A cross-sectional and longitudinal study of neighbourhood disadvantage and cardiovascular disease and the mediating role of physical activity

A Cross-sectional and Longitudinal Study of Neighbourhood Disadvantage and Cardiovascular Disease and the mediating role of Physical Activity

ABSTRACT

We investigate the prospective association between neighbourhood-level disadvantage and cardiovascular disease (CVD) among mid-to-older aged adults and whether physical activity (PA) mediates this association. The data come from the HABITAT project, a multilevel longitudinal investigation of health and wellbeing in Brisbane. The participants were 11,035 residents of 200 neighbourhoods in 2007, with follow-up data collected in 2009, 2011, 2013 and 2016. Multilevel binomial regression was used for the cross-sectional analysis and mixed-effect parametric survival models were used for the longitudinal analysis. Models were adjusted for age, sex, education, occupation, and household income. Those with pre-existing CVD at baseline were excluded from the longitudinal analyses. The mediated effect of PA on CVD was examined using multilevel generalized structural equation modelling. There was a total of 20,064 person-year observations across the five time-points clustered at three levels. Results indicated that the incidence of CVD was significantly higher in the most disadvantaged neighbourhoods (OR 1.50; HR 1.29) compared with the least disadvantaged. Mediation analysis results revealed that 11.5% of the effect of neighbourhood disadvantage on CVD occurs indirectly through PA in the most disadvantaged neighbourhoods while the corresponding figure is 5.2% in the more advantaged areas. Key findings showed that neighbourhood disadvantage is associated with the incidence of CVD, and PA is a significant mediator of this relationship. Future research should investigate which specific social and built environment features promote or inhibit PA in disadvantaged areas as the basis for policy initiatives to address inequities in CVD.

Keywords: Cross-sectional study, Longitudinal study, Cardiovascular disease, physical activity, neighbourhood disadvantage

Abstract word counts: 244
Manuscript word counts: 3,527.

INTRODUCTION

Cardiovascular disease (CVD) is one of the main causes of the death and disease burden in Australia (1). In 2014-15, approximately 4.2 million Australian adults (18.3%) reported having a disease of the circulatory system, and this included around 1.2 million people with cardiovascular conditions such as heart disease and stroke. Also, nearly 2.6 million Australians reported having hypertension (high blood pressure) and 430,000 indicated that they had experienced a heart attack at some point in their life (2).

A number of studies have found that individual indicators of socioeconomic position (SEP) often measured via educational attainment (3), occupational class (4) and household income (5) are associated with cardiovascular morbidity and mortality (6). In addition to individual-level measures of SEP as risk factors for CVD (7), increased attention is now being given to the characteristics of neighbourhoods. Measures of socioeconomic disadvantage can be captured at the neighbourhood level using various indices, typically created using census data, and include variables such as education, occupation, and household income (8). Further, neighbourhoods also have built and social environment characteristics that may contribute to observed outcomes (6). For example, neighbourhoods with greater levels of disadvantage often have higher levels of crime (9, 10), poorer access to health-promoting amenities such as green space and water bodies (11, 12), and poorer access to higher quality public transport (13). This is evidenced by the growing body of research on the role of neighbourhood environments in CVD prevention (3, 6). It is important however to identify behavioural factors that mediate relationships between the neighbourhood environment and cardio-metabolic risk markers (14) and hence increase the incidence of CVD. Physical activity (PA) has been found to be inversely associated with risk of cardiovascular disease (15). Previous cross-sectional research has indicated that the neighbourhood environment is associated with the level of residents' PA (16), and regular participation in PA reduces the risk of CVD (17). However, few studies have examined the longitudinal mediating role of PA in the relationships between neighbourhood disadvantage and CVD. The aims of this study are two-fold: first, to examine the total effect of neighbourhood disadvantage on CVD; and second, to address the limitations of previous research by examining the indirect effects of neighbourhood disadvantage on CVD, mediated through PA at five time-points between 2007 and 2016. It is hypothesized that those living in more disadvantaged neighbourhoods are more likely to have lower levels of PA while reporting one or more heart related diseases or risk factors.

METHODS

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

Participants

Details about the HABITAT study can be found elsewhere (9, 18). Briefly, a two-stage probability sampling design was used to select a stratified random sample of 200 neighbourhood Census Collector's Districts (CCDs), and within each neighbourhood, a random sample of people aged

40–65 years (on average 85 people per CCD). The baseline HABITAT sample (2007) was broadly representative of the wider Brisbane population (19). A structured self-administered questionnaire was sent to 17,000 potentially eligible participants in May 2007 using a mail survey method developed by Dillman (20). After excluding 873 out-of-scope contacts (i.e. deceased, no longer at the address, unable to participate for health-related reasons), 11,035 usable surveys were returned, yielding a baseline response rate of 68.3%: the corresponding response rates from in-scope and contactable participants 2009, 2011, 2013 and 2016 were 72.6% (n=7866), 67.6% (n=6,900), 67.5% (n=6520) and 58.8% (n=5,187), respectively. This study focuses on same respondents who had not moved during five time-points (2007-2016).

Measures

Neighbourhood disadvantage

Each of the 200 neighbourhoods was assigned a socioeconomic score using the Australian Bureau of Statistics' Index of Relative Socioeconomic Disadvantage (IRSD) (21). A neighbourhood's IRSD score reflects each area's overall level of disadvantage measured based on 17 variables which capture a wide range of socioeconomic attributes, including education, occupation, income, unemployment, household structure, and household tenure, among others. The derived IRSD scores for the HABITAT neighbourhoods were then grouped into quintiles, with Q5 denoting the 20% least disadvantaged areas relative to the whole of Brisbane and Q1 denoting the 20% most disadvantaged areas.

