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Associations between physical activity and the neighbourhood social environment: baseline results from the HABITAT multilevel study

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ABSTRACT

Limitations have arisen when measuring associations between the neighbourhood social environment and physical activity, including same-source bias, and the reliability of aggregated neighbourhood-level social environment measures. This study examines cross-sectional associations between the neighbourhood social environment (perceptions of incivilities, crime, and social cohesion) and self-reported physical activity, while accounting for same-source bias and reliability of neighbourhood-level exposure measures, using data from a large population-based clustered sample. This investigation included 11,035 residents aged 40–65 years from 200 neighbourhoods in Brisbane, Australia, in 2007. Respondents self-reported their physical activity and perceptions of the social environment (neighbourhood incivilities, crime and safety, and social cohesion). Models were adjusted for individual-level education, occupation, and household income, and neighbourhood disadvantage. Exposure measures were generated via split clusters and an empirical Bayes estimation procedure. Data were analysed in 2016 using multilevel multinomial logistic regression. Residents of neighbourhoods with the highest incivilities and crime, and lowest social cohesion were reference categories. Individuals were more likely to be in the higher physical activity categories if they were in neighbourhoods with the lowest incivilities and the lowest crime. No associations were found between social cohesion and physical activity. This study provides a basis from which to gain a clearer understanding of the relationship between the neighbourhood social environment and individual physical activity. Further work is required to explore the pathways between perceptions of the neighbourhood social environment and physical activity.

1. Background

Among older populations, physical inactivity has been associated with lower quality of life, and higher rates of morbidity and mortality (Lee et al., 2012; Yen et al., 2009). As physical activity generally declines with age, societies face the challenge of keeping people active as they age (Von Bonsdorff and Rantanen, 2011). Investments in promoting regular physical activity in populations across the life-span can produce returns in the form of greater independence and productivity later in life (Kendig and Browning, 2011). However, evidence is required to develop effective whole-of-government interventions (i.e., coordinated between local councils, state and federal governments) with an integrated approach to the social and community lifestyle of the ageing population (Kendig and Browning, 2011; Loh et al., 2016; Rachele et al., 2016a; Walker and Maltby, 2012).

Recent research on factors associated with physical activity has been informed by social-ecological frameworks that incorporate both environmental and socio-cognitive determinants (Richard et al., 2011). Previous research, including studies undertaken in the Netherlands (Jongeneel-Grimen et al., 2014a), Finland (Halonen et al., 2012) and Australia (Baum et al., 2009; Foster and Giles-Corti, 2008), have found that the environments in which people live may influence their physical activity (Bauman et al., 2012; Kerr et al., 2012; Sallis et al., 2013). Moreover, the social environment, the immediate physical surroundings, social relationships, and cultural milieus within which defined groups of people function and interact (Casper, 2001), play a role in promoting healthy communities (Kawachi et al., 1999), and are likely to influence physical activity levels (Bird et al., 2010; Trost et al., 2002). The social environment can be measured through neighbourhood-level characteristics such as social cohesion (Lochner et al., 1999; Mohnen et al., 2014) and/or crime and safety (Foster and Giles-Corti, 2008). However, recent systematic reviews (Koeneman et al., 2011; Sun et al., 2013; Van Cauwenberg et al., 2011; Wendel-Vos et al., 2007) highlight the limited evidence on the relationship between environmental factors and physical activity.

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Previous studies have observed positive associations between both neighbourhood social capital (the interpersonal trust between residents, norms of reciprocity, sense of community, and social participation (Umberson and Montez, 2010) and social cohesion (the willingness of the residents in a society to cooperate with each other) (Stanley, 2003) and physical activity (Ball et al., 2010; Lindström et al., 2001; Lindstrom et al., 2003; Mummery et al., 2008). Residents of neighbourhoods with high social capital were shown to be more physically active than their counterparts residing in lower social capital neighbourhoods (Mohnen et al., 2012), suggesting that neighbourhoods with, for example, a strong sense of community, might share health-related norms such as walking (Echeverría et al., 2008; Ghani et al., 2016). Moreover, trusting neighbours was associated with an increased likelihood of being physically active in a study of US adults (Addy et al., 2004), and a review of the effects of the neighbourhood environment on physical activity (Foster and Giles-Corti, 2008) noted that increases in perceived safety may be associated with increases in physical activity among vulnerable residents (e.g., women and the elderly).

