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"Can we walk?" Environmental supports for physical activity in India

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ABSTRACT

India is currently facing a non-communicable disease epidemic. Physical activity (PA) is a preventative factor for non-communicable diseases. Understanding the role of the built environment (BE) to facilitate or constrain PA is essential for public health interventions to increase population PA. The objective of this study was to understand BEs associations with PA occurring in two major life domains or life areas—travel and leisure—in urban India. Between December 2014 and April 2015, in-person surveys were conducted with participants ($N = 370$; female = 47.2%) in Chennai, India. Perceived BE characteristics regarding residential density, land use mix-diversity, land use mix-access, street connectivity, infrastructure for walking and bicycling, aesthetics, traffic safety, and safety from crime were measured using the adapted Neighborhood Environment Walkability Scale-India (NEWS-India). Self-reported PA was measured the International Physical Activity Questionnaire. High residential density was associated with greater odds of travel PA (aOR = 1.9, 95% CI = 1.2, 3.2). Land use mix-diversity was positively related to travel PA (aOR = 2.1, 95%CI = 1.2, 3.6), but not associated with leisure or total PA. The aggregate NEWS-India score predicted a two-fold increase in odds of travel PA (aOR = 1.9, 95% CI = 1.1, 3.1) and a 40% decrease in odds of leisure PA (aOR = 0.6, 95% CI = 0.4, 1.0). However, the association of the aggregated score with leisure PA was not significant. Results suggest that relationships between BE and PA in low-and-middle income countries may be context-specific, and may differ markedly from higher income countries. Findings have public health implications for India suggesting that caution should be taken when translating evidence across countries.

1. Introduction

Rapid rates of increase of chronic and co-morbid non-communicable diseases (NCDs) (e.g., diabetes, obesity, cardiovascular disease, and some cancers) have been documented worldwide, with disproportionately higher rates in low-and middle-income countries (LMICs) that are collectively home to 80% of the world's population (Ebrahim et al., 2013; Islam et al., 2014; Terzic & Waldman, 2011; Mathers & Loncar, 2006; Beaglehole & Yach, 2003; Upadhyay, 2012). India, an LMIC and the second most populous country in the world with over 1.25 billion people is experiencing a NCD epidemic (Bloom et al., 2014; Joshi et al., 2006). Three NCDs—diabetes, cardiovascular disease, and obesity—collectively exert a considerable burden on India's population (Joshi et al., 2006; Pradeepa & Mohan, 2002; Pearson, 1999; Millett et al., 2013; Sugathan et al., 2008; Swaminathan & Vaz, 2013; Swaminathan et al., 2013). India has the world's second largest number of people living with diabetes (69 million in 2015), next to China (International Diabetes Federation, 2009; Kumar et al., 2013; Joshi & Parikh, 2007; World Health Organization, 2011a). Cardiovascular disease is the leading cause of death and disability in India with current projections suggesting that India will have the world's largest cardiovascular disease burden by 2020 (Pearson, 1999; Joshi et al., 2007; Rastogi et al., 2004; Patel et al., 2011). India is the third most obese country in the world with one in every five Indian men and women either obese or overweight (Ng et al., 2014; Woodcock et al., 2007). The total economic loss due to NCDs in India is expected to be $4.58 trillion between 2012 and 2030, about two and a half times India's gross domestic product (Bloom et al., 2014). Overall, NCDs currently account for 53% of the total deaths and 44% of disability adjusted life years lost in India, with projections indicating a further increase to 67% of total deaths by 2030 (Upadhyay, 2012). Despite such alarming statistics, there is minimal research examining the rising prevalence and risk factors causing NCDs in the general population of India.

Numerous studies have documented the preventive role of regular physical activity (PA) in the prevention and control of NCDs (Adlakha et al., 2014a; Guthold et al., 2008; Hallal et al., 2012; Milton et al.,

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2014a). Scientific guidelines issued by various international organizations such as the United Nations and the World Health Organization have recommended increasing PA as a key strategy for reducing the impact of NCDs (World Health Organization, 2012; World Health Organization, 2000; World Health Organization, 2011b; United Nations Organization, 2011). At the 2011 United Nations High-level Meeting on NCDs, increasing PA was identified as one of five priority intervention areas, with modification of the built environment (BE) to support PA as a key focus area (Beaglehole et al., 2011). A few studies conducted in different settings in various parts of India point to generally low levels of regular PA, however there has been no comprehensive assessment of BE impacts on PA levels in India (Ebrahim et al., 2013; Millett et al., 2013; Swaminathan et al., 2011; Ebrahim et al., 2010).

Mounting evidence suggests that the BE can facilitate or constrain PA (Sallis et al., 2016; Sallis et al., 2008; Saelens et al., 2003a; Papas et al., 2007; Sallis & Glanz, 2006; Hipp et al., 2013a; Adlakha et al., 2014b; Brownson et al., 2009; Brownson et al., 2006; Committee on physical activity; health; transportation; and land use, 2005; Sallis et al., 2009a; Kerr et al., 2016; Frank et al., 2003; Frank, 2000). The presence of sidewalks, crosswalks, bicycle lanes, and public transportation has been linked to active travel (Millett et al., 2013; Adlakha et al., 2014a; Hipp et al., 2013a; Gordon-Larsen et al., 2005). Studies have consistently found associations between mixed land-use neighborhoods, reduced motor vehicle use, increases in walking, bicycling, and transit use, and a lower likelihood of obesity among residents (Adlakha et al., 2014a; Frank et al., 2003; Handy et al., 2002; Badland et al., 2008; Yang et al., 2015; Sallis et al., 2012). However, studies examining PA and BE associations thus far have been primarily limited to North America, Europe, Australia, and South America (Bassett et al., 2008; Bauman et al., 2013; Becerra et al., 2013). Findings from these studies may not generalize to other parts of the world, particularly LMICs like India where populations face a higher NCD risk (Hallal et al., 2012; Milton et al., 2014a; Prentice, 2006). The BE in India has distinct patterns of urbanization, density, and land-use, which are different from those observed in developed and developing countries (Datta, 2006; Vishwanath et al., 2013).