Cardiovascular disease (CVD)

Participants responded to the question "Have you ever been told by a doctor or nurse that you have any of the long-term health conditions listed below? (please only include those conditions that have lasted, or are likely to last, for six months or more)." Coronary heart disease (CHD), serious circulatory condition (SCC) and high blood pressure (HBP) were three of eight conditions listed, and respondents were asked to indicate "yes" (coded 1) or "no" (coded 0) for each condition. A person was classified as having CVD if they reported experiencing one or more of the three conditions. Self-reported measures of CVD have been shown to be valid when compared to Joshi and Turnbull (22) and Martin et al. (23), and have been extensively in large longitudinal epidemiological studies (6, 24-27).

Physical activity (PA)

PA was assessed using the Active Australia survey (28) which has been widely used in population-based surveys. An overall measure of energy expenditure is derived by multiplying the time (minutes/week) spent in walking, moderate activity, and vigorous activity by an intensity value, and summing the products. Respondents reported time spent walking briskly (3.33 metabolic equivalents [METs]), in moderate (3.33 METs) and in vigorous (6.66 METs) leisure time PA in the previous week. Total metabolic equivalent (MET) minutes/week were calculated as [walking minutes ∗ 3.33METS] + [moderate minutes ∗ 3.33METS] + [vigorous minutes ∗ 6.66METS]), where one MET represents an individual's energy expenditure while sitting quietly (29). To minimize errors due to over-reporting, a cut-off value of 840 min (14 h/wk) for a single activity type was recoded.

Sociodemographic variables

Based on the existing literature, age, gender, education, occupation, and household income were treated as potential confounders of the relationship between neighbourhood disadvantage and CVD (6, 30).

Analysis

Prior to analysis, we assessed the likely robustness of the study's findings to bias resulting from sample attrition (e.g., dropout) under a missing at random (MAR) assumption. Data are considered to be MAR if the probability that the variable is missing does not depend on the value of the variable itself, after controlling for other observed variables. We investigated whether neighbourhood disadvantage, the covariates, and total Met-min of PA at one wave predicted dropout at a subsequent wave using logistic regression with lagged variables (31). The likelihood of dropout was significantly higher for residents of the most disadvantaged areas, lower educated groups, members of low-income households, and significantly lower for older people, and women. Importantly, CVD and total Met-min PA at one wave were not associated with dropout at a subsequent wave after adjustment for neighbourhood disadvantage and the covariates, providing some support for the MAR assumption. When dropout is related to covariates only and not to prior or missing values of the outcome variables (CVD and PA), the regression estimates are minimally biased under the MAR assumption (32). To further explore the potential impact of sample attrition on the robustness of the study's findings, we compared the sociodemographic profile of the HABITAT baseline sample in 2007 with the sample profiles for all subsequent waves (Appendix B). The baseline sample was representative of the Brisbane population aged 40 -65 years in 2007 (33), and the sample profiles did not change substantially across the other waves (except for age and the proportion of people who retired, which was expected). Despite the inevitable loss to follow-up which characterises all longitudinal studies, these analyses confirm our study's analytic sample remained relatively stable over the reference period.

Cross-sectional Analysis

The analytic sample for the cross-sectional analysis included 8,782 participants who recorded long-term conditions including CHD (34), HBP (35) and SCC (36) at baseline (2007).

Binomial regression

The cross-sectional analysis investigates the baseline association between neighbourhood disadvantage along with individual-level SEP and self-reported coronary heart disease (CHD), high blood pressure/hypertension (HBP), any serious circulatory condition (SCC) and CVD Longitudinal analysis was only applied on CVD (the combined measure) excluding those with pre-existing heart disease at baseline. Binomial logistic regression models were separately run to examine associations between explanatory variables and CHD, HBP, SCC and CVD as outcome measurements.

Longitudinal Analysis

The analytic sample for the longitudinal analysis included 6,425 participants at baseline (2007) and 4168, 3600, 3237, and 2634 in 2009, 2011, 2013 and 2016, respectively (see Appendix A). Respondents with pre-existing heart disease at baseline (n=2,357) were excluded from the longitudinal analysis. The reason behind was to reduce possible reverse causality bias on their PA behaviours during the study period and to strengthen claims of a causal association between neighbourhood disadvantage and CVD.

Survival analysis

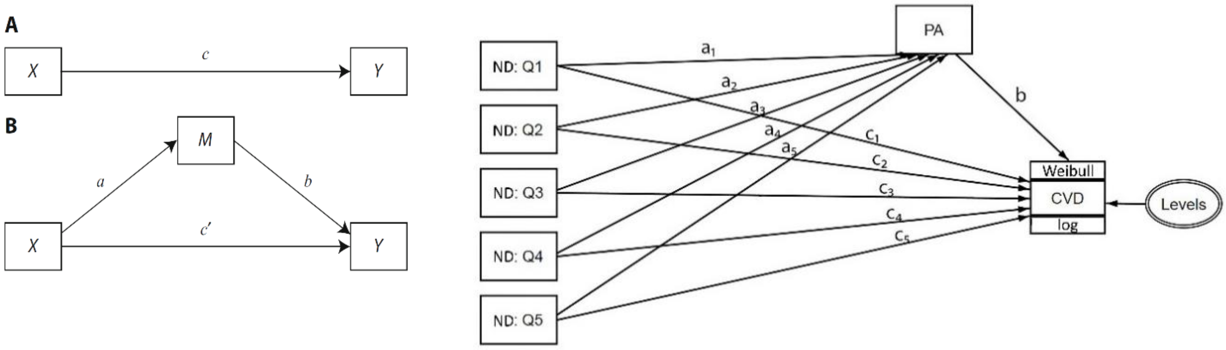
Using STATA/SE, V.16, a multilevel mixed-effect parametric survival (MMPS) model was applied to examine the association between neighbourhood disadvantage and individual-level socioeconomic position on CVD. Mixed-effects survival models contain both fixed- and random-effects. In longitudinal data, random effects are useful for modelling intra-cluster correlations (37). The longitudinal data contained 20,064 observations at five-time points clustered at three levels: year, HABITAT neighbourhood and individual. The failure event in the survival analysis was the year in which the survey participant was told by a medical or health professional that they had one or more of the three CVD-related conditions. The event has been counted once at the wave that CVD incidence reported.