Limitations have arisen when measuring associations between the neighbourhood social environment and physical activity. First, biases occur when data for both the predictors and outcome are collected from the same individuals. This bias, otherwise known as same-source bias, has the potential to generate a spurious association between the predictors and outcomes, due to either correlations between measurement errors, or because the outcome affects the predictor (Diez Roux, 2007). For example, individuals who are more physically active in their neighbourhoods may perceive lower rates of crime, due to the lack of crime observed during these activities. On the other hand, individuals who are physically inactive may perceive greater rates of crime, despite a lack of neighbourhood observations. It is therefore possible that an individual's perception of crime in the neighbourhood may be influenced by their level of physical activity; meaning that it is unclear whether the association observed in the data (e.g., a negative association between physical activity and crime) is overstated. One promising approach suggested by Diez-Roux (2007) to control for the effects of same-source bias is to separately measure environmental characteristics reported by residents of the same neighbourhoods, but whose responses are not used as outcome measures in subsequent analyses. This can be achieved in large multilevel studies by randomly splitting a clustered sample into groups of 'informants' and 'cases' where the former provide measures of the area-level social environment that are used to assess associations with physical activity among the latter.

The second limitation that has arisen when measuring the neighbourhood social environment in the context of its association with physical activity is the reliability of aggregated neighbourhood-level social environment measures. The use of neighbourhood-level means does not take into account the variability of responses within, or between clusters, or the number of participants within each cluster providing exposure measures (when cluster sizes are unequal). To offset this shortcoming, Savitz and Raudenbush (2009) proposed an empirical Bayes exchangeable (EBE) estimation (or "shrinkage" estimator) method, which can be used with or without spatial dependence, that makes allowances for exposure measure variability both within- and between-clusters (i.e., neighbourhoods), and for the number of informants within each cluster: this approach was shown to be superior when compared with an ordinary least squares estimator (Savitz and Raudenbush, 2009). While this approach has been used in previous studies of the social environment (Rachele et al., 2016b), to the authors' knowledge, it has not been used to examine associations between neighbourhood-level social environment exposures and physical activity.

Given the importance of understanding the relationship between the neighbourhood social environment and physical activity, and the limitations of previous studies that have examined this relationship, further investigation is warranted. This study examines associations between the neighbourhood social environment (perceptions of incivilities, crime, and social cohesion) and self-reported physical activity, using an EBE estimation method with data from a large population-based clustered sample. It is hypothesised that lower levels of incivilities and crime, and higher levels of social cohesion will be associated with higher levels of physical activity.

2. Methods

2.1. Sample design and neighbourhood-level unit of analysis

This study used data from the How Areas in Brisbane Influence healTh And acTivity (HABITAT) project. HABITAT is a multilevel longitudinal (2007–2018) study of mid-aged adults (40–65 years in 2007) living in Brisbane, Australia. The primary aim of HABITAT is to examine patterns of change in physical activity, sedentary behaviour and health over the period 2007–2018 and to assess the relative contributions of environmental, social, psychological and socio-demographic factors to these changes. In this paper, we present findings from the HABITAT baseline survey data which were collected in May 2007. Details about HABITAT's sampling design have been published elsewhere (Burton et al., 2009). Briefly, a multi-stage probability sampling design was used to select a stratified random sample ($n = 200$) of Census Collector's Districts (CCD) (from a total of $n = 1{,}625$) from the Australian Bureau of Statistics (ABS), and from within each CCD, a random sample of people aged 40–65 years ($n = 16{,}127$). A total of 11,035 questionnaires with useable data were returned (response rate of 68.4%). This sample was broadly representative of the Brisbane Population (Turrell et al., 2010). CCDs at baseline contained an average of 203 (SD 81) occupied private dwellings, and are embedded within a larger suburb, hence the area corresponding to, and immediately surrounding, a CCD is likely to have meaning and significance for their residents. For this reason, we hereafter use the term 'neighbourhood' to refer to CCDs. The number of respondents per neighbourhood ranged from 12 to 161, with a mean of 55.18. The HABITAT study was approved by the Human Research Ethics Committee of the Queensland University of Technology (Ref. no. 3967H).