To date, there is limited empirical research examining BE and PA relationships in India (Ranasinghe et al., 2013). This study probes the question of how the BE, including density, land-use mix, walking infrastructure, pedestrian safety, and crime influence PA behaviors in India. The objective of this study was to examine relationships between neighborhood walkability, BE variables, and domain-specific (travel, leisure) and total PA in India.

2. Methods

The methodology used in this study is based on the recommendations of the International Physical activity and the Environment Network (IPEN; www.ipenproject.org), an organization that has established common methods and measures for worldwide research on the BE and PA (Kerr et al., 2013). Study procedures were approved by the Institutional Review Board of Washington University in St. Louis.

2.1. Study setting

Participants were recruited from the metropolitan area (164.48 sq. miles) of Chennai city, capital of the state of Tamil Nadu in southern India (Vēṅkaṭācalapati & Aravindan, 2006; Hancock, 2008). It is the fourth most populous city (8.9 million residents) in India and the 31st most populous city in the world (Ministry of Home Affairs, 2013). For administrative purposes, the Chennai metropolitan area is divided into 155 smaller subdivisions called wards. Wards are the smallest geographic areas for which the Census Bureau of India publishes demographic information and are comparable to US census tracts. Due to the lack of consensus on what constitutes a neighborhood (Foster & Hipp, 2011), wards were used as the primary definition and unit for sampling purposes.

2.2. Sampling and recruitment

Study participants were selected from neighborhoods stratified to maximize variance in neighborhood walkability and socio-economic status (SES). This type of stratification by SES was used to enhance the representativeness of the sample because low-SES populations tend to be underrepresented in studies of this nature (Turrell, 2000; Cerin et al., 2009). The goal of this study design was to select participants from wards stratified into four quadrants that represent the following criteria: high-walkable/high-SES (37 wards), high-walkable/low-SES (45 wards), low-walkable/high-SES (36 wards), and low-walkable/low-SES (37 wards). Within each quadrant, two wards were randomly selected for participant recruitment. Details of neighborhood stratification, sampling, recruitment, and survey properties have been discussed in detail elsewhere and will be briefly described (Adlakha et al., 2016).

Participants were recruited using purposive sampling. The principal investigator contacted local city government departments, non-profit organizations, neighborhood associations, resident welfare groups, and other local community organizations to create awareness about the study. These relationships were used to establish contact with a small pool of residents in selected neighborhoods and facilitate the recruitment process. These residents, through their social networks, suggested other residents who were interested in participating in the study.

Inclusion and exclusion criteria for participants were based on IPEN protocol and studies conducted in Africa,(Oyeyemi et al., 2016; Oyeyemi et al., 2013) Brazil,(Parra et al., 2011) and China (Cerin et al., 2010). Eligibility criteria included: (i) current residents of the Chennai metropolitan area; (ii) residents for at least 6 months; (iii) 18–65 years of age; (iv) being able and willing to answer questions in English or Tamil (official language in the study region); (v) not having any disability that prevented independent walking; and (vi) no visible signs of cognitive impairment. One individual per household was recruited to ensure independence of observations. In order to ensure selection of a diverse sample, effort was made to recruit residents from different neighborhoods across the Chennai metropolitan area that matched the walkability and SES selection.

The principal investigator made initial contact with participants to provide introductory information about the study, explain study procedures, and obtain informed consent. Participants were contacted either in-person, via telephone or email. Bilingual Research Assistants were hired and trained for survey administration. Data collection occurred between December 2014 and April 2015.

A moderate-to-large effect size (effect size statistic [d] = 0.75) which is greater than what has been used in previous IPEN studies in LMIC contexts was used for sample size estimation (Oyeyemi et al., 2013; Saelens et al., 2003b). Calculations determined that 73 participants from each of the four stratified neighborhood quadrants were needed to detect a moderate-to-large effect size with >80% power (Cohen, 1988). Recruitment continued until at least 75 individuals from each quadrant had completed the surveys.

2.3. Measures and scoring procedures

Built Environment Assessment: The survey instrument for this phase was adapted from the Neighborhood Environment Walkability Scale (NEWS) that has been used widely by IPEN (Cerin et al., 2009; Cerin et al., 2006; Saelens et al., 2003c; Cerin et al., 2013). The adaptation of NEWS-India and results from test-retest reliability are published in an earlier study (Adlakha et al., 2016). Intra-class correlation coefficients of all NEWS-India subscales were higher than 0.75, indicating excellent reliability (Adlakha et al., 2016). The adapted NEWS-India consists of 91 items that assessed the following perceived environmental characteristics: a) residential density (7 items), b) land use mix-diversity (43 items), c) land use mix-access (7 items), d) street connectivity (5 items), e) infrastructure and safety for walking and bicycling (13 items), f) aesthetics (6 items), g) traffic safety (6 items), and h) safety from crime (4 items). Residential density items asked about the frequency of various types of neighborhood residences, including slums or squatter settlements, independent homes, and apartments between 1 and 20-story or higher apartments with a response range of 1 (none) to 5 (all). Residential density items were weighted relative to the average density of single-family homes (e.g., 7- to 12-story apartments were considered to be 50 times more dense than single-family homes), The weighted values were summed to create the residential density subscale score. Land use mix–diversity was assessed by the walking proximity from home to various types of stores and amenities, with responses ranging from 1- to 5-min walking distance (coded as 5) to ≥30-min walking distance (coded as 1). A higher score on the land use mix–diversity indicated closer average proximity. With the exception of the residential density subscale, all subscale scores were calculated as the mean across the subscale items. Sample items from the NEWS-India scale have been published previously (Adlakha et al., 2016).