MMPS models assume normally distributed random effects, estimated with maximum likelihood utilising Gaussian quadrature. These models are used in the analysis of clustered survival data, such as repeated events, and individual participant data (38). This study applied the commonly-used Weibull parametric survival model, in which the hazard function is of the form $h(t)=\lambda y t^{p-1}$ for parameters $\lambda>0$ and $p>0$ (39). When the shape parameter is equal to 1 ($p=1$), this model reduces to the exponential and has constant risk over time. If $p>1$, then the risk increases over time. If $p<1$, then the risk decreases over time (40).

Mediation analysis

Mediation analysis has been recommended in many fields of treatment and prevention (41). In epidemiological studies, mediation is commonly used to examine how or through what mechanisms a complex exposure causes the development of a disease. People's behaviour has been found to be influenced by their neighbourhood environment (42). Given that this study focused on participants who stayed in the same residence across five waves, it is hypothesized that neighbourhood environment influences the probability of experiencing CVD through the mediating role of PA. There is now a substantial body of evidence which shows that being physically active protects against CVD (15). To test for the mediating effects of PA, using STATA/SE, V.16, we applied multilevel generalized structural equation modelling (GSEM) with a Weibull distribution and log link function. Levels were defined as years, individuals, and HABITAT neighbourhoods. The outcome variable in this model was defined as the time of the CVD occurrence. Age, sex, education, occupation, and household income were added to the model as potential confounders. Significance level was defined at 5% for all the analysis.

Figure 1(a), part A is an illustration of a direct effect: X affects Y. Part B is an illustration of a mediation design. X is hypothesized to exert an indirect effect on Y through M (43). Figure 1(b) depicts the path diagram of the GSEM model builder. Mediation processes involve only one mediating variable (physical activity: PA). Paths a_1, a_2,..,a_5 represent direct effects of neighbourhood disadvantage on PA, whereas path b is the direct effect of PA on CVD. Paths c'_1, c'_2,..., c'_5 show the direct effects of neighbourhood disadvantage on CVD. The ratio of indirect effects (ab) to total effect (c′+ab), represents the proportion of the mediated effect that occurs through PA (44).



1(a): Illustrations of direct effect (A) and a mediation design (B).

1(b): GSEM path diagram of the indirect effect of neighbourhood disadvantage (ND) on CVD through physical activity (PA).
Levels were defined as years, individuals, and HABITAT neighbourhoods.

Figure 1 Illustration of a mediation design

RESULTS

Table 1 presents the proportion of participants classified as experiencing CVD, and the mean total Met-min of PA, by neighbourhood disadvantage and individual-level SEP, in 2007, 2011, and 2016. The probability of being classified as having CVD was highest among residents of socioeconomically disadvantaged neighbourhoods, the least educated, the retired, and members of lower-income families. Moreover, a similar trend can be seen in the total Met-min of PA; each of the above-mentioned groups reported fewer Met-min of total PA.

Table 1: Participants classified as having CVD, and mean Met-min of total physical activity, by neighbourhood disadvantage and individual-level socioeconomic position, in 2007, 2011 and 2016[1]

	Classified with CVD			Total Met-min of physical activity		
	2007	2011	2016	2007	2011	2016
	%	%	%	Mean (95% CI)	Mean (95% CI)	Mean (95% CI)
Overall	23.9	32.3	37.5			
Neighbourhood disadvantage	n= 8,782	n=5,074	n=3,632	n= 8,782	n=5,074	n=3,632
Q5 (Least disadvantaged)	20.0	24.2	30.6	323.2 (297.3,349.1)	293.7 (263.2,324.2)	320.0 (284.3,355.6)
Q4	25.7	30.4	39.5	327.6 (306.1,349.1)	286.3 (261.7,310.8)	328.7 (296.0,361.4)
Q3	26.3	31.7	37.6	344.0 (324.1,364.0)	327.2 (303.7,350.7)	392.3 (359.1,425.6)