2.2. Physical activity

Physical activity was assessed using the Active Australia Survey (Australian Institute of Health and Welfare, 2003). The Survey measures the frequency of and total time spent during the previous week (i) walking continuously for at least 10 min for recreation, exercise, or to get to and from places, (ii) doing vigorous physical activity "which made you breathe harder or puff and pant", e.g., jogging, cycling, aerobics, and (iii) doing moderate physical activity, e.g., gentle swimming, social tennis, golf (Armstrong et al., 2000). These items are used for the national monitoring of activity (Armstrong et al., 2000), and have acceptable levels of reliability and validity (Brown et al., 2004; Brown et al., 2008). Data were cleaned according to the manual and guidelines for the Active Australia Survey (Australian Institute of Health and Welfare, 2003). To avoid errors due to over-reporting, durations >840 min (14 h) for a single activity type were recoded to 840 min, and missing values were not imputed (Australian Institute of Health and Welfare, 2003). 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. 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. Physical activity was then categorised as 'none' (0 MET·mins/week), 'very low' (1–249), 'low' (250–499), 'moderate' (500–999) and 'high' ≥1000) (Brown et al., 2012) to align with adult physical activity recommendations.

2.3. Neighbourhood-level social environment measures

To assess perceptions of incivilities (rubbish/graffiti), crime and safety, and social cohesion, participants were provided with a number of statements and asked to respond on a five-item Likert scale, ranging from 'strongly disagree' to 'strongly agree'. The items have been shown to have acceptable test-retest reliability (Turrell et al., 2011). Principal components analysis (PCA) with varimax rotation was used to generate a score for each set of items.

Incivilities: two items assessed perceptions of neighbourhood incivilities. Participants were asked about the presence of litter or rubbish, and graffiti. PCA showed that disorder and incivilities loaded onto one 'incivilities' factor.

Perceptions of neighbourhood crime and safety: these were ascertained from six items that asked participants about opinions of the level of crime in

their neighbourhood, and perceptions of their personal safety in parks, on the streets, and using public transport in their area. PCA revealed that six of these items loaded on one 'perceptions of crime and safety' factor, with a Cronbach alpha of 0.80. These measures were adapted for the Australian population from the Neighbourhood Environment Walkability Scale (NEWS) questionnaire (Cerin et al., 2006); which has acceptable validity and reliability for measuring perceived neighbourhood walkability (Cerin et al., 2009).

Social Cohesion: this was measured by a five-item modified version of the Buckner Social Cohesion Scale (Buckner, 1988). Participants were provided with a range of statements about common values, trust and social relationships between themselves and residents of their neighbourhood. PCA showed that all five items loaded onto one 'social cohesion' factor, with a Cronbach alpha of 0.82. These measures have been found to be valid and reliable in previous multilevel studies (Fone et al., 2006).

2.4. Covariates

2.4.1. Neighbourhood disadvantage

Neighbourhood socioeconomic disadvantage was derived using weighted linear regression, using scores from the ABS Index of Relative Socioeconomic Disadvantage (IRSD) (Australia Bureau of Statistics, 2006) from each of the previous six censuses, from 1986 to 2011. The derived socioeconomic scores from each of the HABITAT neighbourhoods were then quantised as percentiles, relative to all of Brisbane. The 200 HABITAT neighbourhoods were then grouped into quintiles with Q1 denoting the 20% most disadvantaged areas relative to the whole of Brisbane and Q5 the least disadvantaged 20%.

2.4.2. Education

Participants were asked to provide information about their highest educational qualification attained. This was subsequently coded as: (1) bachelor degree or higher (including postgraduate diploma, master's degree, or doctorate), (2) diploma (associate or undergraduate), (3) vocational (trade or business certificate or apprenticeship), or (4) no post-school qualifications.

2.4.3. Occupation

Participants who were employed at the time of completing the survey were asked to indicate their job title and then to describe the main tasks or duties they performed. This information was subsequently coded to the Australian Standard Classification of Occupations (ASCO) (Australian Bureau of Statistics, 1997). The original 9-level ASCO classification was recoded into five categories: (1) managers/professionals (managers and administrators, professionals, and paraprofessionals); (2) white-collar employees (clerks, salespersons, and personal service workers); (3) blue-collar employees (tradespersons, plant and machine operators and drivers, and labourers and related workers); (4) home duties; (5) retired; or (6) not easily classifiable (not employed, students, permanently unable to work or other).