Physical Activity Assessment: The International Physical Activity Questionnaire-Long Form (IPAQ-LF; IPAQ, 2002) was used to collect participants' leisure and travel PA. The IPAQ-LF is a self-report measure of PA that captures the frequency and duration of walking, moderate-intensity, and vigorous-intensity PA. Modules from IPAQ-LF to assess leisure-time and travel PA were used in this study. WHO guidelines recommend that adults aged 18–64 should do at least 150 min of moderate-intensity aerobic PA throughout the week to incur health benefits. In the context of daily, family, and community activities, this can include PA during leisure time activity (e.g., walking, dancing, gardening, hiking, swimming) or transportation (e.g., walking or bicycling) (World Health Organization, 2010). The reliability (Spearman's rho clustered ~0.8) and criterion validity (median rho ~0.3) of IPAQ-LF has been tested internationally with results comparable to other self-reported validation studies (Craig et al., 2003).

The adapted NEWS-India and modules of IPAQ-LF[78] were administered to residents of selected Chennai neighborhoods between December 2014 and April 2015. Information on age, gender, marital status, religion, income (SES), educational level, and employment status were elicited from the participants using scales validated for Indian contexts (Gururaj, 2014; Bairwa et al., 2013).

3. Data analysis

Data was analyzed using the Statistical Package for the Social Sciences (SPSS) version 21. NEWS item scoring and subscale score calculations followed the NEWS-Adult scoring scheme recommended by the IPEN study protocol. [52, 53, 139] Four-point Likert-type scale response options for all NEWS-India items ranging from 1 (strongly agree) to 4 (strongly disagree) were combined as “agree” (strongly agree, agree) and “disagree” (disagree, strongly disagree). All NEWS-India items were positively scored to ensure that a higher score denotes a more walkable/activity-friendly neighborhood.

A series of multiple logistic regressions were used to identify BE predictors of meeting WHO-recommended levels (≥ 150 min/week of moderate-intensity PA)(World Health Organization, 2010) for travel, leisure, and total PA (dichotomous outcomes). Unadjusted and adjusted odds ratios were calculated for neighborhood SES strata (low, high) and the pooled sample. The covariates were chosen to control for the potential confounding effects of variables (age, gender) shown important in studies other countries (Kerr et al., 2016; Kerr et al., 2013; Cerin et al., 2013).

4. Results

Socio-demographic characteristics of participants ($N = 370$) are presented in Table 1. The mean age of the sample was 37.9 years. The majority of participants were women (54.2%), married (61.2%), employed (62.5%), with a graduate or professional degree (49.7%). 48.2% of participants reported earning <600 US Dollars (approximately 36,017 Indian rupees) per month.

4.1. Meeting/not-meeting WHO guidelines for physical activity

Descriptive statistics of sample population meeting and not meeting WHO recommended guidelines for leisure, travel, and total PA are presented in Table 2. Among residents that were meeting WHO recommended levels of weekly PA from travel movement, the majority ($N = 30$, 44.8%,) belonged to the high-walkability/low-SES neighborhood, Lowest levels of active transportation were observed in the high-walkability/high-SES neighborhood with 4.9% ($N = 6$) of residents meeting weekly PA recommendations from travel-related activities.

Higher percentage of leisure-PA was reported in the high walkability/high-SES neighborhood where 50.8% ($N = 62$) of residents achieved weekly PA recommendations from leisure activities. Overall, a higher number of participants in the low-SES neighborhoods met WHO recommended guidelines for PA through travel-related activities. The highest percentage of residents (65.8%, $N = 48$) meeting weekly recommendations for total PA were in the low walkability/high-SES neighborhood. The highest percentage of residents (49.3%, $N = 33$) not meeting weekly PA guidelines belong to the low-walkability/low-SES neighborhood. In comparing high-SES neighborhoods stratified by walkability (high, low), there were significant differences in the proportion of those meeting WHO recommended levels of travel PA and total PA. No differences were observed in proportion of those meeting leisure or total PA recommended levels. In low-SES neighborhoods stratified by walkability, no differences were observed between proportion of residents meeting WHO recommended levels of leisure, travel, and total PA.

4.2. Logistic regression models

Crude and adjusted odds ratios examining associations between NEWS subscale scores and meeting WHO-recommended levels of leisure, travel, and total PA across low and high-SES neighborhoods are presented in Tables 3 and 4 respectively. In low-SES neighborhoods, land use mix-diversity and aesthetics were the only BE predictors that were significantly related to leisure PA. Residents living in low-SES neighborhoods with greater diversity of land use had 2.7 times the odds of engaging in leisure PA (aOR = 2.7, CI = 1.1, 6.5). Residents in low-SES neighborhoods with aesthetic qualities had approximately 5 times the odds of engaging in leisure PA (aOR = 5.2, CI = 1.7, 15.5). No BE predictors were significantly related to travel PA, except for aesthetics which had a negative association. Adjusted odds of travel PA improved with street connectivity and safety from crime, but these associations were not significant. There were no significant associations between BE predictors and total PA, but the overall adjusted odds were in the positive direction. Land-use mix diversity and aesthetics were the only BE factors negatively associated with total PA.

Table 4 shows BE predictors of PA in high-SES neighborhoods. There was a three-fold increase in adjusted odds of travel PA with infrastructure for walking/bicycling (aOR = 3.4, CI = 1.2, 9.3) and safety from traffic (aOR = 2.9, CI = 1.2, 7.2). Street connectivity significantly reduced adjusted odds of travel PA by 70% (aOR = 0.3, CI = 0.1, 0.8). Street connectivity also improved adjusted odds of leisure PA by two times (aOR = 2.4, CI = 0.9, 6.7), but this association was not statistically significant. Infrastructure for walking/bicycling was associated with a 60% reduction in odds of leisure PA (aOR = 0.4, CI = 0.2, 1.0). No BE predictors were significantly related to the adjusted odds of total PA.