Q2	26.4	32.0	41.9	370.0 (349.2,390.8)	357.1 (334.6,379.6)	389.7 (361.3,418.2)
Q1 (Most disadvantaged)	32.3	39.0	44.3	399.6 (382.7,416.5)	385.2 (361.6,408.7)	426.5 (400.0,453.1)
Highest education attained						
Bachelor's degree or higher	19.9	25.2	32.4	390.0 (374.4,405.6)	369.3 (350.5,388.0)	410.5 (388.5,432.4)
Diploma/Associate diploma	24.0	30.7	36.1	410.6 (381.7,439.4)	352.9 (321.7,384.2)	404.9 (366.5,443.3)
Certificate (trade/business)	24.2	30.4	37.0	370.3 (346.5,394.2)	346.4 (318.9,373.9)	412.4 (373.0,451.8)
None beyond school	30.1	35.7	44.1	316.8 (302.7,330.9)	298.0 (280.0,316.1)	328.6 (305.8,351.4)
Occupation[1]						
Managers & Professionals	20.1	23.8	29.6	394.5 (378.9,410.1)	356.1 (337.6,374.5)	397.8 (373.5,422.2)
White collar	22.5	25.7	28.3	311.4 (293.6,329.1)	299.8 (277.4,322.2)	335.1 (304.2,366.0)
Blue collar	22.8	27.8	33.4	360.1 (332.8,387.5)	312.3 (277.6,347.0)	348.4 (300.6,396.3)
Home duties	24.6	30.7	36.2	331.9 (298.0,365.7)	331.7 (286.7,376.7)	404.0 (320.7,487.4)
Retired	44.3	47.0	49.3	395.5 (364.3,426.7)	363.1 (335.8,390.3)	405.5 (380.4,430.5)
Household income[2]						
$130,000 pa or more	18.6	21.9	25.4	426.8 (405.3,448.4)	399.5 (374.7,424.2)	426.9 (396.3,457.4)
$72,800 - $129,999	22.0	26.6	33.2	358.1 (340.3,375.9)	328.0 (306.6,349.4)	375.8 (348.1,403.5)
$52,000 - $72,799	23.1	30.5	38.8	331.8 (308.3,355.2)	330.0 (296.0,364.0)	371.1 (335.4,406.8)
$26,000 - $51,599	29.1	40.1	48.5	335.7 (314.1,357.3)	303.9 (279.7,328.1)	345.0 (315.4,374.5)
$0 - $25,999	42.0	45.2	52.6	347.8 (316.3,379.3)	320.2 (280.9,359.6)	403.1 (351.6,454.5)

[1,2] The missing categories for occupation and household income were included in the statistical analysis but are not presented in the table

Cross-sectional results

Table 2 shows that residents from more disadvantaged neighbourhoods were more likely to have reported being told by a health professional that they had CHD (OR: 1.79), HBP (OR: 1.47), SCC (OR: 1.63) or CVD (OR: 1.50). The models were adjusted for age, gender, education, occupation, and household income. As the results indicate, each year of increasing age was associated with 8% greater odds of reporting a cardiovascular event. Members of lower income households were also more likely to have CHD (OR: 2.88), HBP (OR: 1.26) and SCC (OR: 1.68). Moreover, less educated people were more likely to report CHD (OR:1.44), HBP (OR:1.39) and CVD (OR:1.38).

Table 2 Binomial regression models at baseline (2007) for coronary heart disease (CHD), high blood pressure/hypertension (HBP), any serious circulatory condition (SCC) and cardiovascular disease (CVD)[1]

	CHD	**HBP**	**SCC**	**CVD**
n=8,782	OR (95% CI)	OR (95% CI)	OR (95% CI)	OR (95% CI)
Age	1.08 (1.07,1.10)	1.08 (1.07,1.09)	1.09 (1.07,1.11)	1.08 (1.07,1.09)
Gender				
Male	1.00	1.00	1.00	1.00
Female	0.64 (0.52,0.77)	0.74 (0.66,0.83)	0.60 (0.46,0.78)	0.74 (0.66,0.83)
Neighbourhood disadvantage				
Q5 (Least disadvantaged)	1.00	1.00	1.00	1.00
Q4	1.24 (0.92,1.68)	1.29 (1.10,1.52)	1.40 (0.94,2.10)	1.32 (1.13,1.53)
Q3	1.24 (0.92,1.68)	1.29 (1.10,1.52)	1.34 (0.91,2.00)	1.29 (1.11,1.51)
Q2	1.29 (1.00,1.74)	1.28 (1.08,1.51)	1.21 (0.81,1.81)	1.28 (1.10,1.51)

Q1 (Most disadvantaged)	1.79 (1.32,2.43)	1.47 (1.22,1.76)	1.63 (1.09,2.45)	1.50 (1.26,1.78)
Highest education attained				
Bachelor's degree or higher	1.00	1.00	1.00	1.00
Diploma/Associate diploma	1.23 (0.86,1.77)	1.19 (0.97,1.45)	1.24 (0.77,1.98)	1.18 (0.98,1.42)
Certificate (trade/business)	1.28 (0.93,1.76)	1.14 (0.95,1.36)	1.22 (0.80,1.86)	1.15 (0.97,1.36)
None beyond school	1.44 (1.10,1.83)	1.39 (1.19,1.62)	1.32 (0.92,1.89)	1.38 (1.20,1.60)
Occupation				
Managers & Professionals	1.00	1.00	1.00	1.00
White collar	0.79 (0.57,1.10)	0.96 (0.81,1.14)	1.20 (0.77,1.88)	0.94 (0.80,1.11)
Blue collar	0.72 (0.50,1.03)	0.85 (0.70,1.03)	0.91 (0.55,1.51)	0.81 (0.68,0.98)
Home duties	0.92 (0.57,1.50)	1.06 (0.82,1.38)	0.64 (0.28,1.48)	0.99 (0.77,1.27)
Retired	0.98 (0.69,1.39)	1.20 (0.97,1.48)	1.41 (0.88,2.25)	1.15 (0.94,1.41)
Household income				
$130,000 pa or more	1.00	1.00	1.00	1.00
$72,800 - $129,999	1.49 (1.00,2.22)	1.08 (0.90,1.30)	1.69 (0.97,2.97)	0.10 (0.92,1.32)
$52,000 - $72,799	1.37 (0.88,2.14)	0.99 (0.81,1.23)	1.60 (0.87,2.95)	1.01 (0.83,1.24)
$26,000 - $51,599	1.84 (1.22,2.79)	1.12 (0.92,1.37)	1.68 (0.94,3.02)	1.18 (0.97,1.44)
$0 - $25,999	2.88 (1.86,4.46)	1.26 (1.00,1.60)	3.21 (1.77,5.84)	1.51 (1.21,1.89)

[1] All models were adjusted for age, gender, education, occupation, and household income

Longitudinal results

For the longitudinal analysis we excluded participants who reported CVD at baseline (2007). The percentage of CVD incidence in 2009, 2011, 2013, and 2016 was 9%, 13%, 17%, and 22% respectively. Table 3 presents the results of the MMPS models. As the HR in Model 1 shows, residents of the most disadvantaged neighbourhoods have a 56% higher risk of reporting CVD compared with the least disadvantaged group. After adjusting for other explanatory variables, people in Q1 are still at the highest risk (HR: 1.29). In relation to education, occupation and household income, people in the least educated group (HR: 1.29), blue collar workers (HR: 1.41) and individuals from the lowest income group (HR: 1.66) were at the greatest risk.