2.4.4. Household income

Participants were asked to estimate their total pre-tax annual household income using a single question comprising 13 income categories. For analysis, these were re-coded into six categories: (1) ≥AU$130,000, (2) AU$129,999–72,800; (3) AU$72,799–52,000; (4) AU$51,999–26,000; (5) ≤AU$25,999; or (6) not classified (i.e. left the income question blank ($n = 214$), ticked 'Don't know' or 'Don't want to answer this').

2.5. Statistical analyses

Of the 11,035 returned questionnaires, n = 613 participants were excluded from analyses, due to incomplete data for physical activity, perceptions of incivilities, crime and social cohesion and education. A sub-sample of participants ('informants') was used to generate measures of the social environment characteristics of each area, and a separate sub-sample of participants ('cases') was used to examine whether area-level factors were associated with physical activity. For each of the 200 neighbourhoods, approximately half the respondents were randomly assigned to the 'informant' group by using the random number generator function of Stata ($n = 5232$, 50.2%), and the remaining participants formed the 'cases' group ($n = 5189$, 49.8%). Participant demographics of the analytic sample are presented in Table 1.

An EBE estimate was used for the neighbourhood social environment exposure in this analysis. The benefit of this estimation procedure is that it adjusts estimates of a neighbourhood exposure (borrows strength) based on the number of 'informants' used per neighbourhood, and the variability of the exposure within and between neighbourhoods (Savitz and Raudenbush, 2009). This reduces the risk of misclassification bias of the neighbourhood exposure. This approach has been shown to be an improvement on using a mean aggregated score (Savitz and Raudenbush, 2009), which relies solely on the information from each neighbourhood in estimating that neighbourhood's latent variable, as has been done in previous studies (Ball et al., 2010; Lindström et al., 2001; Lindstrom et al., 2003; Mummery et al., 2008). Spatial dependence was not considered, because the neighbourhoods included in the study were widely dispersed across the Brisbane area (i.e., the neighbourhoods rarely shared a common boundary). The estimates for the 200 HABITAT neighbourhoods were then grouped into quintiles for each neighbourhood social environment exposure with Q1 denoting the 20% ($n = 40$) highest incivilities and crime, and lowest social cohesion, and Q5 the 20% lowest incivilities and crime, and highest social cohesion ($n = 40$).

The analysis was informed by postulated relationships between the neighbourhood social environment and physical activity, adjusted for potential confounders: age, sex, neighbourhood disadvantage, education, occupation and household income. These relationships are depicted in a directed acyclic graph (Fig. 1). To address the aim of the study, multilevel multinomial logistic regression was used with marginal quasi-likelihood iterative generalized least squares as the starting values for Markov chain Monte Carlo (burn in = 500, chain = 50,000). All models used physical activity as an unordered categorical dependent variable (with 'none' as the reference category), and were adjusted for age, sex, education, occupation, household income and neighbourhood disadvantage. Each of the neighbourhood social environment variables was included separately as independent variables of interest (with the most incivilities, the most crime, and least social cohesion as reference groups). Data were prepared in Stata SE version 13 (StataCorp, 2013). All models were completed using MLwiN version 2.30 (Rasbash et al., 2014) in 2016.

Table 1
Socio-demographic characteristics: persons aged 40–65 years in the HABITAT analytic sample.