Table 5 shows pooled analysis of BE predictors of meeting WHO-recommended levels of leisure, travel, and total PA across all neighborhoods. Five of eight BE characteristics (residential density, land use mix diversity, street connectivity, aesthetics, safety from crime) were significantly associated with travel PA. Among these, residential density

Table 1
Descriptive characteristics of the sample population ($N = 370$).

Descriptive characteristics	Neighborhood quadrants				Full sample N = 370
	1	2	3	4	
	High walkability high SES $n = 122$	Low walkability high SES $n = 88$	High walkability low SES $n = 76$	Low walkability low SES $n = 84$	
Age (years) Mean (SD)	40.2 (17.3)	34.1 (14.2)	40.5 (14.8)	36.4 (12.6)	37.9 (15.3)
Gender (n, %)					
Female	59 (48.4)	41 (46.6)	54 (72.0)	45 (54.9)	199 (54.2)
Male	63 (51.6)	46 (52.3)	21 (28.0)	36 (43.9)	166 (45.2)
Marital status (n, %)					
Married	69 (56.6)	41 (46.4)	58 (77.3)	58 (69.0)	226 (61.2)
Not married	53 (43.4)	47 (53.4)	17 (22.7)	26 (31.0)	143 (38.8)
Religion (n, %)					
Hindu	87 (71.3)	77 (87.5)	65 (86.7)	75 (89.3)	304 (82.2)
non-Hindu	35 (28.7)	11 (12.5)	10 (13.3)	9 (10.7)	65 (17.6)
Educational level (n, %)					
Uneducated	0 (0)	5 (5.7)	26 (34.7)	17 (20.2)	48 (13.0)
Primary–middle school	1 (0.8)	7 (8.0)	21 (28.0)	28 (33.3)	57 (15.5)
High school or diploma	9 (7.4)	16 (18.4)	20 (26.7)	34 (40.5)	79 (21.5)
Graduate or professional	112 (91.8)	59 (67.8)	8 (10.7)	5 (6.0)	184 (49.7)
Monthly family income in US dollars (n, %)					
≤ 80	0 (0)	4 (6.6)	36 (64.3)	34 (63.0)	74 (25.3)
81–200	0 (0)	8 (13.1)	17 (30.4)	18 (33.3)	43 (14.7)
201–549	5 (4.1)	15 (24.6)	2 (3.6)	2 (3.7)	24 (8.2)
≥550	117 (95.9)	34 (55.7)	1 (1.8)	0 (0)	152 (51.9)
Work status (n, %)					
Unemployed	39 (32.0)	34 (39.5)	32 (45.7)	29 (36.7)	134 (37.5)
Blue collar	11 (9.0)	16 (18.6)	37 (52.9)	48 (60.8)	112 (31.4)
White collar	72 (59.0)	36 (41.9)	1 (1.4)	2 (2.5)	111 (31.1)

Note: 1 US Dollar = approx. 65.69 Indian Rupees (average currency exchange rate, January–April 2015); cut-off values in table based on SES classification for India by Gururaj (2014). (Craig et al., 2003)

(aOR = 1.9, 95% CI = 1.2, 3.2) and land use mix-diversity (aOR = 2.1, 95% CI = 1.2, 3.6) significantly increased odds of meeting WHO-recommendations of travel PA by approximately two times. Land use mix-diversity was positively related to travel PA (OR = 2.0, 95% CI = 1.2, 3.5), but not associated with leisure or total PA. Infrastructure for walking/bicycling (aOR = 1.3, 95% CI = 0.7, 2.4) and safety from traffic (aOR = 1.3, 95% CI = 0.8, 2.3) improved likelihood of travel PA by 30%, but this association was not significant. Street connectivity, aesthetics, and safety from crime predicted decreased odds of engagement in travel PA. Only one neighborhood BE characteristic (residential density) was significantly associated with leisure PA, but the adjusted odds of engagement were reduced (aOR = 0.6, 95% CI = 0.4, 1.0). No significant associations between neighborhood BE features and total PA were observed.

The aggregate NEWS-India score of neighborhood BE features significantly predicted an increase in adjusted odds of travel PA by approximately two times (aOR = 1.9, 95% CI = 1.1, 3.1), and a 40% decrease in odds of leisure PA (aOR = 0.6, 95% CI = 0.4, 1.0). Higher aggregate NEWS-India score decreased odds of total PA, but this association was not significant (aOR = 0.9, 95% CI = 0.6, 1.4).

5. Discussion

This study examined associations between neighborhood walkability, BE features, and domain-specific PA (travel and leisure) in a developing country. Previous studies have demonstrated significant associations between individual BE features and PA, predominantly in developed countries (Sallis et al., 2009a). To our knowledge, there are no previous studies examining the associations between neighborhood BE variables and PA in India. This study is the first of its kind to document neighborhood walkability and BE associations with domain-specific PA in India. Results from this study extend the current active

Table 2
Descriptive statistics of sample population for leisure, travel, and total physical activity (meeting, not meeting WHO recommendations[a]).

Physical activity variables	Neighborhood quadrants				Full sample N = 370
	1	2	3	4	
	High walkability high SES n = 122	Low walkability high SES n = 88	High walkability low SES n = 76	Low walkability low SES n = 84	
Travel PA (n, %)					
Meeting WHO guidelines	6 (4.9)	17 (22.7)	30 (44.8)	34 (44.7)	87 (25.6)
Not meeting WHO guidelines	116 (95.1)	58 (77.3)	37 (55.2)	42 (55.3)	253 (74.4)
Leisure PA (n, %)					
Meeting WHO guidelines	62 (50.8)	39 (48.1)	13 (19.1)	17 (25.4)	131 (38.8)
Not meeting WHO guidelines	60 (49.2)	42 (51.9)	55 (80.9)	50 (74.6)	207 (61.2)
Total PA (n, %)					
Meeting WHO guidelines	66 (54.1)	48 (65.8)	36 (54.5)	34 (50.7)	184 (56.1)
Not meeting WHO guidelines	56 (45.9)	25 (34.2)	30 (45.5)	33 (49.3)	144 (43.9)

Note: PA = Physical Activity.
[a] At least 150 min of PA per week based on global recommendations for PA among adults established by the WHO (World Health Organization, 2010).