Table 3 Neighbourhood disadvantage, individual-level socioeconomic position and the likelihood of respondents being told by a health professional that they have CVD.

N = 20,064 observations[1]	**Model 1**		**Model 2**		**Model 3**	
	HR	**95% CI**	**HR**	**95% CI**	**HR**	**95% CI**
Neighbourhood disadvantage[2]						
Q5 (Least disadvantaged)	1.00				1.00	
Q4	1.29	1.06,1.55			1.18	1.04,1.61
Q3	1.39	1.15,1.69			1.25	0.97,1.46
Q2	1.34	1.09,1.66			1.19	1.02,1.51
Q1 (Most disadvantaged)	1.56	1.24,1.90			1.29	1.04,1.61
Highest education[3] attained						
Bachelor's degree or higher	1.00		1.00		1.00	
Diploma/Associate diploma	1.07	0.86,1.31	1.06	0.86,1.30	1.02	0.82,1.26
Certificate (trade/business)	1.27	1,07,1.51	1.22	1.02,1.45	1.14	0.95,1.38

None beyond school	1.29	1.11,1.49	1.23	1.06,1.43	1.14	0.97,1.35
***Occupation*[4,6]**						
Managers & Professionals	1.00		1.00			
White collar	1.08	0.90,1.30	1.06	0.88,1.27	0.96	0.78,1.16
Blue collar	1.41	1.15,1.72	1.35	1.10,1.66	1.20	0.96,1.50
Home duties	1.19	0.89,1.60	1.17	0.87,1.57	1.10	0.81,1.48
Retired	0.91	0.74,1.10	0.92	0.75,1.12	0.85	0.67,1.01
***Household income*[5,6]**						
$130,000 pa or more	1.00		1.00		1.00	
$72,800 - $129,999	1.32	1.09,1.60	1.28	1.05,1.54	1.24	1.02,1.50
$52,000 - $72,799	1.31	1.04,1.64	1.24	0.98,1.56	1.20	0.93,1.50
$26,000 - $51,599	1.42	1.15,1.75	1.34	1.08,1.66	1.28	1.02,1.59
$0 - $25,999	1.66	1.30,2.11	1.53	1.19,1.96	1.41	1.08,1.81

[1] The sample included 6,425 participants at baseline (2007) and 4168, 3600, 3237, and 2634 at 2009, 2011, 2013 and 2016, respectively.

[2]Neighbourhood disadvantage adjusted for age and sex (Model 1), plus education, occupation, and household income (Model 3).

[3]Education adjusted for age and sex (Model 1), plus neighbourhood disadvantage (Model 2), plus occupation and household income (Model 3).

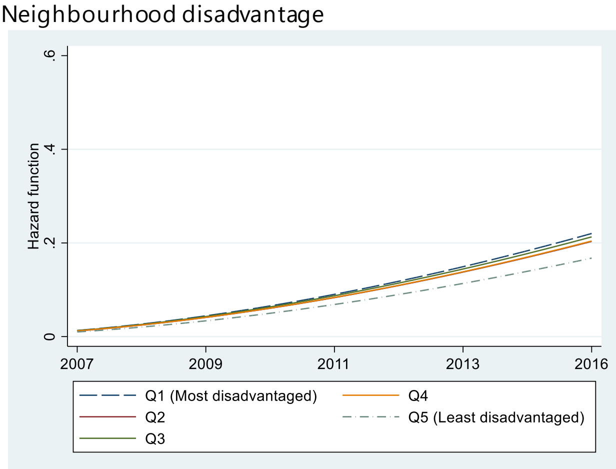
[4]Occupation adjusted for age and sex and (Model 1), plus neighbourhood disadvantage (Model 2), plus education and household income (Model 3).

[5]Household income adjusted for age and sex (Model 1), plus neighbourhood disadvantage (Model 2), plus education and occupation (Model 3).

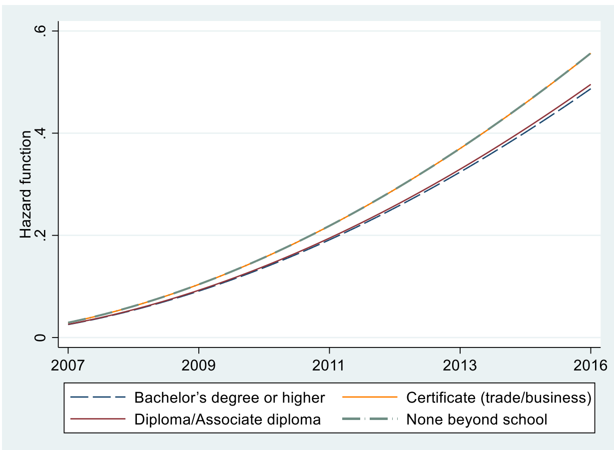
[6]The missing categories for occupation and household income were included in the statistical analysis but are not presented in the table.

Figure 2 shows the cumulative hazard function plots for neighbourhood disadvantage, education, occupation, and household income. Like probability plots, cumulative hazard plots are used for the visual examination of distributional model assumptions for reliability data and they have a similar interpretation to probability plots. As the figure shows, the hazard experienced by individuals increases over time, since the gradient/slope of the cumulative hazard function increases over time. Residents in the most disadvantaged neighbourhoods have the highest risk of CVD compared with those from the least disadvantaged neighbourhoods. Moreover, the least educated, blue collar workers and people from the lowest income families have a higher hazard.