	Cases ($n = 5189$)	Informants ($n = 5232$)	Total sample ($n = 10.421$)
	n (%)	n (%)	n (%)
Neighbourhood disadvantage			
Q5 (most disadvantaged)	680 (13.1)	692 (13.2)	1372 (13.2)
Q4	1056 (20.4)	1053 (20.1)	2109 (20.2)
Q3	888 (17.1)	877 (16.8)	1765 (16.9)
Q2	1016 (19.6)	1036 (19.8)	2052 (19.7)
Q1 (least disadvantaged)	1549 (29.9)	1574 (30.1)	3123 (30.0)
Sex			
Female	2865 (55.2)	2849 (54.5)	5714 (54.8)
Male	2324 (44.8)	2383 (45.6)	4707 (45.2)
Age			
60–65 years	905 (17.4)	928 (17.7)	1833 (17.6)
55–59 years	948 (18.3)	1045 (20.0)	1993 (19.2)
50–54 years	1139 (22.0)	1065 (20.4)	2204 (21.2)
45–49 years	1134 (21.9)	1148 (21.9)	2282 (21.9)
40–44 years	1063 (20.5)	1046 (20.0)	2109 (20.2)
Education			
No post-school qualification	2004 (38.8)	2045 (39.2)	4049 (39.0)
Certificate	908 (17.6)	940 (18.0)	1848 (17.8)
Diploma/associate degree	611 (11.8)	585 (11.23)	1196 (11.5)
Bachelor degree or higher	1648 (31.9)	1641 (31.5)	3289 (31.7)
Occupation			
Retired	434 (8.4)	447 (8.5)	881 (8.5)
Home duties	278 (5.4)	602 (5.8)	580 (5.6)
Blue collar	742 (14.3)	753 (14.4)	1495 (14.4)
White collar	1149 (22.1)	1162 (22.2)	2311 (22.2)
Professional	1763 (34.0)	1761 (33.7)	3524 (33.8)
Not easily classifiable	823 (15.9)	807 (15.4)	1630 (15.6)
Income			
Less than $25,999	478 (9.2)	479 (9.2)	957 (9.2)
$26,000–51,599	924 (17.8)	991 (18.4)	1885 (18.1)
$52,000–72,799	776 (15.0)	776 (14.8)	1552 (14.9)
$72,800–129,999	1354 (26.1)	1351 (25.8)	2705 (26.0)
$130,000 +	919 (17.7)	900 (17.2)	1819 (17.5)
Not classified	738 (14.2)	765 (14.6)	1503 (14.4)

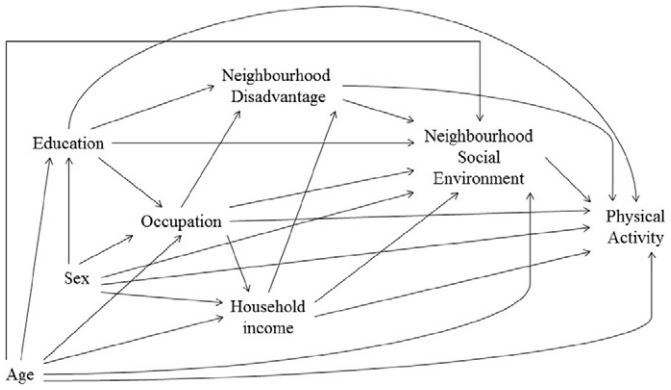

Fig. 1. Directed acyclic graph conceptualising the relationships between neighbourhood disadvantage, the neighbourhood social environment, individual-level socioeconomic characteristics and physical activity.

3. Results

Descriptive statistics for individual and neighbourhood-level socioeconomic measures and physical activity are presented in Table 2. 'High' was the most frequently (39.4%) reported level of physical activity, ranging from 33.5% (individuals residing in Q4 disadvantaged neighbourhoods, where Q5 is the most disadvantaged) to 51.5% (household income greater than $130,000). Very low was the least frequently reported level of physical activity (13.9%), ranging from 9.3% (household income greater than $130,000) to 18.1% (household income less than $25,999).

4. Discussion

This study revealed negative associations between neighbourhood-level perceptions of incivilities and crime, and self-reported physical activity. These findings support our hypothesis that residents of neighbourhoods with lower perceived levels of incivilities and crime are more likely to report higher levels of physical activity. However, we did not find evidence of associations between perceived levels of social cohesion and physical activity.

The study findings are inconsistent with previous research on incivilities and physical activity. Neighbourhood incivilities influence perceptions of neighbourhood quality, and may impact on residents' health behaviours. The presence of incivilities in the neighbourhood may create unappealing settings, which may then discourage physical activities undertaken in the neighbourhood (Ross and Mirowsky, 2001). A previous multilevel study of women in Melbourne, Australia

Table 2
Frequencies of physical activity by individual-level socioeconomic characteristics and neighbourhood disadvantage: persons aged 40–65 years in the HABITAT analytic cases sample ($n = 5098$).