Table 3
Built environment predictors of meeting WHO-recommended levels of leisure, travel, and total physical activity in low-SES neighborhoods in Chennai, India (N = 160), aOR[a] (95% CI).

Independent variables	Leisure PA		Travel PA		Total PA	
NEWS-India subscales~	OR 95% CI	aOR[a] 95% CI	OR 95% CI	aOR[a] 95% CI	OR 95% CI	aOR[a] 95% CI
Residential density	0.5 (0.2, 1.2)	0.6 (0.2, 1.3)	1.8 (0.9, 3.7)	1.8 (0.9, 3.7)	1.1 (0.5, 2.3)	1.1 (0.5, 2.3)
Land use mix–diversity	2.7 (1.1, 6.4)	2.7 (1.1, 6.5)	0.7 (0.3, 1.3)	0.7 (0.4, 1.4)	0.9 (0.5, 1.8)	0.9 (0.5, 1.8)
Land use mix–access	0.9 (0.4, 2.0)	0.9 (0.4, 2.1)	1.1 (0.5, 2.1)	1.1 (0.6, 2.3)	1.4 (0.7, 2.9)	1.5 (0.7, 3.1)
Street connectivity	0.5 (0.2, 1.0)	0.5 (0.2, 1.1)	1.8 (0.9, 3.7)	1.8 (0.9, 3.5)	1.1 (0.6, 2.2)	1.2 (0.6, 2.3)
Infrastructure for walking/bicycling	2.3 (0.9, 5.6)	2.4 (1.0, 6.0)	0.6 (0.3, 1.3)	0.5 (0.2, 1.2)	1.0 (0.4, 2.2)	1.0 (0.4, 2.2)
Aesthetics	4.1 (1.5, 11.3)	5.2 (1.7, 15.5)	0.4 (0.2, 1.2)	0.3 (0.1, 1.0)	0.8 (0.3, 2.1)	0.8 (0.3, 2.3)
Safety from traffic	1.9 (0.8, 4.4)	2.0 (0.8, 4.9)	1.0 (0.5, 2.0)	0.9 (0.4, 2.0)	1.1 (0.5, 2.4)	1.1 (0.5, 2.5)
Safety from crime	0.7 (0.2, 2.2)	0.8 (0.2, 2.4)	1.7 (0.7, 3.9)	1.6 (0.7, 3.9)	1.0 (0.4, 2.4)	1.0 (0.4, 2.6)
Aggregate NEWS-India Score	0.5 (0.2, 1.2)	0.6 (0.2, 1.3)	1.8 (0.9, 3.7)	1.8 (0.9, 3.7)	1.1 (0.5, 2.3)	1.1 (0.5, 2.3)

Note: OR = Unadjusted Odds Ratios, aOR = Adjusted Odds Ratios, CI = Confidence Interval, PA = Physical Activity, NEWS = Neighborhood Environment Walkability Scale.
~ NEWS item scoring and subscale score calculations followed the NEWS-Adult scoring scheme recommended by the IPEN study protocol (Yang et al., 2015; Sallis et al., 2012). All NEWS subscales were dichotomized. Residential density was dichotomized into low (weighted mean ≤ 545) and high (weighted mean > 545) densities. Land use mix-diversity was dichotomized into ≤10 min walking distance or ≥10 min (Steele & Mummery, 2003; Chomitz et al., 2013) Four-point Likert-type scale response options for all other subscales (land use mix-access, street connectivity, infrastructure for walking/bicycling, aesthetics, safety from traffic, and crime safety) ranging from 1 (strongly agree) to 4 (strongly disagree) were combined as "agree" (strongly agree, agree) and "disagree" (disagree, strongly disagree). The aggregate NEWS-India score was dichotomized into low (mean ≤ 560) and high (weighted mean > 560) walkability using the mid-point of the range of NEWS-India aggregate values from the sample.
[a] Adjusted for age and gender.

living research evidence in LMICs like India by demonstrating that the BE is an important correlate of PA in India.

In low-SES neighborhoods, travel PA was the primary contributor to total PA and participants were meeting recommended PA levels (≥150 min of PA per week) from travel related walking and bicycling. Low-SES participants reported lower levels of leisure PA. In high-SES neighborhoods, these variations in domain-specific PA were in the opposite direction—levels of travel PA were lower while engagement in leisure-time PA was more prevalent. These variations can be explained by SES differences across neighborhoods. Compared to high-SES populations, levels of motor vehicle ownership are much lower in low-SES populations making travel related walking, bicycling, and use of public transport indispensable for commuting (Becerra et al., 2013; Cervero et al., 2009; Arango et al., 2013). These findings support a recent

Table 4
Built environment predictors of meeting WHO-recommended levels of leisure, travel, and total physical activity in high-SES neighborhoods in Chennai, India (N = 210), aOR[a] (95% CI).

