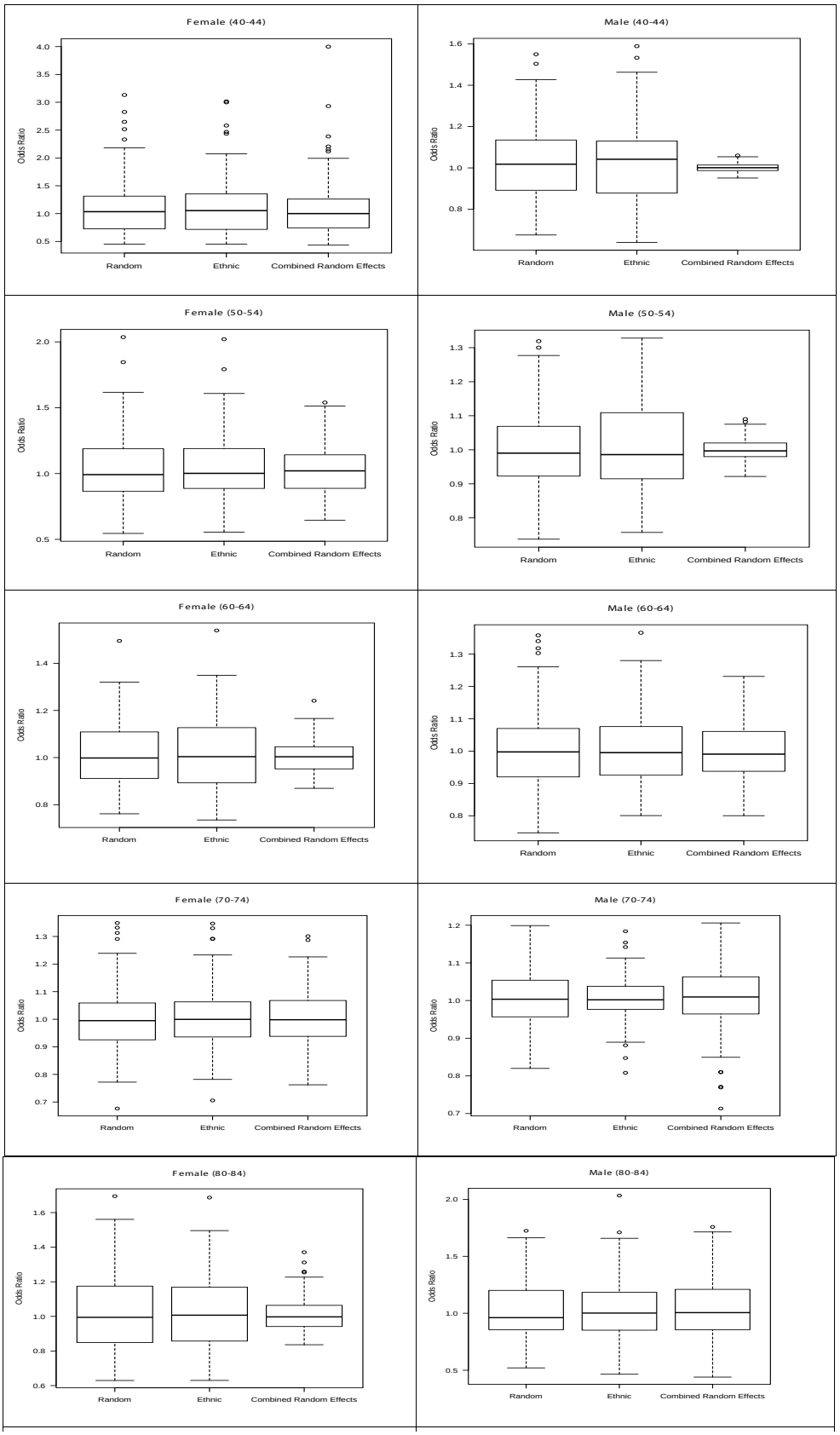

Figure 5: Box plots diagram that shows the interquartile range of odds ratios across the age and sex categories.

hospitalisations for 60-64 year old males were significantly greater in outer suburban areas compared to the inner-suburbs of Brisbane.

Discussion, Limitations and Future Research

A result of urban or semi urban characteristics of our area of interest. This however, remains to be investigated further. In this study, the principal aim was to test for a relationship between urban form and IHD; the results suggest that urban form was not a strong predictor of IHD. In fact, the covariates did little to explain the variation between SLAs, with the exception of 60-64 year old men demographic category. Even with this finding, albeit marginal, there was little additional evidence of an effect of urban form on the incidence of ischemic heart disease. It may be that similar to past attempts to identify the impacts of urban form, these differences are very small or it may be that there better ways to measure urban form. For instance, de Andrade et al. [18]. Suggest that the high mortality rate of IHD within regional areas were dependent on the distance between each city and their reference interventional cardiology centre, which implies that distance to hospital may be a potential confounder. However, in our study we did not find strong evidence pertaining to distance, which may be as strong patterns of spatial variation in IHD have been observed in the study. Spatial variation has been tested after taking multiple risk factors into account. There were generally strong patterns of residual spatial variation in IHD after taking into account the covariates. For example, patterns of spatial variation in the rates of IHD can be seen in women aged 40-44 years of age with higher incidences of hospitalisation on either side of the multi-node corridor. However with the increase in age, women in the study area were more likely to be hospitalised in the fringe city region than the dispersed city category, reasons for that were left unanswered.

The effects of other covariates were generally weak and inconsistent between demographic categories. For instance, different demographic categories showed different amounts of spatial variation and different relationships within the covariates. It appeared that after controlling for socioeconomic status and other covariates, the urban form variables were not associated with strong effects of IHD hospitalisation. The improved model simply did not reveal a sufficient difference.

Several limitations must be considered in this study. In general, the study did not reveal why IHD may have a relationship to urban form. It was found that the effect of most covariates was generally weak, but there were some effects that varied between demographic categories, which may require further investigation. Therefore, we were not able to make any firm conclusions about why or whether a particular set of covariates was important for a particular demographic group. Also, for some demographic groups, there was a decrease in residual variation (e.g., male 50-54 and male 40-44), after including all covariates in the model. This is an important finding, since it creates an opportunity for further investigation focused on these two age groups. The potential of limitations of geographic scale which constrained the study to an aggregated SLA level as opposed to the more detailed SA1 (statistical Area Level 1), may have been more suitable scale and may have yielded higher spatial resolution. Other limitations that were found in our dataset were those related to the type of datasets being assembled and some of the measures used in the covariates. With regards to some of the measures used in the covariates, the Walk Score data that was used ignores topography, urban design measures (other than those that affect networks and distances such as 'connectivity' etc.) and in Australia has a reduced level of information than in US cities, which could have limited its utility. Also, the fact that we used centroids to represent a large area of SLAs rather than specific location reduces its reliability as SLAs can vary spatially in its walk ability level, especially if they are large areas. In Summary, this study was pioneering in its nature and perhaps is one of the first attempts in the literature to test the relationship between urban form and IHD and health measures in general. More research will be required to address the unanswered questions raised (e.g., better way to measure urban form or the findings associated with the 40-44, 50-54 male group) in this study and may constitute a new avenue for future studies in this domain.

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