	Physical activity					
	None N (%)	Very low N (%)	Low N (%)	Moderate N (%)	High N (%)	Total N (%)
Total	721 (14.1)	170 (13.9)	722 (14.2)	909 (17.8)	2036 (39.4)	5098
Age						
40–44 years	116 (11.5)	154 (14.8)	149 (14.3)	199 (19.1)	422 (40.6)	1040 (20.4)
45–49 years	175 (15.9)	134 (12.2)	147 (13.3)	194 (17.6)	452 (41.0)	1102 (21.6)
50–54 years	159 (14.7)	144 (13.3)	159 (14.7)	186 (17.1)	437 (40.3)	1085 (21.3)
55–59 years	133 (13.9)	138 (14.4)	142 (14.9)	160 (16.7)	383 (40.1)	956 (18.8)
60–65 years	138 (15.1)	140 (15.3)	125 (13.6)	170 (18.5)	342 (37.4)	915 (18.0)
Sex						
Male	313 (13.7)	323 (14.2)	274 (12.0)	387 (17.0)	986 (43.2)	2283 (44.8)
Female	408 (14.5)	387 (13.8)	448 (15.9)	522 (18.5)	1050 (37.3)	2815 (55.2)
Education						
Bachelors +	137 (8.6)	195 (12.3)	233 (14.7)	315 (19.8)	708 (44.6)	1588 (38.8)
Diploma/Assoc Deg	64 (10.6)	74 (12.2)	79 (13.0)	121 (20.0)	268 (44.2)	606 (18.2)
Certificate (trade/Business)	130 (14.0)	150 (16.2)	123 (13.3)	153 (16.5)	371 (40.0)	987 (11.9)
None beyond school	390 (19.7)	291 (14.7)	287 (14.5)	320 (16.2)	689 (34.9)	1977 (31.2)
Occupation						
Mgr/prof	163 (9.5)	209 (12.2)	255 (14.9)	335 (19.6)	747 (43.7)	1709 (33.5)
White collar	180 (15.4)	166 (14.2)	197 (16.9)	200 (17.2)	423 (36.3)	1166 (22.9)
Blue collar	156 (21.9)	116 (16.3)	67 (9.4)	101 (14.2)	273 (38.3)	713 (14.0)
Home duties	42 (14.7)	39 (13.6)	35 (12.2)	48 (16.8)	122 (42.7)	286 (5.6)
Retired	55 (12.8)	56 (13.1)	58 (13.5)	86 (20.1)	174 (40.6)	429 (8.4)
Missing/NEC	125 (15.7)	124 (15.6)	110 (13.8)	139 (17.5)	297 (37.4)	795 (15.6)
Household income						
$130,000 +	79 (8.8)	83 (9.3)	98 (10.9)	174 (19.4)	462 (51.6)	896 (17.6)
$72,800–129,999	168 (12.8)	164 (12.5)	229 (17.4)	236 (18.0)	517 (39.4)	1314 (25.8)
$52,000–72,799	125 (16.1)	132 (17.0)	109 (14.1)	131 (16.9)	279 (36.0)	776 (15.2)
$26,000–51,599	164 (17.2)	152 (15.9)	119 (12.5)	167 (17.5)	354 (37.0)	956 (18.8)
Less than $25,999	69 (15.3)	82 (18.1)	61 (13.5)	80 (17.7)	160 (35.4)	452 (8.9)
Missing	116 (16.5)	97 (13.8)	106 (15.1)	121 (17.2)	264 (37.5)	704 (13.8)
Neighbourhood disadvantage						
Q1 (least disadvantaged)	173 (11.5)	194 (12.9)	199 (13.2)	255 (16.9)	689 (45.6)	1510 (29.6)
Q2	133 (12.9)	127 (12.3)	172 (16.7)	191 (18.5)	407 (39.5)	1030 (20.2)
Q3	87 (10.3)	121 (14.3)	117 (13.8)	164 (19.4)	357 (42.2)	846 (16.6)
Q4	182 (17.6)	166 (16.1)	143 (13.9)	195 (18.9)	346 (33.5)	1032 (20.2)
Q5 (most disadvantaged)	146 (21.5)	102 (15.0)	91 (13.4)	104 (15.3)	237 (34.9)	680 (13.3)

Associations between the self-reported neighbourhood social environment (informant sample), and physical activity (cases sample) are presented in Table 3.

Table 3
Odds ratios (and 95% credible intervals) for participants in each physical activity category being in each social environment quintile.