Independent variables	Leisure PA		Travel PA		Total PA	
NEWS-India subscales~	OR 95% CI	aOR[a] 95% CI	OR 95% CI	aOR[a] 95% CI	OR 95% CI	aOR[a] 95% CI
Residential density	1.0 (0.5, 1.7)	1.1 (0.6, 2.1)	0.7 (0.3, 1.9)	0.7 (0.3, 1.9)	0.8 (0.4, 1.4)	0.9 (0.5, 1.6)
Land use mix–diversity	0.6 (0.1, 2.6)	0.6 (0.1, 2.8)	0.0 (0.0, 0.0)	0.0 (0.0, 0.0)	0.5 (0.1, 2.4)	0.6 (0.1, 2.8)
Land use mix–access	0.9 (0.4, 1.8)	0.7 (0.3, 1.6)	2.2 (0.5, 9.8)	2.1 (0.5, 9.5)	1.0 (0.4, 2.1)	0.8 (0.4, 1.9)
Street connectivity	1.8 (0.7, 4.6)	2.4 (0.9, 6.7)	0.3 (0.1, 0.9)	0.3 (0.1, 0.8)	0.5 (0.2, 1.5)	0.6 (0.2, 1.8)
Infrastructure for walking/bicycling	0.4 (0.2, 1.0)	0.4 (0.2, 1.0)	3.2 (1.2, 8.7)	3.4 (1.2, 9.3)	0.7 (0.3, 1.5)	0.7 (0.3, 1.5)
Aesthetics	0.6 (0.3, 1.2)	0.5 (0.3, 1.0)	0.6 (0.2, 1.9)	0.6 (0.2, 1.8)	0.8 (0.4, 1.6)	0.7 (0.4, 1.4)
Safety from traffic	0.6 (0.3, 1.1)	0.6 (0.3, 1.2)	2.7 (1.1, 6.5)	2.9 (1.2, 7.2)	0.6 (0.3, 1.1)	0.6 (0.3, 1.2)
Safety from crime	0.6 (0.4, 1.1)	0.7 (0.4, 1.3)	0.9 (0.4, 2.1)	0.9 (0.3, 2.1)	0.5 (0.3, 0.9)	0.5 (0.3, 1.0)
Aggregate NEWS-India Score	0.9 (0.5, 1.6)	1.1 (0.6, 2.0)	0.7 (0.3, 1.8)	0.7 (0.3, 1.8)	0.7 (0.4, 1.3)	0.8 (0.5, 1.6)

Note: OR = Unadjusted Odds Ratios, aOR = Adjusted Odds Ratios, CI = Confidence Interval, PA = Physical Activity, NEWS = Neighborhood Environment Walkability Scale.
~ NEWS item scoring and subscale score calculations followed the NEWS-Adult scoring scheme recommended by the IPEN study protocol.[52, 53, 139] All NEWS subscales were dichotomized. Residential density was dichotomized into low (weighted mean ≤ 545) and high (weighted mean > 545) densities. Land use mix-diversity was dichotomized into ≤10 min walking distance or ≥10 min (Steele & Mummery, 2003; Chomitz et al., 2013). Four-point Likert-type scale response options for all other subscales (land use mix-access, street connectivity, infrastructure for walking/bicycling, aesthetics, safety from traffic, and crime safety) ranging from 1 (strongly agree) to 4 (strongly disagree) were combined as "agree" (strongly agree, agree) and "disagree" (disagree, strongly disagree). The aggregate NEWS-India score was dichotomized into low (mean ≤ 560) and high (weighted mean > 560) walkability using the mid-point of the range of NEWS-India aggregate values from the sample.
[a] Adjusted for age and gender.

Table 5
Pooled analysis of built environment predictors of meeting WHO-recommended levels of leisure, travel, and total physical activity across all neighborhoods in Chennai, India ($N = 370$), aOR[a] (95% CI).

Independent variables	Leisure PA		Travel PA		Total PA	
NEWS-India subscales~	OR 95% CI	aOR[a] 95% CI	OR 95% CI	aOR[a] 95% CI	OR 95% CI	aOR[a] 95% CI
Residential density	0.6 (0.4, 0.9)	0.6 (0.4, 1.0)	2.0 (1.2, 3.3)	1.9 (1.2, 3.2)	0.8 (0.5, 1.3)	0.9 (0.6, 1.4)
Land use mix–diversity	0.6 (0.4, 1.1)	0.6 (0.3, 1.0)	2.0 (1.2, 3.5)	2.1 (1.2, 3.6)	0.8 (0.5, 1.3)	0.7 (0.4, 1.2)
Land use mix–access	1.2 (0.7, 2.0)	1.2 (0.7, 2.0)	0.7 (0.4, 1.3)	0.7 (0.4, 1.3)	1.3 (0.8, 2.1)	1.2 (0.7, 2.1)
Street connectivity	1.4 (0.8, 2.4)	1.7 (0.9, 2.9)	0.6 (0.3, 1.0)	0.6 (0.3, 1.0)	1.0 (0.6, 1.7)	1.1 (0.6, 1.9)
Infrastructure for walking/bicycling	0.8 (0.4, 1.4)	0.8 (0.4, 1.5)	1.4 (0.7, 2.5)	1.3 (0.7, 2.4)	0.8 (0.4, 1.4)	0.8 (0.5, 1.5)
Aesthetics	1.2 (0.7, 2.1)	1.2 (0.7, 2.1)	0.4 (0.2, 0.9)	0.4 (0.2, 0.9)	0.9 (0.5, 1.5)	0.8 (0.5, 1.4)
Safety from traffic	0.9 (0.6, 1.5)	0.9 (0.6, 1.6)	1.3 (0.8, 2.2)	1.3 (0.8, 2.3)	0.8 (0.5, 1.2)	0.8 (0.5, 1.3)
Safety from crime	1.2 (0.8, 1.8)	1.2 (0.8, 1.9)	0.5 (0.3, 0.9)	0.5 (0.3, 0.9)	0.8 (0.5, 1.2)	0.8 (0.5, 1.2)
Aggregate NEWS-India Score	0.6 (0.4, 0.9)	0.6 (0.4, 1.0)	2.0 (1.2, 3.2)	1.9 (1.1, 3.1)	0.8 (0.5, 1.3)	0.9 (0.6, 1.4)

Note: OR = Unadjusted Odds Ratios, aOR = Adjusted Odds Ratios, CI = Confidence Interval, PA = Physical Activity, NEWS = Neighborhood Environment Walkability Scale.
~ NEWS item scoring and subscale score calculations followed the NEWS-Adult scoring scheme recommended by the IPEN study protocol.[52, 53, 139] All NEWS subscales were dichotomized. Residential density was dichotomized into low (weighted mean ≤ 545) and high (weighted mean > 545) densities. Land use mix-diversity was dichotomized into ≤10 min walking distance or ≥10 min (Steele & Mummery, 2003; Chomitz et al., 2013). Four-point Likert-type scale response options for all other subscales (land use mix-access, street connectivity, infrastructure for walking/bicycling, aesthetics, safety from traffic, and crime safety) ranging from 1 (strongly agree) to 4 (strongly disagree) were combined as "agree" (strongly agree, agree) and "disagree" (disagree, strongly disagree). The aggregate NEWS-India score was dichotomized into low (mean ≤ 560) and high (weighted mean > 560) walkability using the mid-point of the range of NEWS-India aggregate values from the sample.
[a] Adjusted for age and gender.

multi-country IPEN study on physical activity, including LMICs such as Mexico, Colombia, and Brazil, where car ownership was low and active travel was therefore a necessity and not by choice (Sallis et al., 2016).