Neighbourhood disadvantage



Education



Occupation Household income

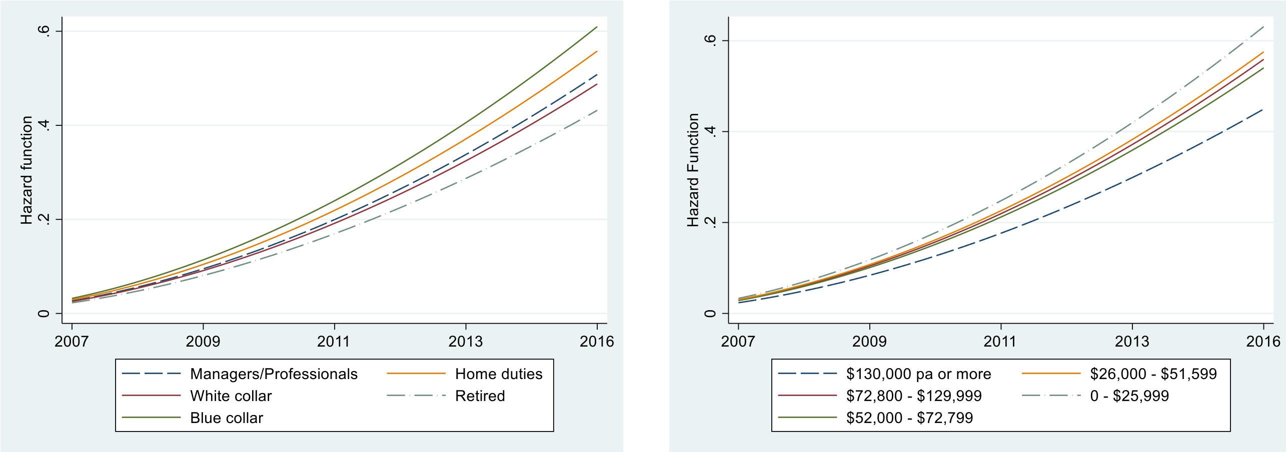


Figure 2 Hazard functions of neighbourhood disadvantage, education, occupation and household income adjusted for age and sex

Table 4 presents the coefficients of direct effects. The direct effect of neighbourhood disadvantage on CVD shows that the probability of being classified with CVD is highest in Q1 neighbourhoods (Coeff.: 0.26, $P<0.05$); while the total Met-min of PA is negatively associated with CVD. Furthermore, residents of more disadvantaged neighbourhoods reportedly engaged in fewer Met-min of total PA.

Table 4 Path coefficient estimates for direct effects[1]

	Coeff.	Std. Err.	95% CI
ND --->CVD [2]			
Q5 (least disadvantaged)	0		
Q4	0.257	0.067	0.126,0.388
Q3	0.224	0.070	0.086,0.363
Q2	0.256	0.076	0.106,0.405
Q1 (Most disadvantaged)	0.268	0.080	0.126,0.388
PA ---> CVD [3]			
PA	-0.0004	0.00008	-.0006, -0.0002
ND ---> PA [4]			
Q5 (least disadvantaged)	0		
Q4	-34.222	5.628	-45.25, -23.19
Q3	-46.712	5.892	-58.26, -35.16
Q2	-69.396	6.168	-81.48, -57.31
Q1 (Most disadvantaged)	-85.150	6.917	-98.70, -71.59

[1]Model adjusted for age, sex, education, occupation, and household income.
[2] ND --->CVD shows the direct effect of neighbourhood disadvantage on CVD
[3] PA ---> CVD shows the direct effect of physical activity on CVD
[4] ND ---> PA denotes the direct effects of neighbourhood disadvantage on PA

Table 5 presents the direct, indirect, total effect and the proportion of the mediated effect (P_M) which is the ratio of indirect effect to the total effect (44) of neighbourhood on CVD. P_M in Table 5 show that 11.3% of the effect of neighbourhood disadvantage on CVD occurs indirectly through PA in the most disadvantaged neighbourhoods while this figure is 5.1% in the more advantaged areas like Q4.

Table 5 Direct, indirect, and total effect of neighbourhood disadvantage on CVD through mediation of physical activity

	Direct effects	*Indirect effects* [2]	*Total effect*	(P_M)[3]
Neighbourhood disadvantage[1]	Coef. (95% CI)	Coef. (95% CI)	Coef. (95% CI)	
Q5 (least disadvantaged)	0	0	0	0
Q4	0.257 (0.126,0.388)	0.014 (0.007,0.021)	0.271 (0.140,0.403)	0.052
Q3	0.224 (0.086,0.363)	0.019 (0.010,0.029)	0.243 (0.105,0.383)	0.078
Q2	0.256 (0.106,0.405)	0.029 (0.016,0.041)	0.284 (0.134,0.434)	0.102
Q1 (Most disadvantaged)	0.268 (0.126,0.388)	0.035 (0.020,0.051)	0.303 (0.146,0.460)	0.115

[1] Neighbourhood disadvantage adjusted for age, sex, education, occupation, and household income.
[2] Indirect effects were calculated by multiplying the direct effects of PA ---> CVD and ND ---> PA from table 4 (e.g. indirect effect for Q4: -34.222*-0.0004=0.014).
[3] $P_M = ab/(c' + ab)$; see figure 1(a) and 1(b).