Physical activity					
Social environment	None	Very low OR (95% CrI)	Low OR (95% CrI)	Moderate OR (95% CrI)	High OR (95% CrI)
Incivilities					
Q1 (most)	1.00	1.00	1.00	1.00	1.00
Q2	1.00	1.25 (0.78, 1.97)	1.17 (0.82, 1.68)	1.16 (0.82, 1.67)	1.09 (0.81, 1.51)
Q3	1.00	1.27 (0.80, 2.03)	1.07 (0.68, 1.67)	1.26 (0.82, 1.98)	1.29 (0.89, 1.92)
Q4	1.00	0.93 (0.64, 1.38)	1.07 (0.68, 1.66)	1.49 (0.99, 2.28)	1.34 (0.93, 1.95)
Q5 (least)	1.00	1.68 (0.99, 2.87)	1.43 (0.83, 2.43)	2.45 (1.50, 4.40)	2.29 (1.45, 3.59)
Crime					
Q1 (most)	1.00	1.00	1.00	1.00	1.00
Q2	1.00	1.35 (0.90, 2.01)	0.98 (0.65, 1.46)	1.13 (0.77, 1.66)	1.26 (0.90, 1.78)
Q3	1.00	1.52 (0.96, 2.40)	1.19 (0.75, 1.86)	1.31 (0.85, 2.00)	1.45 (0.98, 2.12)
Q4	1.00	1.67 (1.04, 2.65)	1.17 (0.73, 1.84)	1.24 (0.80, 1.92)	1.45 (0.97, 2.16)
Q5 (least)	1.00	2.18 (1.25, 3.76)	1.53 (0.86, 2.63)	1.61 (0.95, 2.72)	2.19 (1.34, 3.49)
Social cohesion					
Q1 (least)	1.00	1.00	1.00	1.00	1.00
Q2	1.00	1.03 (0.73, 1.46)	0.99 (0.68, 1.44)	1.01 (0.71, 1.40)	1.04 (0.77, 1.41)
Q3	1.00	1.00 (0.69, 1.45)	1.09 (0.73, 1.60)	0.93 (0.64, 1.34)	1.29 (0.93, 1.78)
Q4	1.00	1.02 (0.69, 1.48)	1.27 (0.85, 1.86)	1.09 (0.76, 1.56)	1.12 (0.80, 1.55)
Q5 (most)	1.00	1.22 (0.83, 1.81)	0.95 (0.62, 1.42)	1.03 (0.69, 1.50)	1.16 (0.83, 1.61)

Model adjusted for age, sex, education, occupation, household income and neighbourhood disadvantage.
Incivilities: residents of neighbourhoods with the least incivilities (Q5) were more likely to be in the moderate and high physical activity categories.
Crime: those residing in and Q5 (least crime) were more likely to be in the very low and high physical activity categories, and Q4 in the very low physical activity category.
Social cohesion: No significant associations existed for between neighbourhood-level social cohesion and physical activity.

reported that police-recorded incivilities were not associated with physical activity, although it showed some trends in the expected direction (Ball et al., 2010). Another study (Heinrich et al., 2007) among men and women residing in low-income neighbourhoods also reported that trainee recorded incivilities were not associated with vigorous physical activity. Further, a study examining how peer social support mediates the relationship between neighbourhood disadvantage, incivilities, crime and physical activity among minority African American and Hispanic Latina women also found no association (Soltero et al., 2015). However, these studies used different measures of incivilities (Ball et al., 2010), had smaller samples (Heinrich et al., 2007; Soltero et al., 2015) and fewer neighbourhoods (Heinrich et al., 2007) than in this study, which would have limited the statistical power to detect an effect.

Similarly, studies examining neighbourhood perceptions of crime and safety and physical activity have found mixed results. Some studies (Li et al., 2005; Piro et al., 2006; Wilcox et al., 2003) report a negative association between perceived crime and leisure-time physical activity, while others found no association (Booth et al., 2000; Lim and Taylor, 2005). However, several issues have arisen among studies examining the relationship between perceptions of crime and physical activity. First, certain populations who may be less physically active, such as women and older adults, may feel more vulnerable to crime than men and younger adults, and this may have confounded the relationship (or acted as an effect modifier) between crime and physical activity. Second, the measurement of crime used in these studies does not explicitly capture the sources of insecurity (i.e., the reasons why an individual might feel "unsafe" walking in their neighbourhood at night), and has been criticised for overestimating concerns about crime that respondents may rarely encounter, but nonetheless feel apprehensive about (Ball et al., 2007; Booth et al., 2000; Ferraro and Grange, 1987).