Lower levels of leisure PA in low-SES populations can be attributed to social and environmental barriers that exist to a greater degree in low-SES neighborhoods.[182] Studies have found that unsafe neighborhood conditions, lack of parks, playgrounds and open spaces, and financial barriers to access recreational facilities (e.g., gyms, sports clubs, etc.) limit the ability of low-SES populations to engage in leisure and recreational activities (Cutts et al., 2009). Low-income populations are financially constrained in choosing activity-friendly alternatives such as living in a safer neighborhood, purchasing a gym membership, paying a fee to access a recreation center, or procuring services that afford time for PA such as housecleaning or childcare (Milton et al., 2014b; Sallis et al., 2009b). Overall, these variations in leisure and travel PA are consistent with previous research in LMICs such as Nigeria (Oyeyemi et al., 2013), Brazil (Parra et al., 2011; Hino et al., 2011; Rech et al., 2014; Reis et al., 2013), Columbia (Cervero et al., 2009; Gomez et al., 2010; Sarmiento et al., 2010),Bangladesh (Ranasinghe et al., 2013; Jayawardena et al., 2012) and Sri Lanka (Katulanda et al., 2013).

A comparison of travel PA between the high-SES neighborhoods showed that a higher percentage of residents in the low walkability neighborhoods reported meeting travel PA recommendations compared to high walkability neighborhoods, which is a counter-intuitive finding. This may be explained by high-SES residents being forced to walk longer distances in their low walkable environments due to limited access to amenities, public transit stops, etc. Although levels of car-ownership are known to be higher in high-SES groups, residents may be opting out of driving privately owned automobiles due to traffic congestion and lack of parking. Instead, they may prefer to walk, bicycle, or use public transport to commute (e.g., for work or errands). Studies have shown that factors impacting travel PA in LMICs may be different from high-income countries (Parra et al., 2011). This study is first-generation research in India and some findings may not be in agreement with what has been shown in high-income countries. Data from this study is insufficient to explain these patterns in domain-specific PA in India. More research is needed to understand and assess additional factors (e.g., socio-economic status, car ownership, commuting patterns, and travel distances) and their relationship to PA across larger geographical areas and over extended periods of time in LMIC contexts.

Results from logistic regression modeling indicate that the relationships between the BE and PA may be context-specific, and that the context in India may differ markedly from that in high-income countries. In most LMICs like India, parks and green spaces are being destroyed to make way for housing and infrastructure to accommodate the growing population,(Vishwanath et al., 2013) thus limiting access to places for leisure PA. Low-SES neighborhoods in India are frequently overcrowded with high density of slum settlements without any planned open spaces such as parks or playgrounds. The positive association between residential density, land use mix-diversity, and travel PA (Table 5) implies that dense neighborhoods and the availability of a variety of destinations can promote increases in walking, bicycling, and active travel. The availability of a diversity of land uses provides proximate destinations that serve as incentives for people to walk and bicycle. Perceiving local destinations nearby was significantly related to more adults being active to travel to those destinations, but did not impact levels of leisure PA. Perceived land use mix-access was also positively related to travel PA implying having better access to shops, recreation uses, and transit stops improves likelihood of active travel. Many other studies have shown associations between local destinations and travel PA (Bauman et al., 2009; Saelens & Handy, 2008a).

Crime is a well-recognized barrier to PA, particularly in low-income neighborhoods (Adlakha et al., 2014b; Foster & Giles-Corti, 2008; Hipp et al., 2013b). However, this analysis yielded inconsistent associations between crime and PA levels. Previous research has also produced inconclusive results, suggesting that the impact of perceived safety from crime on walking and other forms of PA needs further examination (Foster & Giles-Corti, 2008; Ding et al., 2013). The influences of perceived crime and safety on PA is complex (e.g., time of occurrence, people's perceptions, response and coping mechanisms influence PA differently) (Ding et al., 2013). Future studies should include objective measures of crime and use better specified models to understand crime-PA associations.

This study used operational definitions of high and low walkability to classify neighborhoods. Empirical models have demonstrated that smaller block sizes and complete sidewalks along major streets, as well as higher residential density are associated with increased walking. The presence of and distance to destinations (mixed land use) near homes are important indicators of walkability (Ewing et al., 2006; Frank et al., n.d.) High residential density, mixed land use, and street connectivity are essential components of walkable neighborhoods since local patronage supports nearby shops and services while encouraging residents to use walk, bicycle, or use public transport for commuting to these destinations. However, values of low density, low street connectivity, or low land-use mix in Chennai may be equivalent to high density, high land-use mix, and high street connectivity in neighborhoods of high-income countries. Perhaps neighborhoods that are too dense, mixed, or connected represent a barrier for PA, resulting in inverse or insignificant relationships between BE characteristics and PA behaviors. For example, the population density of the city of Chennai (17,000/km^2) is approximately 6.5 times the population density of Seattle, United States (2593.5/km^2), where residents of high density neighborhoods reported 70 more minutes of physical activity and had lower obesity prevalence than did residents of low-walkability neighborhoods (Saelens et al., 2003d). In contrast, recent IPEN cross-country analyses in LMICs such as Bogota (population density = 13,500/km^2) and Hong Kong (population density = 6654.74/km^2) has demonstrated inverse BE-PA associations, similar to this study (Kerr et al., 2016).