DISCUSSION

This study contributes to the growing evidence that a neighbourhood's socioeconomic environment plays an important role in the incidence of CVD, independent of individual level socioeconomic factors. Adjustment for a range of confounders only partially explained these associations, suggesting that other underlying behavioural pathways may be involved. A review of the literature showed that higher levels of PA are associated with a lower risk of experiencing heart disease (15), and our findings are consistent with this. A recent study on trajectories of PA (45) suggests that encouraging inactive adults to achieve moderate levels of PA in midlife may lead to long-term survival benefits from CVD.

This study examined the total effect of neighbourhood disadvantage on CVD, and whether PA mediates this relationship. The risk of CVD showed the highest hazard ratio (HR) in the most disadvantaged neighbourhoods (Q1: HR 1.56, 95% CI). The HRs for CVD in Q1 are 1.22 (95% CI 1.01,1.47), 1.42 (95% CI 1.14,1.76), 1.38 (95% CI 1.11,1.72) after adjusting for education occupation and household income, respectively. Our cross-sectional examination at baseline (2007), indicated that neighbourhood environment and individual-level SEP were associated with the likelihood of experiencing CVD, a finding consistent with previous research (7, 46). The longitudinal analysis of residents who did not change address for the duration of the study found that more disadvantaged neighbourhoods may increase the risk of experiencing CVD. For the total effect of neighbourhood disadvantage on CVD, we found that more disadvantaged neighbourhoods are related to higher risk of CVD and less physical activity. These findings suggest that living in less disadvantaged areas may be protective against the development of CVD. The mediation analysis indicated that PA as a mediator was negatively associated with neighbourhood disadvantage ($p<0.001$), while the proportion of mediation effect of fewer Met-min of total PA is highest in the most disadvantaged neighbourhoods ($P_M=11.5\%$).

There are several possible reasons why PA is lower in disadvantaged neighbourhoods. The built environment may be less supportive, and with fewer people physically active, social norms may not be supportive of an active lifestyle. For example, Schultz et. al, (11) have argued that access to safe parks along with social support that encourage engagement in park-based physical activity could positively influence PA in more disadvantaged neighbourhoods. In our previous paper (8), we found that health benefits accrue to residents of disadvantaged neighbourhoods as a result of their higher levels of walking for transport and these might help offset the negative effects of less healthy behaviours (e.g. smoking, poor diet), thus serving to contain or reduce neighbourhood inequalities in chronic disease. The results suggested that pedestrian-friendly disadvantaged neighbourhood were associated with increased walking, suggesting that if we could create more pedestrian-friendly neighbourhoods in disadvantaged areas, we could potentially decrease inequalities. However, the current research goes beyond walking to include other types of moderate and vigorous intensity PA. Multiple interventions are likely to be required to encourage overall PA in disadvantaged neighbourhoods including interventions that enhance social norms in favour of being physically active. Booth et. al. (47) also concluded that identifying predictors of physical activity in older adults, including social support, access to facilities, and neighbourhood safety, can inform the development of policy and intervention strategies to promote PA among this group of people. Nevertheless, Kalache and Kickbusch suggested that different interventions are required to improve physical activity at each life stage (48). A study by Peeters et. al., concluded that interventions that aim to maximise levels of PA at the early life stage may result in long-last benefits; however, later interventions may also be effective (49). Hence, consistent with earlier findings, creating supportive environments would provide a passive intervention that facilitate physically active lifestyles; while policies to prevent cardiovascular disease may need to consider features of residential environments. However, other types of negative exposures in disadvantaged neighbourhoods can complicate these relationships. For example, poor air quality is also associated with CVD risk, so if residents of disadvantaged neighbourhoods are walking/biking for transportation on heavily trafficked roads and therefore exposed to poor air quality, diesel exhaust, etc., this could negatively impact CVD risk (50).

The strengths of our study include the large sample size (n=6,425 at baseline), the longitudinal design with a 9-year follow-up period (five time-points), and the use of the IRSD (a census-based socioeconomic index, which was updated across all waves) as the measure of neighbourhood disadvantage. IRSD is a general socio-economic index that summarises a range of information about the economic and social conditions of people and households within an area. Hence, the methodology in this study can be replicated in other countries by using similar measurements for neighbourhood inequity such as the social vulnerability index (51). The study also examined the mediating role of PA following recent advances in mediation analysis methods. We were able to deal with the clustered nature of the data (stratified cluster sampling: observations within individuals within neighbourhoods) using a multilevel mixed-effect survival model.

An important limitation of this study is the use of self-reported CVD, hence, measurement error may have resulted in biased estimates, although our MAR analysis suggested that this bias was not likely to be large (14). In addition, the use of self-reported heart disease has been extensively used in previous epidemiological studies (24-27), including previous HABITAT research (6). Despite the limitations of using self-report data, notably, the findings from our study are consistent with previous longitudinal studies which used medical records of CVD for the analysis (7, 52-54).

Physical activity was self-reported using questions that asked respondents to estimate the total time they spent walking or doing vigorous or moderate activities in the last seven days. Retrospective accounts of time-based activities are prone to recall error (55) and the extent and direction of error varies by respondent characteristics such as age and socioeconomic status (56). Further, this measure of PA does not differentiate between the purpose of the physical activity undertaken (i.e. for recreation, transport, in the household or occupational). Future research should endeavour to examine the difference domains of physical activity, specifically those likely to be undertaken in the neighbourhood: recreation and transport physical activity. Among the limitations, survey nonresponse in the HABITAT baseline study was 31.5%; it was slightly higher among residents from lower individual socioeconomic backgrounds and those living in more disadvantaged neighbourhoods (57).