The findings from this study for social cohesion and physical activity were not consistent with previous studies in this field, which found associations between neighbourhood level social capital and social cohesion and increased physical activity levels (Addy et al., 2004; Echeverría et al., 2008; Mohnen et al., 2012). However, each of these studies used different instruments to measure social cohesion. It has been suggested that social cohesion is difficult to measure, and therefore it might be more susceptible to measurement error than other neighbourhood predictors (Echeverría et al., 2008), such as neighbourhood incivilities, for which we found an effect.

'Social cohesion' and 'crime and safety' are two domains of urban liveability likely to contribute to health and wellbeing through the social determinants of health (Badland et al., 2014). Some studies (Baum et al., 2009; Kawachi et al., 1999) note that levels of social cohesion/social capital are associated with perceived and actual crime in neighbourhoods, and these factors are correlated with neighbourhood disadvantage. Although the data are cross-sectional, the present study indicates that policies aimed at improving the social environment of neighbourhoods in Brisbane (particularly in relation to perception of crime and incivilities), may increase the physical activity levels of its residents. While the Brisbane City Plan 2014 (Brisbane City Council, 2014) acknowledges that urban development should be 'designed to minimise environmental risks, contribute to crime prevention and promote active travel and recreation', there is a knowledge translation gap on how these social environment measures and their indicators should guide urban policy and practice (Badland et al., 2014) which should be explored in future studies. For instance, it is currently unclear which specific built environment characteristics support a safe and healthy neighbourhood. Additionally, further research should investigate those population subgroups that are likely to be more sensitive to their environment in terms of physical activity outcomes, including women and the elderly.

Several factors may limit the generalizability of this study's findings. First, survey non-response in the HABITAT baseline study was 31.5%, and slightly higher among residents with lower individual socioeconomic profiles, and living in more disadvantaged neighbourhoods. However, the study sample has been shown to be representative of the Brisbane population at 40–65 years of age (Turrell et al., 2010). Further to this point, it should be noted that the measures of the neighbourhood social environment are only as perceived by the mid-to-older adult population, and should not be interpreted as perceived by the general population. Another limitation is that there may be confounding by unobserved individual and neighbourhood-level factors, or bias from the misclassification of self-reported responses. One of the strengths of this study was the method used to remove the potential

of reverse causation. For example, neighbourhoods might also generate social capital as result of residents being active and regular users of public spaces (Mohnen et al., 2012). By randomly splitting clusters and using a separate sample to obtain measurements of the social environment, we are effectively de-linking the outcome from its predictors, and therefore eliminating same-source bias. This is a strength of the current study. However, we are not claiming causality from the results of this cross-sectional study. Prospective studies of changes in the neighbourhood social environment and physical activity over time would, and intervention studies, would assist in making stronger causal assertions. Examples include multilevel longitudinal observational studies of residents who remain in the same neighbourhood, as well as those who move; in addition to studies that attempt to intervene, resulting in changes to the neighbourhood social environment. Another strength was the use of the EBE approach as described by Savitz and Raudenbush (2009) to obtain more accurate measures of the neighbourhood social environment. To our knowledge, this is the first time this approach has been used in this context. This approach has the advantage of taking into account the number of 'informants' used per neighbourhood, and the variability of the exposure within and between neighbourhoods (Savitz and Raudenbush, 2009); rather than solely using a mean aggregated score, as has been done in previous studies (Ball et al., 2010; Lindström et al., 2001; Lindstrom et al., 2003; Mummery et al., 2008). However, it is worth noting that the EBE approach did not substantially change the social environment classification of neighbourhoods, and that a mean aggregated measure did produced similar findings. Notwithstanding, this does not mean that the EBE approach was not an advancement on estimating neighbourhood-level social environment exposure, as was demonstrated by Savitz and Raudenbush (2009).

The present study documents associations between the neighbourhood social environment (perceptions of incivilities and crime and safety), with physical activity, using a best-practice approach to generating unbiased social environment measures. Future research should be directed at why these associations exist; such as whether there are actually higher rates of incivilities and crime in these neighbourhoods. Future research should also seek to establish the factors that underpin the relationship. This may require longitudinal cohort studies to examine how changes to the social environment are related to changes in physical activity. Future studies should also endeavour to use more objective measures of the neighbourhood social environment (such as an audit), and movement-detection instruments (e.g., accelerometers) to measure individual levels of physical activity.

Conflict of interest

The authors declare there is no conflict of interest.

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