Similar findings have been documented in other studies from Latin America and Africa where PA is constrained, rather than promoted, by high levels of land use mix and density (Parra et al., 2011; Oyeyemi et al., 2012; Oyeyemi et al., 2014). In many LMICs, areas of high density include a large number of individuals or households living together which results in overcrowding. These neighborhoods are often unattractive, with a lack of space for parks, green spaces, and pedestrian infrastructure such as sidewalks which hinder residents' PA (Parra et al., 2011). Data from this study are insufficient to test this hypothesis. A cross-country analyses of the full IPEN data set combined with a larger sample size from India could help address this question. Some BE characteristics showed stronger associations with PA in unadjusted models, but these relationships were removed in adjusted models. Cross-sectional studies with larger sample sizes and longitudinal tracking BE changes and PA behaviors are needed to elucidate these complex relationships in LMICs.

5.1. Limitations

Inference of causality and generalizability of results is limited due to the cross-sectional study design and a relatively small sample from a single city in India (Glass et al., 2013). Purposive sampling was used to recruit participants from neighborhoods stratified by walkability and SES, but this was not adjusted for in statistical models. The demographic differences between the neighborhoods may limit generalizability (Saelens et al., 2003d; Saelens & Handy, 2008b). Residual confounding and self-selection of individuals into walkable neighborhoods is a limitation of this study (Handy et al., 2006; Baar et al., 2015).

Self-reported PA and neighborhood BE measures are subject to bias (e.g., overestimation of PA; social desirability of PA; physically active people may notice more BE features and destinations to walk or bicycle to) (Montoye, 1996; Wood, 2000). Self-report PA data is also prone to reliability and validity problems with recall of activity. Recent studies have used accelerometers to measure PA which provide objective data. However, given the early stages of this research in India, this study provides baseline evidence of PA and BE associations in India. A lack of consensus on measuring domain-specific PA in LMICs (e.g., lack of tested items, inadequate details on types of PA) is another limitation of this study and PA literature in general (Wood, 2000; Steele & Mummery, 2003). The leisure and travel modules of IPAQ-LF have not been validated in India. Variations in domain-specific PA suggest that measuring only leisure-time PA, as most studies in the developed countries have done, may underestimate levels of total PA in LMICs. Physically intensive activities may be intersecting domestic, work, and travel domains in the daily routines of LMIC populations, making it important to include household and occupational PA to gain a complete understanding of PA and where it occurs (Chomitz et al., 2013).

5.2. Strengths and implications

Although this study was based on a relatively small sample, it is among the first to measure and document BE features and PA levels in India. This project has the potential to establish the current state of active living research in India. As part of IPEN, state-of-the-art methods, measures, and instruments were used (Kerr et al., 2013; Cerin et al., 2013). Overall, findings suggest that diverse, attractive, and walkable neighborhoods can support walking, bicycling, and use of public transit. Public health practitioners and researchers could benefit by utilizing domains and measures from this study for future BE assessments in India and with testing/adaptation, in other LMICs.

Transportation and planning research supports the proposition that the physical environment is associated with leisure and transport PA. A growing number of policy experts, urban planners, and transportation experts have expressed concern that PA has been engineered out our daily lives since the design of our neighborhoods makes it difficult, and in many cases dangerous, to walk or bicycle (Saelens et al., 2003a; Saelens & Handy, 2008c). Study findings have public health implications for India and potentially other LMICs, showing associations of PA with BE that are discordant with those observed in high-income countries and suggesting that caution should be taken when translating evidence from high-income countries to LMICs. Overall, results from this study yield actionable and real-world knowledge for environmental design and physical infrastructure likely to support and encourage healthy, active lifestyles in India. The results of this study can inform efforts to alter the environments in which people live their daily lives so as to promote and sustain population shifts in PA.

Future research should consider exploring BE, PA, and NCD outcomes in other Indian cities and settings. An understanding of environmental correlates of all PA domains (domestic, occupation, transport, and leisure) is urgently needed to support the development of contextually tailored interventions to reverse the rapidly changing determinants of inactivity occurring through patterns of urbanization and sprawl. Key recommendations for future research in India include measure development, objective studies of PA, intervention research, longitudinal tracking of PA, enhancing transdisciplinary collaborations, and research translation. Research into the role of public transport access, assessment of policies such as traffic congestion charging and road rationing, and their impacts in car owners and non-owners would be useful in LMIC settings. Recommendations for practice include enhanced training for public health practitioners, improved collaborations, advocacy, and knowledge transfer with sectors outside of public health.

6. Conclusion

Large scale epidemiologic studies that incorporate the diverse and dense BE contexts of LMICs can contribute important evidence for prioritizing BE supports, policies, and interventions aimed at curbing the NCD epidemic in LMICs. Interdisciplinary collaboration and dialogue between researchers, practitioners, policy makers, and the community on designing neighborhoods and cities to promote active living will help create disciplined approaches to generating and reframing evidence that will hopefully result in cost-effective actions with improved health outcomes in LMIC contexts.

While this study is first-generation research in India, its findings have the potential to begin to guide design decisions for healthy living in urban Indian neighborhoods. By analyzing how health outcomes are part of the complexity of urban processes, this project draws attention to the potential role of urban planning and transport policies on the BE for active transportation. Environmental and policy changes affecting the BE are likely to have numerous public health benefits and hold potential for reshaping the fabric of Indian cities.

Conflicts of interest

The authors declare no conflict of interest. The funding sponsors had no role in the design of the study, in the collection, analyses, or interpretation of data, in the writing of the manuscript, and in the decision to publish the results. The content is solely the responsibility of the authors and does not necessarily represent the official views of their affiliations.

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