CONCLUSION

Our study suggests that some characteristics of disadvantaged neighbourhoods are directly and causally associated with the prevalence and incidence of CVD. Moreover, more deprived neighbourhoods appear to cause residents of these environments to be less physically active which contributes to their increased risk of CVD. Improvement to disadvantaged neighbourhoods may be a potential strategy to enhance population health by encouraging more PA. Further studies are recommended to examine specific environmental attributes that may contribute to the reduction of CVD risk through PA. This includes the role of greenways and vegetative buffers, around pedestrian and bicycle paths, particularly in disadvantaged neighbourhoods, which may help mitigate heat and air-quality issues in places where people may engage more PA. This understanding would help urban planners and policymakers to develop healthier neighbourhoods.

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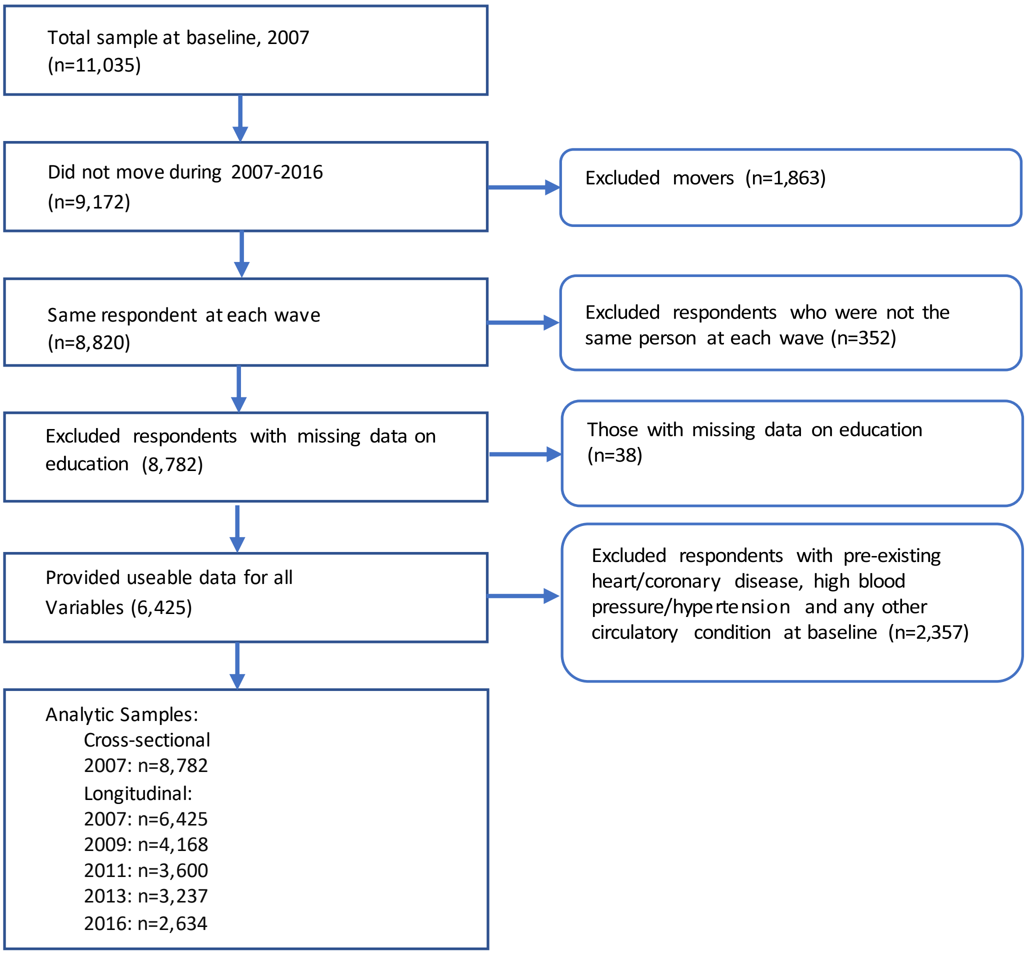
APPENDIX

Appendix A. Analytic sample



APPENDIX B. HABITAT baseline sample profile in 2007 and analytic samples at all waves

	Habitat baseline	Analytic sample				
	2007: n=11,035	**2007: n=6,465**	**2009: n=4,168**	**2011: n=3,600**	**2013: n=3,237**	**2016: n=2,634**
Neighbourhood disadvantage	%	%	%	%	%	%
Q5 (Least disadvantaged)	13.39	12.06	11.52	11.72	12.48	12.34
Q4	18.91	18.55	17.87	17.03	14.74	13.97
Q3	18.63	18.58	19.15	20.31	21.59	19.67
Q2	19.38	19.38	23.54	26.36	26.75	22.78
Q1 (Most disadvantaged)	29.68	31.42	27.93	24.58	24.44	31.25
Highest education attained						
Bachelor's degree or higher	31.46	33.42	34.88	36.58	37.75	40.32
Diploma/Associate diploma	11.54	11.36	11.06	11.19	11.46	12.00
Certificate (trade/business)	17.76	17.95	17.85	17.39	17.64	17.24
None beyond school	39.23	37.28	36.20	34.83	33.15	30.45
Occupation						
Managers & Professionals	33.42	34.93	34.40	35.86	35.46	32.57
White collar	22.05	22.77	21.31	21.06	21.38	17.43
Blue collar	14.32	15.28	13.56	12.56	11.52	9.00
Home duties	5.58	5.71	5.66	5.36	5.10	4.56

Retired	8.53	6.55	9.17	14.31	17.45	28.59
Household income						
$130,000 pa or more	17.12	17.79	20.01	22.89	23.63	23.16
$72,800 - $129,999	25.78	26.77	26.49	25.69	24.28	24.83
$52,000 - $72,799	14.73	14.77	13.36	12.11	12.51	12.41
$26,000 - $51,599	18.13	17.63	16.67	16.17	16.81	16.36
$0 - $25,999	9.46	7.50	8.71	7.58	7.88	8.92